MATERIALS SCIENCE MA(S)TERS

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Teacher Guides

Part 1

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UNIVERSITY OF SILESIA IN KATOWICE

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

ADDITIVE MANUFACTURING

Code: AM

Course content – lecture

Topics 1

1.	The subject of the lecture

Introduction to Additive Technologies: From Early Experiments to Modern Industrial Applications

2.	Thematic scope of the lecture (abstract, maximum 500 words)

The lecture serves as an introduction to a series of lectures dedicated to additive technologies, also known as 3D printing. These terms will be used interchangeably during the presentation. The aim of the lecture is to provide a comprehensive overview of the theoretical and practical aspects related to 3D printing, laying a solid foundation for subsequent presentations that will discuss more detailed topics related to this technology. To start, the lecturer will present the multidisciplinary nature of additive technologies, showcasing their broad applications and impact on various sectors, from engineering and design, through pharmaceuticals and medicine, to the arts. Following this, the current state of 3D printing development and its role in the industry will be introduced as a reference point for further discussions. The lecture will highlight the key stages in the evolution of 3D printing, from the pioneering experiments of the 1980s, through the introduction of the first commercial devices, to the current advanced industrial applications. Profiles of visionaries who contributed to progress in this field will be presented, along with the challenges they faced, such as the limited selection of materials, initially low printing precision, and long printing times. The speaker will illustrate how 3D printing has revolutionized traditional manufacturing methods, opening new possibilities in many industries. The benefits of this technology will be discussed, such as greater product customization, the creation of complex geometries, and the reduction of production costs for small batches, while minimizing material waste. Inspiring examples of applications in aerospace, automotive, and medicine will allow the audience to recognize the vast potential of additive technologies. Particular emphasis will be placed on the advantages of 3D printing in the context of sustainable development. The speaker will compare additive technologies to conventional methods, such as machining or casting, highlighting their ecological advantages. An analysis of the benefits and limitations of AM in terms of environmental protection will be provided. Furthermore, the lecture will show how 3D printing can support a sustainable approach to production. Methods of reducing waste generation and promoting circular economy models, based on material reuse and minimizing raw material consumption, will be presented. The audience will learn about innovative materials and technologies aimed at further reducing the negative environmental impact of AM. Practical case studies from various industries will illustrate the positive environmental impact of 3D printing. In conclusion, the speaker will present trends and forecasts regarding the future of additive technologies, focusing on new materials and techniques that will emerge in the coming years. The lecture will also discuss how 3D printing can support sustainable development and industrial transformation towards a circular economy.

3. Learning outcomes

The student:

- knows and understands the history of the development of 3D printing technology, from its beginnings to its current industrial applications,
- identifies key events that influenced the advancement of 3D printing technology,
- possesses knowledge of the potential applications of 3D printing,
- recognizes the challenges faced by 3D printing technology,
- can explain how 3D printing technology has transformed traditional manufacturing processes,
- analyzes and evaluates the advantages of additive manufacturing in terms of cost savings, waste reduction, and increased design freedom,
- compares and contrasts the advantages and limitations of additive technologies with conventional manufacturing processes,
- is ready to engage in discussions about the potential benefits of sustainable and environmentally-friendly production through the use of additive technologies,
- understands the significance of 3D printing technology for the development of the economy and society.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Gibson, I., Rosen, D., Stucker, B., & Khorasani, M. (2020). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing. Springer. DOI: 10.1007/978-3-030-56127-7
- Bourell, D. L., Frazier, W., Kuhn, H., & Seifi, M. (Eds.). (2020). ASM Handbook, Volume 24: Additive Manufacturing Processes. ASM International. ISBN 978-162708-288-4.
- Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Rab, S. (2021). Role of additive manufacturing applications towards environmental sustainability. Advanced Industrial and Engineering Polymer Research, 4(4), 312-322.
- Hegab, H., Khanna, N., Monib, N., & Salem, A. (2023). Design for sustainable additive manufacturing: A review. Sustainable Materials and Technologies, 35, e00576.

- Beaman, J. J., Bourell, D. L., Seepersad, C. C., & Kovar, D. J. J. O. M. S. (2020). Additive manufacturing review: early past to current practice. Journal of Manufacturing Science and Engineering, 142(11), 110812.

6. Additional notes

The introductory lecture will be accessible to listeners with varying levels of knowledge and experience. The speaker will encourage questions and active participation in discussions, creating an atmosphere of openness and engagement. In summarizing the key points, the speaker will provide a brief overview of the topics that will be covered in upcoming presentations, aiming to spark interest and anticipation for the rest of the series.

Topics 2

1. The subject of the lecture

Classification and Characteristics of Additive Manufacturing Processes

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, various additive manufacturing (AM) methods will be presented along with their brief characteristics. A classification of additive manufacturing processes will be shown, based on an analysis covering the operating principles, device structure, material characteristics, ability to replicate complex geometries, and the need for post-processing. The foundation for the classification will be the ISO/ASTM 52900 standard, a widely used industry standard defining the fundamental principles of additive manufacturing and providing clear definitions of the associated scientific terminology. This standard classifies additive manufacturing processes into seven categories: vat photopolymerization, material extrusion, sheet lamination, powder bed fusion, binder jetting, material jetting, and directed energy deposition, all of which will be discussed during the lecture. Each category will be illustrated with relevant examples and short video materials demonstrating the process in action. During the discussion of individual categories of additive manufacturing processes, examples of the entire production process will be presented, from start to finish, using selected products as examples. This will cover all stages, from the CAD design (computer 3D model), through the additive manufacturing process, to obtaining the final, finished product. In this way, participants will be able to follow the complete production path and understand how the entire manufacturing cycle works using a given AM technology. This visualization will help participants familiarize themselves with the advantages and limitations of various technologies across different industries. As a result, they will understand why knowledge of AM process classification is essential when selecting appropriate technologies tailored to specific application requirements. Another important aspect addressed during the lecture will be the issue of terminology used in the field of additive manufacturing. The importance of using consistent and precise terminology in the area of AM technologies will be emphasized to facilitate communication between scientists, engineers, designers, and industry representatives involved in this sector. Establishing a common, coherent technical language will help avoid misunderstandings and misinterpretations in the future. The lecturer will also present an overview of EN/ISO/ASTM standards concerning metals and polymers in the context of additive manufacturing. Key standards defining material, process, and quality requirements for AM technologies used in metal and polymer processing will be discussed. This will provide participants with knowledge of current guidelines and best practices in additive manufacturing with these materials.

3. Learning outcomes

The student:

- is able to classify additive manufacturing processes based on an analysis that includes the process operating principles, machine architecture, surface quality requirements, material characteristics, the ability to replicate complex geometries, and the need for post-processing,
- is capable of defining and describing additive manufacturing processes in accordance with the ISO/ASTM 52900 standard,
- is proficient in searching for and using EN/ISO/ASTM standards in the context of additive manufacturing, including understanding material, process, and quality requirements for a given AM technology,
- can effectively communicate and convey information about additive manufacturing processes, both in technical and non-technical contexts, utilizing consistent and precise terminology aligned with ISO/ASTM standards.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

https://www.astm.org/products-services/standards-and-publications/standards/additive-manufacturing-standards.html#section3

The student should have access at the university to the standards presented by the lecturer during the lecture, such as ISO/ASTM 52900-21 Additive Manufacturing — General Principles — Fundamentals and Vocabulary.

6. Additional notes

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Topics 3

1. The subject of the lecture

FDM Technology (Fused Deposition Modeling) - From Basics to Advanced Applications

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to comprehensively present FDM (Fused Deposition Modeling) technology, covering its history, technical foundations, current applications, and future development perspectives. The lecturer will begin by reviewing the history of FDM technology, including key information about the patents that shaped its development. This historical background will help better understand how the technology evolved into its current form and why it has found applications in so many fields. Next, the wide-ranging applications of FDM in various industries, such as aerospace, automotive, and medicine, will be presented, allowing participants to grasp the significance and potential of the technology in the context of modern industrial and scientific challenges. The lecturer will thoroughly discuss various types of FDM printers, focusing on their design, including kinematics. Cartesian printers, Delta-type printers, CoreXY and H-Bot systems, Polar 3D printers, robotic arm printers, and those using SCARA kinematics will be introduced. Different types of filament feeding mechanisms will also be covered, including Bowden and Direct Drive systems, as well as the construction and principle of operation of the extruder. A key element of the lecture will be the discussion of critical FDM printing parameters. The impact of various parameters on the quality, strength, accuracy, and aesthetics of prints will be explained. Best practices for FDM printing and tips for optimizing settings to achieve maximum quality with minimal print time will also be presented. The lecturer will demonstrate common FDM printing issues, such as warping, stringing, and under-extrusion, along with methods for solving them. An important topic will be the post-processing of FDM prints. Various surface finishing methods, techniques for joining 3D-printed parts, and ways to improve the mechanical properties of prints will be showcased. The lecturer will analyze the properties and applications of the most popular FDM printing materials, such as ABS, PLA, PETG, nylon, and thermoplastic elastomers. Guidance will be provided on selecting the appropriate material based on requirements for strength, thermal properties, aesthetics, and production economy. The lecture will also touch on the economic and environmental aspects of FDM printing. A cost analysis compared to other manufacturing methods will be conducted, along with discussions on filament and print recycling opportunities and the environmental impact of this technology. In conclusion, the lecturer will highlight the importance of ISO and ASTM standards in the context of FDM technology and outline the future of FDM technology and its potential directions of development. Innovative materials, such as conductive and magnetic filaments, as well as prospects for increasing the precision, speed, and reliability of FDM printing, will be discussed. The lecture will end with a summary and reflection on the ecological dimension of 3D printing in FDM technology.

3. Learning outcomes

The student:

- knows and understands advanced topics related to FDM technology, including its history, technical foundations, current applications, and development perspectives.
- characterizes different types of FDM printers, their design, and kinematics, including Cartesian printers, Delta-type printers, CoreXY and H-Bot systems, Polar 3D printers, robotic arm printers, and those utilizing SCARA kinematics.
- describes filament feeding mechanisms, including Bowden and Direct Drive systems, as well as the construction and operation of the extruder.
- identifies key FDM printing parameters, such as layer height, print temperature, print speed, infill, supports, and model orientation, and explains their impact on print quality, strength, accuracy, and aesthetics.
- analyzes best practices for FDM printing and methods for optimizing settings to achieve maximum quality with minimal print time.
- characterizes different post-processing methods for FDM prints, including surface finishing techniques, joining of 3D-printed parts, and improving the mechanical properties of prints.
- compares the properties and applications of different FDM printing materials, such as ABS, PLA, PETG, and nylon.
- analyzes the economic and environmental aspects of FDM printing, including costs compared to other manufacturing methods, recycling possibilities for filaments and prints, and the environmental impact of this technology.
- anticipates potential directions for the development of FDM technology, including the advancement of innovative 3D printing materials (e.g., conductive and magnetic filaments).
- critically assesses their knowledge of FDM technology and recognizes the importance of expert knowledge in solving cognitive and practical problems.
- can identify, using databases, key ASTM and ISO standards related to FDM technology, including standards for terminology, testing methods, and material specifications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Gibson, I., Rosen, D., Stucker, B., & Khorasani, M. (2020). *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*. Springer. DOI: 10.1007/978-3-030-56127-7
- Bourell, D. L., Frazier, W., Kuhn, H., & Seifi, M. (Eds.). (2020). *ASM Handbook, Volume 24: Additive Manufacturing Processes*. ASM International. ISBN 978-162708-288-4.

6. Additional notes

Topics 4

1. The subject of the lecture

3D Printing Technologies Based on Photopolymerization: Materials, Applications, and Development Prospects

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will begin with a brief historical overview, showcasing the evolution of 3D printing technologies based on photopolymerization, starting from the pioneering work on stereolithography (SLA) in the 1980s to modern solutions. The speaker will highlight key milestones in the development of these techniques, illustrating the progress made in this field over recent years. Following this, an introduction will be given to familiarize the audience with basic concepts related to polymerization and photochemistry. This part of the lecture will cover key topics in photochemistry and polymerization, providing all participants with a solid theoretical foundation necessary for understanding more advanced topics discussed later in the presentation. The speaker will present examples of commonly used photoinitiators, helping the audience better understand the practical aspects of the photopolymerization process. In the next section, the speaker will thoroughly discuss various 3D printing techniques using photopolymerization, detailing the construction of devices, operating principles, and the specificities of each method. The following techniques will be presented: Stereolithography (SLA) – a method using a laser to selectively cure resin; Digital Light Processing (DLP) – a technique using a digital projector to expose entire layers of the model; Masked Stereolithography (MSLA) – a modification of SLA that uses an LCD array to mask the layer image; Continuous Liquid Interface Production (CLIP) – a method that uses controlled oxygen presence for continuous printing. After presenting each technique, the speaker will compare them, highlighting the advantages and disadvantages of each method. Topics such as printing precision, process speed, resolution, scalability, surface quality of prints, and costs associated with devices and materials will be discussed. This comparison will give the audience a better understanding of the specifics of each technique and allow them to assess their usefulness in different applications. Different types of resins, their specific properties, and their impact on the final product's characteristics will also be discussed. The latest trends in material development will be presented, including biocompatible resins and those with high mechanical strength. The speaker will provide concrete examples of applications of each discussed technique in various industries, medicine, and art, including the production of prototypes, manufacturing of casting molds, printing personalized medical implants, and creating jewelry. Current challenges and limitations associated with photopolymerization techniques will also be addressed, such as relatively high material costs, the need for post-processing of prints, or limitations on the size of printed objects. The speaker will analyze the costs associated with different techniques, both in terms of equipment purchase and operating costs, while also presenting potential savings from using these technologies in production processes. A significant portion of the lecture will cover a detailed discussion of safety aspects related to working with resins and 3D printing devices. The speaker will thoroughly outline recommended personal protective measures and safety procedures, emphasizing their crucial importance for operator health and environmental protection. Finally, the speaker will present future directions in material design and technology development, aimed at overcoming current limitations and expanding their scientific and commercial applications.

3. Learning outcomes

- The student:
  - has in-depth and organized knowledge about the historical development and evolution of 3D printing technologies using photopolymerization, from stereolithography to modern solutions,
  - demonstrates advanced theoretical knowledge in the fields of photochemistry and polymerization, essential for understanding the processes involved in 3D printing techniques based on photopolymerization,
  - possesses detailed knowledge of various 3D printing techniques utilizing photopolymerization (SLA, DLP, MSLA, CLIP), including their construction, principles of operation, and the specific characteristics of each method,
  - has extensive knowledge of the types of resins used in 3D printing, their properties, and their impact on the final product's characteristics, including the latest trends in material development,
  - is knowledgeable and understands advanced applications of 3D printing techniques based on photopolymerization in various industries and medicine,
  - has well-organized and theoretically supported knowledge of the current challenges, limitations, and economic aspects associated with photopolymerization techniques in 3D printing,
  - understands the need for continuous education and keeping up with the latest trends in 3D printing technology,
  - is aware of the responsibility involved in the safe use of 3D printing technologies and photopolymer materials, including their impact on operator health and the environment,
  - is ready to think and act entrepreneurially, utilizing acquired knowledge about 3D printing technologies to identify and solve problems in various fields.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.

- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Wang, X. (Ed.). (2024). Vat Photopolymerization Additive Manufacturing: 3D Printing Processes, Materials, and Applications. Elsevier.
- Zhang, F., Zhu, L., Li, Z., Wang, S., Shi, J., Tang, W., Li, N., & Yang, J. (2021). The recent development of vat photopolymerization: A review. Additive Manufacturing, 48(Part B), 102423. https://doi.org/10.1016/j.addma.2021.102423
- Appuhamillage, G. A., Chartrain, N., Meenakshisundaram, V., Feller, K. D., Williams, C. B., & Long, T. E. (2019). Vat photopolymerization-based additive manufacturing: Current trends and future directions in materials design. Industrial & Engineering Chemistry Research, 58(33). https://doi.org/10.1021/acs.iecr.9b02679
- Colorado, H. A., Gutierrez-Velasquez, E. I., Gil, L. D., & et al. (2024). Exploring the advantages and applications of nanocomposites produced via vat photopolymerization in additive manufacturing: A review. Advanced Composites and Hybrid Materials, 7(1). https://doi.org/10.1007/s42114-023-00808-z

6. Additional notes

Topics 5

1. The subject of the lecture

Selective Laser Melting (SLM) Technology - From Basics to Advanced Applications

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will begin with a brief historical overview, showcasing the evolution of 3D printing technology using additive manufacturing techniques based on laser technology, starting from the early experiments to modern solutions. The speaker will present the key stages of development in these techniques, highlighting the progress made in this field over recent years. Following this, an introduction will be provided to familiarize the audience with the classification of additive manufacturing techniques using laser technology. The speaker will discuss various technologies, paying particular attention to SLS (Selective Laser Sintering), SLM (Selective Laser Melting), DMLS (Direct Metal Laser Sintering), and LMS (Laser Metal Sintering), pointing out their differences and unique characteristics. After the general introduction to laser technologies, the speaker will focus on a detailed discussion of the Selective Laser Melting (SLM) process. The construction of a typical SLM device will be presented, and its key components will be discussed. The lecture will cover the key physical phenomena that occur during the SLM process and their impact on the melting process and the final result of the produced components. Specifically, the interaction of the laser beam with metallic powder will be addressed, including the absorption of laser energy and its penetration into the material and substrate, the reflectivity of the material, heat transfer through conduction, radiation, and convection, phase transformations in the material, chemical reactions, processes occurring in the liquid melt pool, heat transfer between the liquid and solid phases, crystallization, and the flow of liquid metal caused by stress gradients. The speaker will demonstrate to students how important it is to combine knowledge from various fields, such as optics, materials engineering, thermodynamics, and mechanics, to fully understand the complexity of the processes occurring during laser melting. This will help students grasp how an interdisciplinary approach enables the effective application of acquired knowledge in engineering practice, which is crucial for optimizing production processes and making informed technological decisions in the field of 3D printing using SLM technology. The speaker will then proceed to discuss the key parameters of the SLM process, including laser power, exposure time per point, distance between scanning points, distance between scanning lines, and layer thickness. By showing practical examples, the speaker will explain how these parameters influence the porosity of the produced part, microstructure, stresses, and production time. The speaker will also discuss the properties of metallic powders used in SLM technology, emphasizing aspects such as particle shape, size, size distribution, and other key parameters affecting the process. The importance of selecting the appropriate powders for specific applications will be highlighted, as well as how controlling these parameters can lead to optimal mechanical and structural properties of the manufactured parts. Furthermore, the speaker will cover the wide-ranging applications of SLM technology in various industries, such as aerospace, automotive, medical, and energy sectors. Specific examples will be presented where SLM is used to produce components with complex geometries, high mechanical strength, and personalized parts, such as medical implants. In conclusion, the speaker will address the economic and ecological aspects of SLM technology. It will be emphasized that a sustainable approach to SLM requires considering both the advantages (e.g., minimal waste, efficient material use) and disadvantages (e.g., difficulties in recycling metallic powders, high energy consumption) of this technology, in order to effectively develop innovative products while minimizing environmental impact.

3. Learning outcomes

The student:

- possesses well-structured and in-depth knowledge of the development and evolution of 3D printing technology using additive manufacturing techniques based on laser technology, from the initial experiments to modern solutions.
- demonstrates advanced understanding of the theoretical foundations concerning the physical phenomena occurring in the SLM process, essential for comprehending the impact of process parameters on the quality and properties of the manufactured components.
- is capable of classifying and discussing various additive manufacturing techniques using laser technology, such as SLS, SLM, DMLS, and LMS.
- has deep knowledge of the construction and operating principles of SLM devices.
- can identify and explain the relationships between SLM process parameters and the properties of the manufactured parts.
- is able to critically evaluate the economic and ecological aspects of using SLM technology, considering both its advantages and disadvantages.
- can discuss the applications of SLM technology across different industries, highlighting its potential benefits and limitations in practical applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Manjaiah, M., Raghavendra, K., & Balashanmugam, N. (2021). Additive manufacturing: A tool for Industrial Revolution 4.0. Springer.
- Bian, L., Shamsaei, N., & Usher, J. (Eds.). (2017). Laser-based additive manufacturing of metal parts: modeling, optimization, and control of mechanical properties. CRC Press.
- Kurzynowski, T. (2019). Method of designing and implementing selective laser melting technology for powder micrometallurgy [in Polish]. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, Poland.

6. Additional notes

Topics 6

1. The subject of the lecture

Designing for Additive Manufacturing: How to Adapt the Design Process to the Specifics of 3D Printing?

2. Thematic scope of the lecture (abstract, maximum 500 words)

At the beginning of the lecture, participants will be encouraged to reflect on two fundamental questions that arise during the production planning phase: (1) Should a particular part be made using AM (Additive Manufacturing)? (2) Can a particular part be produced using AM? The first question pertains to evaluating whether the part is suitable for production using AM technology, taking into account strategic and design aspects. The second question relates to the technological limitations of AM and assesses whether the designed part can be produced with the available technologies. A misjudgment of these aspects can lead to significant design issues, such as poor product quality, excessive production costs, or unforeseen technical complications, which could ultimately result in the failure of the entire project. To better illustrate the importance of these questions, participants will be introduced to a practical example involving the use of conformal cooling channels in injection molds. Thanks to AM technology, these channels can be designed in a way that ensures optimal coolant flow, leading to increased production efficiency and improved final product quality. In traditional manufacturing methods, creating such channels would be much more difficult or even impossible. In the next part of the lecture, the speaker will introduce the concept of Design for Additive Manufacturing (DFAM), which is a specialized approach to design that leverages the unique capabilities of additive technologies (AM). Topics covered will include material distribution optimization within the design space, allowing for the creation of complex geometries that are difficult to achieve with traditional methods; Generative Design, which uses artificial intelligence algorithms to generate multiple possible designs based on given criteria such as material, strength, and cost constraints; and the use of lattice structures, which offer unique benefits such as increased stiffness with low weight, better energy absorption, and thermal efficiency. The lecture will conclude with a presentation of tools and software that support Design for Additive Manufacturing (DFAM) and a demonstration of the practical application of these tools in a real project. The speaker will show how advanced software can be used to conduct the entire design process, from concept to optimization, with consideration for the specific requirements of additive technologies.

3. Learning outcomes

The student:

- possesses advanced knowledge in the field of additive manufacturing (AM) technology, including an understanding of technological processes, the capabilities and limitations of AM, and is familiar with the principles of Design for Additive Manufacturing (DFAM).
- is capable of presenting issues related to topological optimization and generative design, explaining how these methods enable the creation of more innovative design solutions, particularly in the context of additive manufacturing.
- is aware of the potential of modern CAD software in designing components intended for additive manufacturing.
- is ready to apply design guidelines for components, taking into account various technologies and materials used in additive manufacturing, including polymers and metals, and is aware of the need for regular updates of this knowledge as technology evolves.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Diegel, O., Nordin, A., & Motte, D. (2019). A practical guide to design for additive manufacturing. Springer Nature Singapore.
- Wiberg, A., Persson, J., & Ölvander, J. (2019). Design for additive manufacturing–a review of available design methods and software. Rapid Prototyping Journal, 25(6), 1080-1094.
- Egan, P. F. (2023). Design for Additive Manufacturing: Recent Innovations and Future Directions. Designs, 7(4), 83.
- Pilagatti, A. N., Atzeni, E., & Salmi, A. (2023). Exploiting the generative design potential to select the best conceptual design of an aerospace component to be produced by additive manufacturing. The International Journal of Advanced Manufacturing Technology, 126(11), 5597-5612.

- Junk, S., & Burkart, L. (2021). Comparison of CAD systems for generative design for use with additive manufacturing. Procedia CIRP, 100, 577-582.
- Çalışkan, C. İ., Koca, A., Özer, G., Akbal, Ö., & Bakır, S. (2023). Efficiency comparison of conformal cooling channels produced by additive and subtractive manufacturing in automotive industry plastic injection moulds: a hybrid application. The International Journal of Advanced Manufacturing Technology, 126(9), 4419-4437.

6. Additional notes

Topics 7

1. The subject of the lecture

Sustainable Development and Additive Manufacturing Technologies

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, students will acquire the knowledge necessary to understand the complex relationships between additive manufacturing technologies and various aspects of sustainable development. This will enable them to actively and critically evaluate the role of 3D printing in the context of sustainable development, which in turn will allow for more informed participation in debates and more thoughtful decision-making regarding the implementation of these technologies in practice. The lecture will begin with a review of the concept of sustainable development. Its definition and significance in the context of global challenges will be briefly recalled. Following this, the UN's Sustainable Development Goals (SDGs) will be introduced. The next part of the lecture will focus on analyzing 3D printing in the context of the Sustainable Development Goals. Particular emphasis will be placed on the environmental impact of 3D printing, discussing the potential of additive technologies to reduce raw material consumption and minimize waste. Opportunities for the use of biodegradable and environmentally friendly materials in 3D printing will be presented, as well as the role of this technology in creating local supply chains and reducing emissions associated with transportation. Another important aspect will be the social dimensions of sustainable development in the context of 3D printing. The impact of additive technologies on improving the quality of life through the production of personalized products (e.g., prosthetics, implants) will be discussed. Challenges related to access to additive technologies and the risk of exacerbating social inequalities will be highlighted. The lecture will also address the economic aspects of 3D printing in the context of sustainable development, discussing the impact of additive technologies on the transformation of business models and the creation of new market opportunities. The potential of 3D printing to optimize production costs and shorten time-to-market will be emphasized, while also drawing attention to challenges related to intellectual property protection and the potential impact on the labor market. Ethical and legal aspects of additive technologies will not be overlooked either. The lecture will address security and liability issues related to 3D printing (e.g., weapon production, copyright infringement), the need for regulations and standards for the use of additive technologies, and ethical dilemmas, such as those related to bioprinting. Finally, a discussion will be held on the prospects for the development of additive technologies and their potential impact on achieving the Sustainable Development Goals. Challenges and opportunities associated with the widespread adoption of 3D printing in various sectors of the economy will be discussed, and the importance of an interdisciplinary approach in maximizing the positive impact of additive technologies on sustainable development will be emphasized.

3. Learning outcomes

The student:

- has in-depth and well-structured knowledge of additive technologies, covering key issues related to 3D printing and its applications. They are able to link the potential of additive technologies to the realization of the UN Sustainable Development Goals (SDGs), identifying and analyzing potential applications of 3D printing in achieving specific goals.
- is ready to initiate and develop interdisciplinary collaboration aimed at utilizing additive technologies for sustainable development, in both local and international contexts.
- is prepared to responsibly plan, implement, and oversee activities related to the development and implementation of additive technologies, guided by the principles of sustainable development in social, economic, and environmental dimensions.
- is able to critically assess their level of knowledge and skills, identify areas requiring further improvement, and actively seek information on innovations in the field of 3D printing, analyzing their potential applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia Presentation: Utilizing a multimedia presentation, such as PowerPoint, Prezi, or Google Slides, to visually present the discussed topics.
- Case Study: Presenting specific examples of 3D printing applications in various fields, such as the automotive industry and medicine.
- Discussion: Encouraging participants to actively engage in a discussion about the topics covered.
- Quiz: Conducting a short quiz after the lecture to assess how well participants have absorbed the information presented.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Agrawal, R. (2022). Sustainable design guidelines for additive manufacturing applications. Rapid Prototyping Journal.
- Arifin, N. A. M., Alkaabi, S., Reffat, R., & Nassrullah, Z. (2022). Sustainability implications of additive manufacturing. In Human-Centered Technology for a Better Tomorrow: Proceedings of HUMENS 2021 (pp. 441-452).
- Landi, D., Angella, G., Rallini, M., & Monti, M. (2022). Comparative life cycle assessment of two different manufacturing technologies: Laser additive manufacturing and traditional technique. Procedia CIRP, 105, 700-705.
- Wu, H., Tavangar, R., Nasiri, A., Cao, S., & Paul, D. (2022). Additive manufacturing of recycled plastics: Strategies towards a more sustainable future. Journal of Cleaner Production, 335, 130236.

- Mangla, S. K., Kumar, D., & Patnaik, A. (2023). Optimizing fused deposition modelling parameters based on the design for additive manufacturing to enhance product sustainability. Computers in Industry, 145, 103833.
- Roozkhosh, P., Pooya, A., Soleimani Fard, O., & Bagheri, R. (2024). Revolutionizing supply chain sustainability: An additive manufacturing-enabled optimization model for minimizing waste and costs. Process Integration and Optimization for Sustainability, 8(1), 285-300.
- Hegab, H., Khanna, N., Monib, N., & Salem, A. (2023). Design for sustainable additive manufacturing: A review. Sustainable Materials and Technologies, 35, e00576.

6. Additional notes

- It is recommended that students independently search for additional scientific literature related to the topics of sustainable development and additive technologies in order to deepen their knowledge and better prepare for the lecture and practical sessions.

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

The Influence of Printing Parameters on the Mechanical Properties of Parts Printed Using FDM Technology

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Laboratory classes will serve as a practical extension of the theoretical knowledge gained during lectures on FDM technology. The aim of the classes is to assess the impact of various 3D printing parameters on the mechanical properties of the produced parts. Students will have the opportunity to experimentally verify the influence of factors such as nozzle and bed temperature, print speed, layer height, infill density, and infill pattern on the quality and mechanical properties of prints. Through this practical approach, participants will deepen their understanding of the relationship between selected parameters and the characteristics of the final product, which will allow them to optimize 3D printing processes more effectively in their future professional careers. Students will work with popular materials like ABS, PLA, and PET, allowing them to learn the specific characteristics of each and determine their optimal applications in various industries. An essential component of the laboratory will be familiarizing participants with ASTM and ISO standards that regulate the testing of 3D printed materials. The ability to search for, interpret, and practically apply these standards is invaluable in an industrial environment. Based on these standards, students will design their own test samples using CAD software, enabling them to gain a deeper understanding of the relationship between geometry and the mechanical properties of printed parts. The culmination of the classes will involve solving an individual engineering problem. Each team will be assigned a unique challenge, such as designing a component with a specified strength while minimizing its weight or optimizing printing parameters to achieve maximum bending resistance. This task will allow students to apply the theoretical knowledge they have gained in a practical context while developing their analytical skills and creative problem-solving abilities. Through this laboratory, future engineers will not only delve into the theoretical aspects of 3D printing but will also acquire practical skills essential for modern industry. They will learn to select appropriate materials and printing parameters for specific applications, conduct standardized tests, and optimize production processes. This knowledge will be crucial in industries such as aerospace, automotive, and medicine, where additive technologies are playing an increasingly important role.

Co-funded by the European Union

3. Learning outcomes

The student:

- is able to analyze and modify key 3D FDM printing parameters to optimize the mechanical properties of the produced parts.
- is capable of planning and conducting research experiments in accordance with ASTM and ISO standards, focusing on bending, compression, and tensile strength tests for samples made from materials such as ABS, PLA, and PET.
- can design test samples in CAD software, taking into account the specifics of strength testing and the requirements of 3D printing standards.
- is able to interpret the results of mechanical tests and draw conclusions regarding the relationship between printing parameters and mechanical properties.
- is able to develop solutions for individual engineering problems related to optimizing the mechanical properties of printed parts.
- can apply safety regulations when operating 3D printers, mechanical testing devices, and working with materials used in 3D printing.
- can critically evaluate the results of their own research and experiments in 3D printing, taking into account the method's limitations and potential sources of error.
- is capable of collaborating in a research team, assuming different roles and sharing responsibility for the execution of complex experimental and design tasks.
- is ready to responsibly approach the design and optimization of 3D printed parts, considering their potential impact on the safety and functionality of the final products.
- is prepared to consciously use 3D printing in the context of sustainable development, with a focus on material selection and the management of laboratory waste.

4. Necessary equipment, materials, etc

The exercise is conducted in two laboratories:

- 3D Printing Laboratory, equipped with FDM printers and appropriate equipment for post-processing the prints.
- Mechanical Testing Laboratory, equipped with a universal testing machine for strength testing.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory Outline:

1. Knowledge Check from Lecture:
   - A short test covering key concepts from the lecture will be conducted to ensure that students are well-prepared for the session.
2. Introduction:
   - Presentation of the laboratory's purpose along with a brief theoretical introduction.

- Explanation of the laboratory procedure and criteria for completion.
- Discussion of laboratory regulations and the occupational health and safety (OHS) rules applicable during the session.

3. Team Formation:
   - Students will be divided into small teams. Each team will receive a research problem from the instructor related to the impact of 3D printing parameters on the mechanical properties of printed components. Example research topics might include the effect of print orientation on tensile strength or the impact of infill density on compressive strength.
   - Teams will be responsible for developing a research plan and assigning roles to each team member. The plan must be methodologically sound, feasible within available resources, and focused on achieving the research objectives.
   - The instructor will act as a mentor, offering teams technical support in developing their research plans.
   - The instructor will verify and approve the research plan to ensure alignment with scientific objectives and correct methodological approaches.
4. Conducting Research:
   - Following the assigned research topic and the developed research plan, teams will conduct experiments to analyze the impact of selected printing parameters on the mechanical properties of samples in static compression, tension, or bending tests.
   - Depending on the assigned research topic, students will design 3D models of samples that meet the requirements of relevant ASTM/ISO standards (e.g., for compression, tension, or bending tests) using CAD software.
   - Each team will be responsible for preparing the 3D printer for operation, including calibrating the machine, selecting appropriate print parameters based on the research plan, and printing the samples.
   - Students will monitor the printing process to ensure the model is printed as expected and adjust the print settings if necessary.
   - Teams will conduct tests using the universal testing machine, following ASTM/ISO standards for the specific type of test (e.g., tension, compression, bending), taking into account the specifics of 3D printed materials.
5. Data Analysis:
   - Teams will analyze the collected data and prepare a presentation of their research results.
   - Each team will present their research results to the other groups in a short presentation, discussing their findings on the impact of printing parameters on the mechanical properties of FDM-manufactured parts.
   - Teams will submit a full written report to the instructor by the designated deadline. The report should include a detailed analysis of the results,

conclusions from the research, and a discussion of the findings in relation to the current literature.

6. Conclusion:
    - The instructor will summarize the laboratory session, reiterating its objectives and key assumptions.
    - A closing discussion will follow, focusing on the experiences gained and potential directions for future research, with particular emphasis on the practical applications of the acquired knowledge in the field of 3D printing.

Team Self-Evaluation:

After the laboratory session, each team should conduct an internal evaluation of their work using a form provided by the instructor. Students will assess the contributions of team members, the effectiveness of communication, and collaboration. Teams will identify strengths and areas for improvement, discussing the results with the instructor to enhance their teamwork skills.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Gordelier, Tessa Jane, et al. "Optimising the FDM additive manufacturing process to achieve maximum tensile strength: A state-of-the-art review." Rapid Prototyping Journal 25.6 (2019): 953-971.
- Rajpurohit, Shilpesh R., and Harshit K. Dave. "Effect of process parameters on tensile strength of FDM printed PLA part." Rapid Prototyping Journal (2018).
- Birosz, Márton Tamás, Dániel Ledenyák, and Matyas Ando. "Effect of FDM infill patterns on mechanical properties." Polymer Testing 113 (2022): 107654.

7. Additional notes

The laboratory can be divided into three parts to effectively utilize time and ensure comprehensive execution of the research plan:

- Part One: Teams focus on designing and preparing 3D model samples for printing and then printing them. (The printing process is time-consuming).
- Part Two: Teams conduct mechanical property testing.
- Part Three: Teams analyze the collected data, prepare, and present their research results.

8. Optional information

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Topics 2 – Lab 2

1. The subject of the laboratory classes

Study of the Influence of Printing Parameters and Resin Type on the Mechanical Properties of Elements Manufactured Using MSLA Technology

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Laboratory exercises will enable the practical application of theoretical knowledge acquired during the lecture "3D Printing Technologies Based on Photopolymerization: Materials, Applications, and Development Prospects." The aim of these sessions is to evaluate the impact of various printing parameters on the mechanical and qualitative properties of manufactured components. Before starting the experiments, students will undergo training on the operation of the MSLA printer as well as safety and hygiene regulations (OSH). Special attention will be paid to the toxicity of photopolymer resins, exposure to UV radiation, and the necessity of using appropriate personal protective equipment. Students will learn how to properly configure and calibrate the MSLA printer to ensure optimal print quality. This includes setting up the work platform, entering the correct printing parameters, and preparing the resin. Additionally, participants will learn how to properly clean and maintain the printer and resin containers, which is crucial for long-term, trouble-free operation of the device. During the course, the procedure for replacing the FEP film in the MSLA printer will be discussed and demonstrated, which is key to ensuring optimal printing conditions and avoiding adhesion issues with prints. They will also learn post-processing techniques, such as removing supports and curing prints, which are essential for achieving high-quality final products. The most important part of the course will be solving an engineering problem. This task will allow students to apply their theoretical knowledge in a practical context. Students will be required to independently propose a research plan, taking into account the impact of printing parameters and post-processing techniques on the strength properties of printed components. As part of the project, students will need to demonstrate the ability to search for, interpret, and practically apply ASTM and ISO standards. Based on these standards, they will design their own test samples using CAD software and select the appropriate test (bending, tension, compression). After conducting the tests, students will interpret the results, analyzing the data in terms of the impact of printing parameters and post-processing on the strength properties of the printed components. At the end of the project, each team will present the results of their research in the form of a report and presentation.

3. Learning outcomes

The student:

- is capable of properly configuring, calibrating, and operating an MSLA printer, including setting up the work platform, entering appropriate printing parameters, and preparing the resin.
- can analyze and modify key 3D MSLA printing parameters to optimize the mechanical and qualitative properties of the manufactured parts.

- plans and conducts research experiments according to ASTM and ISO standards, focusing on bending, compression, and tensile strength for samples made from various resins.
- designs test samples in CAD software, considering the specifics of strength tests and the requirements of standards for 3D printing.
- interprets mechanical test results and draws conclusions regarding the relationship between MSLA printing parameters and the mechanical properties of the prints.
- is ready to critically assess the results of their own research and experiments in the field of MSLA 3D printing, considering method limitations and potential sources of error.
- is prepared to critically evaluate their knowledge and the content they receive in the field of 3D printing technology, recognizing the importance of knowledge in solving cognitive and practical problems.
- applies and promotes OSH principles when operating MSLA printers, mechanical testing devices, and working with photopolymer resins, demonstrating a readiness to initiate actions for safety in the work environment.

4. Necessary equipment, materials, etc

- 3D MSLA printers
- Post-processing devices (UV curing chamber, ultrasonic cleaner)
- Computers with CAD software (e.g., Fusion 360, SolidWorks)
- Software for 3D print preparation (e.g., Chitubox, Lychee Slicer)
- Consumables (resins, isopropyl alcohol, FEP film)
- Strength testing machine (for tensile, compression, and bending tests)
- Personal protective equipment

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

The course of the laboratory

1. Knowledge Assessment from Lecture:
    - Short test covering key concepts from the lecture to ensure students are well-prepared for the class.
2. Introduction:
    - Presentation of the laboratory's purpose and a brief theoretical introduction.
    - Discussion of the laboratory procedure and grading criteria.
    - Review of laboratory rules and health and safety regulations (OSH) applicable in the lab.
3. Team Formation:
    - Students will be divided into small teams. Each team will receive a research problem from the instructor related to the impact of 3D printing and post-processing parameters on the strength properties of MSLA-printed elements.

Example research topics may include: "The effect of layer thickness on selected mechanical properties of MSLA-printed elements using Plant-based Eco Clear resin" and "The effect of post-processing operations on selected mechanical properties of MSLA-printed elements using Plant-based Eco Clear resin."

4. Conducting Research:
    - According to the assigned research topic and developed research plan, teams will conduct experiments analyzing the impact of selected printing parameters on the mechanical properties of samples in static compression, tensile, or bending tests.
    - Depending on the assigned research topic, students will design 3D models of samples that meet the requirements of relevant ASTM/ISO standards (e.g., for compression, tensile, or bending tests) using CAD design software.
    - Each team will be responsible for preparing the 3D printer, including calibrating the device, selecting appropriate printing parameters (e.g., Bottom Exposure Time, Normal Exposure Time, Layer Height, Lift Speed, Lift Distance, UV Power) according to the research plan, and printing the samples.
    - Students will monitor the printing process to ensure the model is printed as expected and will adjust the printing settings if necessary.
    - After the printing process is complete, teams will remove the prints from the printer and perform post-processing, which includes cleaning the print, removing supports and other surface imperfections, and curing the print in a UV chamber. Teams will independently select the curing time, taking into account the properties of the resin used and the research objectives. The decision on curing time should be justified and documented as part of the research process.
    - Teams will conduct tests using a universal testing machine. The tests will be carried out in accordance with the ASTM/ISO standards for the given type of test (e.g., tensile, compression, bending), considering the specifics of 3D printed materials.
5. Results Analysis:
    - Teams will analyze the collected data and prepare a presentation of their research results.
    - Each team will present a brief report of their research results to the other groups, discussing their conclusions regarding the impact of the investigated printing parameters on the mechanical properties of parts manufactured using MSLA technology.
    - Teams will submit a full written report of the exercise to the instructor within the specified deadline. The report should include a detailed analysis of the results, conclusions from the conducted research, and a discussion of the findings in relation to current literature on the subject.

6. Summary:
    - The instructor will summarize the laboratory, reiterating its goals and main objectives.
    - At the end of the session, there will be a concluding discussion of the experiences gained and potential directions for further research, with a particular focus on the practical applications of the knowledge gained in the field of 3D printing.

Team Self-Assessment:
After the laboratory session, each team should conduct an internal assessment of their work using a form provided by the instructor. Students will evaluate the contributions of team members, the effectiveness of communication and collaboration. Teams will identify strengths and areas for improvement, and the results will be discussed with the instructor, contributing to the development of teamwork skills.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Literature:

- Štaffová, Martina, et al. "3D printing and post-curing optimization of photopolymerized structures: Basic concepts and effective tools for improved thermomechanical properties." Polymer Testing 108 (2022): 107499.
- Uzcategui, Asais Camila, et al. "Understanding and improving mechanical properties in 3D printed parts using a dual-cure acrylate-based resin for stereolithography." Advanced engineering materials 20.12 (2018): 1800876.
- Mendes-Felipe, Cristian, et al. "Evaluation of postcuring process on the thermal and mechanical properties of the Clear02™ resin used in stereolithography." Polymer Testing 72 (2018): 115-121.

7. Additional notes

The laboratory can be divided into three parts to efficiently utilize time and ensure the comprehensive execution of the research plan:

- Part One: Teams focus on designing and preparing 3D model samples for printing and printing them. (The printing process is time-consuming.)
- Part Two: Teams conduct mechanical property testing.
- Part Three: Teams analyze the collected data, prepare, and present the results of their research.

8. Optional information

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Topics 3 – Lab 3

1. The subject of the laboratory classes

Assessment of the Influence of SLM Process Parameters on the Mechanical Properties and Microstructure of Components Manufactured from Metals and Their Alloys

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The objective of the laboratory is to examine the influence of Selective Laser Melting (SLM) process parameters on the microstructure and hardness of various metals and their alloys. The laboratory session begins with a brief introduction to the SLM process by the instructor. The instructor refers to the students' previous visit to an industrial facility or research institute, where they had the opportunity to see an SLM machine in operation. Key aspects of the technology, such as process parameters, types of powders used, and the operating principles of the machine, are reviewed. Next, each group of students is provided with a set of pre-manufactured samples made from different alloys (e.g., 316L, Ti6Al4V, H13, AlSi10Mg), which were produced earlier using various SLM parameters. The instructor explains the parameters used to manufacture each sample, emphasizing their potential impact on microstructure and mechanical properties. The students will begin by preparing metallographic specimens, followed by microscopic observations. The primary goal will be to identify the characteristic features of the microstructure for the assigned alloy and to analyze the impact of the SLM parameters on this microstructure. Available light microscopes will be used for observations, and if possible, a scanning electron microscope (SEM) will also be employed. The next stage will involve hardness measurements using the Vickers method. The students will perform a series of measurements for each sample, paying attention to differences resulting from the process parameters and the location of the measurements. During the laboratory session, participants will need to demonstrate the ability to search for, interpret, and practically apply information from literature and databases. This will ensure that their research is aligned with international standards and that they can compare their results with data from the literature. This skill will allow students to conduct accurate research, analyze the results, and critically assess them in the context of the current state of knowledge in the field of SLM technology and the properties of materials produced by this method. At the end of the session, each group will prepare a report and presentation analyzing the influence of SLM parameters on the microstructure and hardness of the studied alloy, and they will present their findings to other students. Since each group may have worked with a different alloy, these presentations will provide all participants with exposure to a broader range of materials.

3. Learning outcomes

The student:

- has an in-depth understanding of the key aspects of Selective Laser Melting (SLM) technology, including process parameters, types of powders used, and the principles of device operation.
- possesses advanced knowledge about the influence of SLM process parameters on the microstructure and mechanical properties of various metals and their alloys.
- is capable of preparing metallographic specimens and conducting microscopic observations to identify the characteristic microstructural features of the assigned alloy.
- is able to perform hardness measurements using the Vickers method, taking into account differences arising from process parameters and measurement location.
- is proficient in planning and organizing individual and team work, efficiently managing time and resources.
- can monitor work progress and respond to emerging issues, adjusting the action plan to changing circumstances as necessary.
- is skilled in critically analyzing research results, including microstructure observations and hardness measurements, and drawing conclusions regarding the impact of SLM process parameters on the properties of the studied alloys, while comparing them with the current state of knowledge in the field.
- can prepare a report and presentation analyzing the influence of SLM parameters on the microstructure and hardness of the studied alloy and present the findings.
- is ready to acknowledge the importance of knowledge in solving cognitive and practical problems related to SLM technology and to seek expert opinions when encountering difficulties in independently solving a problem.

4. Necessary equipment, materials, etc

The laboratory exercise should be conducted in the Metallography Laboratory, equipped with tools and equipment for preparing metallographic specimens and observing microstructures. The following devices and materials are required:

- Pre-prepared samples made from various alloys (e.g., 316L, Ti6Al4V, H13, AlSi10Mg) using Selective Laser Melting (SLM) technology with different process parameters
- Equipment for preparing metallographic specimens, along with consumables
- Optical microscopes, SEM microscope
- Vickers hardness tester

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory Outline

1. Knowledge Check from the Lecture:
   - A short test covering key concepts from the lecture to ensure students are well-prepared for the lab session.
2. Introduction:
   - Presentation of the laboratory objective and a brief theoretical introduction, during which the instructor initiates a discussion referring to the students' previous visit to an industrial facility or research institute where they were introduced to the SLM machine.
   - Overview of the laboratory procedure and presentation of the grading criteria.
   - Discussion of laboratory rules and safety and hygiene regulations (BHP) applicable in the laboratory.
3. Team Formation:
   - Students will be divided into small teams. Each team will receive a set of samples made from materials such as AlSi10Mg, Ti6Al4V, H13, and 316L, along with complete information about the SLM process parameters used for manufacturing each sample (e.g., laser power, scanning speed, hatch spacing, layer thickness, scan strategy, platform temperature, protective atmosphere).
4. Conducting the Research:
   - Teams will prepare the samples for microscopic observation, familiarizing themselves with the recommendations for preparing samples from the materials being studied. Team members will collaborate throughout all stages of the research, sharing knowledge and experience. However, each team member must individually prepare at least one metallographic specimen.
   - Each team will be responsible for conducting and documenting observations using the scanning electron microscope (SEM) and/or optical microscope.
   - Students will perform microhardness tests on the prepared samples, paying special attention to the measurement locations (in accordance with the guidelines provided with the samples). Teams will document the exact locations of the microhardness measurements on diagrams or microstructure photographs, justifying the choice of these locations in the context of the SLM process parameters and/or observed microstructure.
5. Data Analysis and Presentation Preparation:
   - Teams will analyze the collected data and prepare a presentation of their research findings.

- Each team will give a short presentation of their research results to the other groups. During the presentation, they will discuss their conclusions regarding the influence of the SLM process parameters on the microstructure and mechanical properties of the assigned set of samples.
- Teams will submit a full written report on the exercise to the instructor by the specified deadline. The report should include a detailed analysis of the results of microscopic observations and microhardness tests, conclusions from the conducted research, and a discussion of the results in relation to the current literature on SLM technology and the properties of materials manufactured by this method.

6. Summary:
   - The instructor will summarize the laboratory session, reiterating its goals and main objectives.
   - At the end of the session, there will be a concluding discussion on the gained experience and potential directions for further research, with particular emphasis on the practical applications of the acquired knowledge in the field of additive manufacturing of metals and their alloys using the SLM method.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Literature

1. Bian, Linkan, Nima Shamsaei, and John M. Usher, eds. Laser-based additive manufacturing of metal parts: modeling, optimization, and control of mechanical properties. CRC Press, 2017.
2. Shakil, S. I., et al. "Additive manufactured versus cast AlSi10Mg alloy: Microstructure and micromechanics." Results in Materials 10 (2021): 100178.
3. Zhai, Wengang, et al. "Selective Laser Melting of 304L and 316L Stainless Steels: A Comparative Study of Microstructures and Mechanical Properties." steel research international 93.7 (2022): 2100664.
4. Zheng, Zhongpeng, et al. "Microstructure and anisotropic mechanical properties of selective laser melted Ti6Al4V alloy under different scanning strategies." Materials Science and Engineering: A 831 (2022): 142236.

7. Additional notes

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8. Optional information

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Topics 4 – Lab 4

1. The subject of the laboratory classes

Quality Control of Components Manufactured by Additive Methods Using Computed Tomography

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory will begin with a brief theoretical introduction, during which the instructor will discuss the principles of X-ray Computed Tomography (X-ray CT) and its application in the quality analysis of components manufactured by additive methods. Students will then participate in a demonstration of measurement using a micro-CT scanner, observing the scanning process of a selected sample. The instructor will explain the key measurement parameters and the 3D image reconstruction process, allowing students to understand the practical aspects of this research technique. After the demonstration, participants will be divided into working groups. Each group will receive a unique set of micro-CT measurement data, containing scan results of samples produced by various 3D printing techniques, such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM). This selection of samples will enable a comprehensive comparison of the quality of products obtained through different additive methods. The main part of the laboratory will take place in a computer lab, where students, using specialized software, will conduct a detailed analysis of the provided data. The analysis process will include importing and visualizing 3D data, segmenting the image to isolate material and voids, analyzing porosity and pore distribution, as well as identifying and classifying defects, such as cracks or discontinuities. Students will also learn to perform geometric accuracy measurements by comparing the results with the original CAD model and analyzing the wall thickness and uniformity of the printed components' structure. During data analysis, groups will need to pay particular attention to differences in the quality of products made by various 3D printing methods. They will seek characteristic features and defects typical for each method, which will help them better understand the advantages and limitations of individual additive manufacturing technologies. After the analysis is complete, each group will prepare a short report describing the analyzed samples, the results of the porosity and defect analysis, an assessment of geometric accuracy, and a comparison of the quality of products made using different methods. An essential part of the report will be the conclusions and recommendations regarding the optimization of 3D printing processes, based on the conducted analysis. The laboratory will conclude with a presentation session, where each group will present their results and conclusions. After each presentation, there will be a short discussion, allowing students to exchange insights and deepen their understanding of the topic. The session will culminate in a moderated comparative discussion led by the instructor, where students will have the opportunity to discuss the differences between 3D printing techniques in the context of the quality of the produced components. The laboratory will not only provide students with practical skills in analyzing micro-CT data but will also enhance their critical thinking and ability to draw conclusions based on complex data. The knowledge and experience gained will be invaluable for future engineers working with additive manufacturing technologies, enabling them to optimize production processes and ensure quality control in industry effectively.

3. Learning outcomes

The student:

- knows and understands in depth the role and importance of quality control in 3D printing and its impact on the development of additive technologies.
- has advanced knowledge of methods and techniques used in the quality assessment of components manufactured by additive methods, with a particular focus on computed tomography.
- knows and understands the complex relationships between the selection of 3D printing process parameters and the occurrence of characteristic features and defects in printed components.
- is able to select and utilize advanced software and tools for conducting comprehensive quality assessments of 3D prints.
- can plan and perform porosity measurements, analyze geometric accuracy, and identify production process issues using appropriate methods and tools.
- is prepared for critical evaluation of their own knowledge and received content, as well as consulting experts when facing difficulties in independently solving a problem related to 3D print quality control.
- can independently gather information from various sources, including literature and databases, interpret and critically assess it, as well as draw conclusions and form opinions regarding 3D print quality control, integrating knowledge from different fields and applying it in practice.
- can independently plan and pursue lifelong learning, focusing on the application of acquired knowledge and skills in industrial practice related to 3D print quality control.

4. Necessary equipment, materials, etc

Measurements will be conducted in the Quality Control Laboratory equipped with a tomograph.
Qualitative and quantitative analyses will be carried out in a computer lab with the appropriate software.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory Outline

1. Verification of Theoretical Knowledge
   - The purpose of verifying students' knowledge of the theoretical issues related to the exercise is to ensure that they possess the necessary understanding to complete the practical tasks in the laboratory. Prior to the exercise, students will receive topics covering quality control methods in additive

manufacturing, with a particular focus on the application of micro-computed tomography (micro-CT) in the evaluation of the quality of printed components.

2. Introduction
   - The objectives of the laboratory and a brief theoretical introduction to computed tomography (CT) will be presented.
   - The instructor may initiate a brief discussion on possible applications of micro-computed tomography (micro-CT) in the evaluation of additively manufactured components, such as the detection of internal defects, porosity assessment, and dimensional measurements.
   - The laboratory procedure and grading criteria will be explained.
   - The laboratory rules and safety regulations (BHP) applicable to the lab will be discussed.
3. Measurement Procedure Demonstration
   - The instructor will present the tomograph available in the laboratory, discussing the main components and operating parameters. A demonstration of the scanning procedure on a selected sample will be conducted, explaining the importance of each stage of the measurement.
4. Team Formation
   - Students will be divided into small teams. Each team will receive a set of measurement data for samples made from different materials, along with full information on the manufacturing method and the process parameters used during the production of each sample. The information will also include the measurement parameters for the computed tomography (CT) scan.
   - Each team's task will be to analyze the provided data based on the assigned research problem.
5. Research
   - During the laboratory exercises, student groups will analyze the measurements using specialized software and visualize the obtained results.
   - Each team is responsible for conducting and documenting the micro-CT data analysis for the assigned samples. Team members will collaborate at all stages of the research, sharing knowledge and experience. However, each team member is responsible for independently analyzing at least one sample.
6. Data Analysis and Presentation
   - Each team will prepare a short presentation of their research results to be presented to the other groups. During the presentation, they will discuss their conclusions regarding the quality control of the examined components.
   - Teams will submit a complete written report to the instructor by the designated deadline. The report should include a detailed analysis of the results, conclusions from the conducted research, and a discussion of the

results in relation to the current literature on the quality control of additively manufactured components using computed tomography.

7. Summary
   - The instructor will summarize the laboratory, revisiting its objectives and main points.
   - A concluding discussion will be held to reflect on the experiences gained and explore potential directions for further research, with a special focus on practical applications of the acquired knowledge in the field of quality control for additively manufactured components.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

As part of the preparation for the research, students should study scientific literature, particularly case studies and articles demonstrating the use of micro-computed tomography (micro-CT) in the quality control of components manufactured by 3D printing.

It is essential for students to familiarize themselves with the applications of this technique in various industry sectors, such as aerospace, automotive, and medicine. Furthermore, their literature analysis should be focused on the research problem at hand, enabling them to draw accurate conclusions based on the results of their experiments.

Sample Literature:

1. Industrial X-Ray Computed Tomography. (2017). Germany: Springer International Publishing.
2. Khosravani, M. R., & Reinicke, T. (2020). On the use of X-ray computed tomography in assessment of 3D-printed components. *Journal of Nondestructive Evaluation, 39*(75). https://doi.org/10.1007/s10921-020-00721-1
3. Zhang, K., Meng, Q., Zhang, X., Qu, Z., & He, R. (2022). Quantitative characterization of defects in stereolithographic additive manufactured ceramic using X-ray computed tomography. Journal of Materials Science & Technology, 118, 144-157. https://doi.org/10.1016/j.jmst.2021.11.060
4. VGStudio Max (Version 2024.2) [Documentation]. Volume Graphics GmbH. Retrieved August 10, 2024, from https://www.volumegraphics.com/en/products/vgsm.html

7. Additional notes

- Students should possess knowledge of 3D printing techniques such as SLM, SLS, and FDM, as well as their advantages and limitations.
- Familiarity with the principles of computed tomography and its applications in non-destructive testing is recommended.
- Knowledge of basic image processing techniques, such as segmentation and 3D visualization, will be useful during the practical part of the laboratory.

8. Optional information

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Topics 5 – Lab 5

1. The subject of the laboratory classes

Additive Technologies - Threats, Challenges, and Perspectives

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory course "Additive Technologies - Threats, Challenges, and Perspectives" integrates the knowledge students have acquired during a series of lectures and practical exercises focused on additive technologies. As part of the laboratory, an interdisciplinary debate is planned, aimed at placing issues related to 3D printing within the broader context of global challenges and Sustainable Development Goals (SDGs). In preparation for the debate, students will be divided into groups, each responsible for analyzing the connections between additive technologies and selected Sustainable Development Goals. The task for the students will be to identify specific examples of 3D printing applications that could contribute to the achievement of the goals assigned to them. Participants will be asked to consider how 3D printing can positively impact the environment and society, for example, by reducing raw material consumption, minimizing waste, creating local supply chains, or enabling the production of personalized products. At the same time, each group will be required to critically analyze the potential threats and challenges associated with the widespread adoption of additive technologies in the context of the assigned Sustainable Development Goals. Students will need to consider issues such as intellectual property protection, consumer safety, environmental threats, ethical concerns, and the impact of 3D printing on the labor market. In preparing for the debate, participants will have to gather strong arguments and compelling examples that illustrate both the positive and negative aspects of using additive technologies in the pursuit of sustainable development. Students should draw on diverse sources of information, such as scientific publications, industry reports, case studies, and expert opinions, to gain a comprehensive understanding of the impact of 3D printing on the realization of the Sustainable Development Goals. The collected data and examples will serve as the foundation for formulating thoughtful arguments during the debate, taking into account the complexity and multifaceted nature of the topic. Participants will need to demonstrate the ability to critically analyze, synthesize information, and present their views clearly, logically, and persuasively, while remaining open to counterarguments and alternative perspectives presented by other debate participants.

3. Learning outcomes

The student:

- is able to critically analyze and synthesize information from various sources regarding the impact of additive technologies on the environment, society, and the economy.
- can formulate thoughtful arguments, present their own views, and engage in substantive discussion on the role of 3D printing in shaping a sustainable future, taking into account ecological, social, and economic aspects, as well as different perspectives and alternative opinions.

- is prepared to critically assess their knowledge of the impact of additive technologies on the environment, society, and the economy and to recognize the importance of expert knowledge in solving related issues.
- is ready to think and act in an entrepreneurial and innovative manner, seeking opportunities to improve existing processes, technologies, and materials in the field of 3D printing, and to develop new ones that can contribute to environmental protection, improved quality of life, and sustainable economic development.
- is able to communicate about topics related to additive technologies, using specialized language while skillfully adapting their message to different audiences, including those outside the industry, effectively explaining complex concepts and technical issues.

4. Necessary equipment, materials, etc

- flipchart / dry erase board
- multimedia projector
- notebooks, markers, pens, pencils, etc.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Introduction:

The Moderator will begin the session by introducing the debate topic and presenting the thesis, for example, "Additive manufacturing is a more environmentally friendly alternative to traditional manufacturing methods." In this context, the moderator will highlight the global drive towards more ecological solutions in production and the need for a critical analysis of new technologies, such as 3D printing, in terms of their real environmental impact. The moderator will then outline the debate format, explaining the roles of the speakers and the rules for conducting the discussion, including the time allotted for each speech. At the end of the introduction, the moderator will remind the participants of the evaluation criteria, which students were informed about before the session. These include: relevance of the speech to the topic, selection and quality of argumentation, level of expertise, delivery, and appropriate behavior.

Preparation time:

After the introduction, the moderator will conduct a draw to determine which team will argue for the thesis and which team will argue against it. The moderator will then announce the time for final preparations before the start of the formal debate. Students will be given a set amount of time to organize their arguments, consult within their teams, and prepare their strategy, taking into account their assigned position. During this time, teams may:

- Review their notes and source materials
- Discuss the order and key points of their speeches

- Anticipate potential counterarguments from the opposing team and prepare responses
- Assign responsibility for various aspects of the argumentation to different team members

Presentation of arguments:

After the preparation time, the moderator will commence the main part of the debate by inviting the speakers to present their arguments. The debate will proceed according to the predetermined structure. Speakers from both teams will alternately present their arguments, starting with the team arguing "for the thesis," followed by the team arguing "against the thesis." The moderator will strictly control the time for each speech, signaling to the speakers when their time is nearing its end.

Example arguments for the thesis may include:

- Additive manufacturing allows for on-demand production, reducing overproduction and the associated waste.
- 3D printing enables optimization of part geometries, leading to material savings and reduced product weight.

Example arguments against the thesis may include:

- The 3D printing process can be energy-intensive, especially when producing with metals, which increases the carbon footprint.
- Some materials used in 3D printing, particularly plastics, are difficult to recycle and may contribute to environmental pollution.

Cross-examination round:

After the main arguments have been presented by both teams, the moderator will initiate the cross-examination round. This part of the debate aims to deepen the discussion and allow for direct confrontation of the arguments. It offers participants the opportunity to demonstrate rhetorical skills and the ability to defend their position in a direct exchange.

Closing statements:

Following the cross-examination, the closing statements phase will begin, giving both teams a chance to summarize their positions and reinforce their key arguments.

Evaluation and summary by the moderator:

After the closing statements, the moderator will proceed to evaluate and summarize the debate. This part is intended to provide a comprehensive analysis of the discussion and the arguments presented. The moderator will offer a general assessment based on the previously outlined criteria, such as relevance to the topic, the selection and quality of arguments, the level of expertise, delivery, and appropriate behavior. The moderator will highlight the strengths of both teams' presentations, pointing out particularly strong arguments and effective presentation techniques. Areas for improvement will also be noted, with constructive criticism provided. The moderator will emphasize the key points of the debate and relate them to the broader context of the topic, stressing its importance in the face of contemporary technological and environmental challenges.

Participant reflection and discussion:

After announcing the results, the moderator will initiate a brief reflection and discussion session. Participants will have the opportunity to share their thoughts on the debate. Students from both teams will be encouraged to express their opinions on their own performances, their opponents' arguments, and the overall flow of the debate. The moderator may pose guiding questions, such as: "What was the biggest challenge during the debate?", "Which argument from the opposing team did you find the most difficult to refute?", or "How did this debate influence your perception of the topic?"

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Before the debate, students will be divided into two groups—one supporting the thesis and the other opposing it. Both groups will know the debate topic in advance, but they will not be informed whether they will be defending or opposing the thesis. Each group will defend their assigned position. This approach will give students the opportunity to understand different perspectives and strategies on the topic, as well as to hone their argumentation and presentation skills.

Students should familiarize themselves with the debate topic and gather information that will help them understand the subject and the facts they will defend during the debate. Based on the information collected, students should develop their own arguments. Additionally, students should consider possible counterarguments that may be presented during the debate and prepare responses to them.

Suggested Literature:

1. Agrawal, Rohit. "Sustainable design guidelines for additive manufacturing applications." Rapid Prototyping Journal (2022).
2. Arifin, Nabila Afif Mohmd, et al. "Sustainability implications of additive manufacturing." Human-Centered Technology for a Better Tomorrow: Proceedings of HUMENS 2021 (2022): 441-452.
3. Landi, Daniele, et al. "Comparative life cycle assessment of two different manufacturing technologies: laser additive manufacturing and traditional technique." Procedia CIRP 105 (2022): 700-705.
4. Wu, Haishang, et al. "Additive manufacturing of recycled plastics: Strategies towards a more sustainable future." Journal of Cleaner Production 335 (2022): 130236.

5. Mangla, Sachin Kumar, et al. "Optimizing fused deposition modelling parameters based on the design for additive manufacturing to enhance product sustainability." Computers in Industry 145 (2023): 103833.

7. Additional notes

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8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

ADVANCED TESTING METHODS IN MATERIALS SCIENCE

Code: ATMMS

Course content – lecture

Topics 1

1. The subject of the lecture

Light microscopy

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, the properties of the electromagnetic wave will be discussed, with particular emphasis on the range of visible light, as well as the phenomena of light in the visible range. The construction of a metallographic microscope to examine non-transparent samples will be discussed. The lecture will remind the students about the basic parameters used in microscopy, such as magnification, resolution, and depth of field. Basic techniques of light-field and dark-field microscopy, as well as polarizing microscopy, will be described. Students will learn practical examples of structural analysis using microscopic imaging. The method of preparing samples for metallographic examinations will be approached with the various stages dedicated to non-transparent materials. From a practical point of view, the main goal of this topic is to provide students with a quantitative description of a structure using a set of discrete points, lines, or planes.

3. Learning outcomes

- Understanding the wave nature of light.
- Understanding the phenomena used in the construction of lenses.
- Understanding the basics of a metallographic microscope
- Understanding imaging in microscopy using both basic and advanced techniques
- Getting to know the practical possibilities of describing the structure of engineering materials, both qualitatively and quantitatively.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
Case study - presentation of specific examples of microscopic images and methods of their qualitative and quantitative analysis.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should review knowledge about the wave nature of light and the formation of images in lenses. Also, they sloud read chapter "Microscopy with light and electrons" in Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001
as well as "Fundamentals of light microscopy" in Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

6. Additional notes

Topics 2

1. The subject of the lecture

X-rays and their interaction with matter

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will discuss X-rays' nature, formation, and properties as electromagnetic waves. Sources of X-ray radiation will be discussed, with particular emphasis on the construction of the X-ray tube. Students will learn about the formation of the real X-ray spectrum and its components: continuous and characteristic radiation. The student will learn the mechanisms of formation of each of these radiations as well as the mechanisms of interaction of X-rays with matter. The phenomena that X-rays undergo and their use for detecting and characterizing materials will be discussed. The widest part of the lecture will be devoted to the discussion of the phenomenon of X-ray diffraction on the crystal lattice. Hence, in the form of a quiz, the features of a crystalline and amorphous body will be reminded. In addition, students will learn the basics of the Bragg theory describing this phenomenon and the possibilities of its application to the characteristics of crystalline materials. Students will learn about the construction of a device used to record diffraction effects - a diffractometer, the way it works, and the most important operating parameters of the device that should be considered when characterizing engineering materials.

3. Learning outcomes

- Understanding the nature of X-rays and the phenomena they undergo.
- Familiarization with the construction of a diffractometer and the possibility of characterizing engineering materials.

• Understanding the formation of continuous and characteristic spectrums and their use in the characterization of engineering materials.
• Getting to know the possibilities of distinguishing an amorphous body from a crystalline body.
• Learned and practical way of determining interplanar distances.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
Case study - presentation of real X-ray spectrum components and conditions/requirements for their formation.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read chapter "Properties of X-Rays" in
B.D. Cullity, S.R. Stock, Elements of X-ray diffraction, Prentice-Hall Inc 2001
as well as " X-rays and their interaction with matter" in
Jens Als-Nielsen, Des McMorrow, Elements of Modern X-ray Physics, John Wiley & Sons, Ltd 2011.

6. Additional notes

Topics 3

1. The subject of the lecture

Qualitative phase analysis of multiphase materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will enable students to learn about the primary application of the phenomenon of X-ray diffraction in materials engineering, which is qualitative and quantitative phase analysis. In the form of a quiz, students will recall the basic information about the phases and their characteristics. The rules that should be used when applying phase analysis will be discussed. The application of these rules will be discussed with real examples. Students will learn the practical possibility of determining the phase composition of multiphase materials.

During the lecture, examples of single-phase material identification as well as multiphase material will be discussed.

3. Learning outcomes

- Understanding the rules and principles of qualitative and quantitative analysis of engineering multiphase materials.
- Learning how to carry out phase identification of multiphase materials.
- Understanding the importance of this technique in characterizing engineering materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
Case study - example of qualitative phase analysis done for multiphase material.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to remind knowledge gathered during the previous lecture and to read first chapter " Phase Identification By X-Ray Diffraction" in
B.D. Cullity, S.R. Stock, Elements of X-ray diffraction, Prentice-Hall Inc 2001

6. Additional notes

Topics 4

1. The subject of the lecture

Advanced structure research techniques using X-ray diffraction

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, advanced techniques using X-ray diffraction as well as reflectometry will be discussed. Special techniques will be discussed in the context of such methods as grazing incidence angle of the primary beam, reflectometry, and analysis of phase transitions occurring under the influence of temperature changes and/or changes in pressure. Students will also learn the possibility of characterizing materials characterized by a privileged crystallographic orientation of the grains. The construction of attachments used to extend the research possibilities of the diffractometer will be discussed. Students will learn specific examples of the application of special techniques for the characterization of multilayer, gradient materials, materials undergoing phase transitions, and one characterized by privileged grain orientation. They will learn about the possibility of non-destructive determination of layer thickness, density, and roughness. An example of pole figures as evidence of presence will also be presented and discussed a fiber and sheet textures.

3. Learning outcomes

- Understanding the basic assumptions of special techniques using the phenomenon of diffraction.
- Learning how to modify the measurement geometry with the attachment dedicated to a new method.
- Ability to interpret measurement data in the context of advanced characteristics of engineering materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
Case study - how to managed with thin layers characterization.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read chapter "Refraction and reflection from interfaces" in Jens Als-Nielsen, Des McMorrow, Elements of Modern X-ray Physics, John Wiley & Sons, Ltd 2011.

6. Additional notes

Topics 5

1. The subject of the lecture

Scanning electron microscopy - SEM

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will familiarize students with the limitations of using light in the visible range to study engineering materials. In the form of a quiz, students will consider other possibilities of "creating" a wave using, for example, particles such as neutrons or electrons. Students learn about the effects of electron beam interaction with matter. The basic behavior of the electron in electric and magnetic fields and the benefits resulting from it leading to the possibility of constructing a new lens capable of focusing the electron beam will be discussed. Also, the division of electron beam microscopes with particular emphasis on the scanning electron microscope will be done during the lecture. Students will learn about the construction of such a microscope and the possibilities of imaging using secondary and backscattered electrons. Students' knowledge will be extended by the possibilities related to the additional equipment of the scanning microscope in the form of an EDS detector used to analyze the chemical composition. In addition, advanced in-situ testing techniques applied for phase transformation (temperature/stress) and the diffraction phenomenon of backscattered electrons will be discussed.

3. Learning outcomes

- Understanding the dual nature of the electron beam.
- Getting to know the construction of the scanning electron microscope.
- Learning new research techniques using the additional equipment of a scanning microscope.
- Ability to interpret images formed by backscattered electrons and secondary electrons.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
Case study - which of the detectors: SE or BSE should be used to achieve the research objective.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read the chapter "The scanning electron microscope" in Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001

6. Additional notes

Topics 6

1. The subject of the lecture

Transmission electron microscopy -TEM

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will familiarize students with the effects of the interaction of the electron beam with the matter used for analysis in the transmission electron microscope. Students will learn about the structure of the transmission microscope. Types of lenses used in electron microscopes and their disadvantages with correction options will be discussed. The most important part of the lecture will be the presentation of the ways of creating contrast in transmission microscopes and their use for imaging. Observation techniques in the bright and dark fields will be discussed as well as high-resolution microscopy. Students learn about the phenomenon of electron diffraction on a crystal lattice, its description, and its application to determine the interplanar distance. The reverse crystal lattice will be used to interpret the diffraction phenomenon. In addition, students will learn how to solve electron diffraction patterns, characteristic of monocrystalline and polycrystalline materials, respectively.

3. Learning outcomes

- Understanding the effects of electron beam interaction with matter.
- Ability to interpret images observed in the light and dark field.
- Understanding the phenomenon of electron diffraction on a crystal lattice.
- Understanding the basics leads to solving electron diffraction patterns.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.

Case study - solving the electron diffraction pattern taken for polycrystalline material.
Discussion - encouraging students to participate in the discussion on the issues actively.
Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read the chapter "The transmission electron microscope" in Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 200

6. Additional notes

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

Light microscopy - quantitative analysis

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory aims to familiarize students with the use of metallographic microscopy to characterize the structure of engineering materials. Many metallic and ceramic engineering materials will be used in the lab exercise. The samples for the exercise will contain single-phase or multiphase materials. During the preparation of metallographic microsections, students will reveal the grain structure. The obtained microscopic images will be used for individual analysis. For this purpose, students will use computer aid to perform a quantitative analysis of objects such as crystal grains. The average grain size for multiphase materials will be determined. The exercise will aim to learn the qualitative and quantitative methodology used in metallographic microscopy. The exercise will end with report preparation.

3. Learning outcomes

By working on this laboratory project, students:
• will gain practical skills in preparing non-transparent materials for microscopic examination,
• will gain experience in operating metallographic microscopes,
• will learn to interpret the observed microscopic images and the quantitative approach to the analyzed objects.

4. Necessary equipment, materials, etc

The exercise is conducted in two laboratories.

- Laboratory equipped with deviced decitated to a sample preparation.
- Laboratory equipped with metallographic microscopes.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
    a. A brief test on key concepts from the lecture to ensure students is well prepared for the lab.
2. Introduction:

   a. Introducing the lab's objective and discussing the image formation in the metallographic microscope.
   b. Discussing the techniques, which can be applied for non-transpartent object observation.
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
   c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
   d. The instructor approves the research plan to ensure that teams are working towards the intended objectives.
4. Research:
   a. Depending on the adopted research plan, teams will prepare samples one from metals and second made of ceramics.
   b. In teams, student will be observing microstructure of the previosuly prepared samples.
5. Results analysis:
   a. Studnets will calculate avergae grain size.
   b. Each team will present the results of their research in a presentation.
   c. Teams will discuss and compare their results to ones recived from others.
   d. Students will create conclusions regarding the observation.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. In temas studnets will prepare reports.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

1. Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

8. Optional information

Exercise manuals will be available

Topics 2 – Lab 2

1. The subject of the laboratory classes

X-ray tube radiation spectrum

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The exercise aims to familiarize with the formation and nature of X-ray radiation by examining the influence of the X-ray tube operating parameters on the formation of the real spectrum. In this context, students will use the accelerating voltage as a variable. By increasing its values and recording the spectrum, they will determine the minimum wavelength of the continuous spectrum. In addition, they will determine the value of the accelerating voltage (excitation voltage) that causes the formation of the characteristic spectrum. For an X-ray tube with a molybdenum anode, they will determine the wavelength value for Kα1 and 2 and Kß radiation. Students divided into groups will independently carry out measurements on special X-ray aparatus dedicated to laboratory work in student laboratories. The exercise will end with report preparation.

3. Learning outcomes

By working on this laboratory project, students:

- will gain experience concering components of real the X-ray spectrum.
- will develop skills in oprating with X-ray diffractometer.
- will learn how to interpret and analyze the results and communicate their findings effectively.

4. Necessary equipment, materials, etc

- Laboratory equipped with X-ray diffractometer.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:

   a. A brief test on nature, sources and properties of the X-rays from the lecture to ensure students are well prepared for the lab.

2. Introduction:
   a. Introducing the lab's objective and discussing the significance of the impact of accelerating voltage as well as on formation of the real X-ray spectrum from tube.
   b. Discussing importance of the materials used for anode in X-ray tube.
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
   c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
   d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
   a. Depending on the adopted research plan, teams will carry out an experiment on X-ray difractometer.
   b. Teams will be responsible for preparing X-ray apparatuse for carriung out experiment by setting all required parameters.
   c. Each group will conduct an experiment with the active participation of each student.
   d. From the obtained results, the student will determine the dependencies of the vawelength minimum and excitation voltage versus accelerating voltage.
5. Results analysis:
   a. First the members of the team will discuss in the groupe received results, its correctness and sens.
   b. Each team will present the results of their research in a presentation.
   c. Teams will discuss their conclusions regarding the impact of the accelerating voltage on X-ray real spectrum.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the experience and identifying possible use of the X-ray spectrum for materials characterization.
   c. In temas studnets will prepare reports.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

1. B.D. Cullity, S.R. Stock, Elements of X-ray diffraction, Prentice-Hall Inc 2001
2. H. Czichos, T. Saito, L. Smith – Handbook of Materials Measurement Methods, Springer Sciente Media Inc, Leipzig 2006

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

8. Optional information

Exercise manuals will be available

Topics 3 – Lab 3

1. The subject of the laboratory classes

X-ray diffraction on a crystal lattice

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory exercise aims to apply the diffraction phenomenon to determine the distance between crystallographic planes and the crystal lattice parameter for metals crystallizing into the A1 structure type. The exercise will be held based on a demonstration of registering a diffractogram on a professional diffractometer used for professional, scientific research. Students will be able to set the working parameters of the lamp and, after a discussion, choose the appropriate measurement method, measuring range, step, and pulse counting time for the reference substance, which will be copper. Each student will receive individual diffractogram on which she/he will calculate the crystal lattice parameter. At the end of the exercise, each student will present their result. It will be discussed in the context of group work. From all the results of the whole group, students will prepare an appropriate report. The exercise will end with report preparation.

3. Learning outcomes

After completing the laboratory, studens:

- are aware of the importance of X-ray diffraction in materilas characterization,
- can distinguish between amorphous and crystalline materials,
- can determine interplanar distances and lattice parameters.

4. Necessary equipment, materials, etc

- Laboratory equipped with X-ray diffractometer.
- Computer labs equipped with the database.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
    a. A brief test on diffraction of the X-rays on the crystals from the lecture to ensure student is well prepared for the lab.
2. Introduction:
    a. Introducing the lab's objective and discussing the significance of X-ray diffraction phenomena.
    b. Discussing the importance of interplanar determination for engineering mateials.
    c. Students will discuss the conditions for carrying out the measurement.
3. Research:
    a. For all students, a demonstration measurement will be carried out on a professional diffractometer.
    b. Students will actively participate in the show by setting the measurement parameters and observing its progress.
4. Results analysis:
    a. Each student will receive an individual defractogram to calculate interplanar distances and crystal lattice parameters.
    b. Each student will discuss the result obtained in the group forum,, its correctness and sens.
    c. From the summary of all the results, students will draw conclusions regarding the parameters of the crystal lattice.
5. Summary:
    a. Summarizing the lab and reminding of its objectives.
    b. Summarizing the experience and identifying possible use of the X-ray spectrum for materials characterization.
    c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.
The second part concerns conducting an experiment in which the students takes an active part.
In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:
1. B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, Pearson Education Limited 2014

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

8. Optional information

Exercise manuals will be available

Topics 4 – Lab 4

1. The subject of the laboratory classes

X-ray qualitative phase analysis of multiphase materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The exercise aims to acquire the ability to identify the phases of polycrystalline material in multiphase systems. During the exercise, students will participate in a demonstration of the registration of the diffractogram of multiphase material. Demonstration measurement will be carried out with the use of a professional diffractometer. Students will plan the course of the experiment and determine the measurement parameters. After selecting the optimal measurement conditions, they will perform the measurement. Based on their knowledge gained from previous lab exercises, they will apply the phenomenon of X-ray diffraction to determine the phase composition. Phase identification will be carried out by each student individually. In the end, the correctness of the obtained results will be discussed with the whole group. The exercise will end with report preparation.

3. Learning outcomes

After completing the laboratory, studens:

- Understand methodology for qualitative phase analysis of multiphase materials.
- Use appropriate software and tools for analysis support.
- Independently identifies the presence of multiple phases in one material.

4. Necessary equipment, materials, etc

- Laboratory equipped with X-ray diffractometer.
- Computer labs equipped with the database.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
    a. A brief test on the rules of qualitative phase analysis gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
    a. Introducing the lab's objective and discussing the significance of the identification proecedure.
    b. Discussing the importance of interplanar determination for qunalitative phase analysis.
    c. Students will discuss the conditions for carrying out the measurement.
3. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
    d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
    a. For all students, a demonstration measurement will be carried out on a professional diffractometer done for multi-phase material.

   b. Students will actively participate in the show by setting the measurement parameters and observing its progress.
5. Results analysis:
   a. Each team will receive an individual defractogram for phase indentification.
   b. Basing on the number diagram they will carry out identyfication with use of handbook and copmuter support.
   c. Each group will discuss the result obtained, its correctness and sens.
   d. From the summary of all the results, students will draw conclusions regarding identyfied phases.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the experience and identifying possible use of phase identification for materials characterization.
   c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

1. B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, Pearson Education Limited 2014

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

8. Optional information

Exercise manuals will be available

Topics 5 – Lab 5

1. The subject of the laboratory classes

Determination of layer sequences in multilayer materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The exercise aims to familiarize students with the non-destructive method of testing thin-film materials composed of many layers. During the exercise, students will learn how to modernize the diffractometer using a special attachment to test thin layers. They will learn the basics of the geometry of the grazing incidence angle of the primary beam. During the exercise, a demonstration measurement will be carried out with the active participation of students. Their participation will consist in optimizing the measurement parameters and conducting a demonstration measurement for the entire group. Students working in groups will receive results for individual solving. Based on the experience gained in implementing previous exercises and using phase identification skills, they will determine the sequence of layers. The test sample will be a two-layer material composed of ceramic layers deposited on an alloy substrate. Each team's results will be discussed in the forum of the whole group. The exercise will end with a report.

3. Learning outcomes

After completing the course, students:

- will be aware of the important role of non-destructive methods in the characterization of engineering materials,
- gaining the ability to analyze thin- and multi-layer materials,
- will be able to modify the diffractometer dedicated to the study of layers and the selection of appropriate measurement conditions,
- will learn how to interpret and analyze the results and communicate their findings effectively.

4. Necessary equipment, materials, etc

- Laboratory equipped with X-ray diffractometer and ayyachement dedicated for thin layer studies.
- Computer labs equipped with the database.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:

a. A brief test on the rules of X_ray techniqu for thin layer investigation gathered from the lecture to ensure student is well prepared for the lab.

2. Introduction:
    a. Introducing the lab's objective and discussing the possibility of X-ray application the thin layer studies.
    b. Discussing the importance of interplanar determination in determination of the layer sequence.
    c. Students will discuss the conditions for carrying out the measurement.
3. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
    d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
    a. For all students, a demonstration measurement will be carried out on a professional diffractometer equipped with the attachement dedicated to thin layers studiung.
    b. Students will actively participate in the show by setting the measurement parameters and observing its progress.
5. Results analysis:
    e. Each team will receive an individual set of defractograms taken for the seperate incidence angle.
    f. Basing on the caluculated interpenar distances they will carry out identyfication with use of handbook and copmuter support.
    g. Basing on the results students will deduce the layer sequence.
    h. Each group will discuss the result obtained, its correctness and sens.
    i. From the summary of all the results, students will draw conclusions regarding identyfied phases.
6. Summary:
    d. Summarizing the lab and reminding of its objectives.
    e. Summarizing the expanding the research possibilities of X-ray techniques with the use of appropriate attachments.
    f. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

1. International Tables for Crystallography Volume H: Powder diffractionGrazing Incidence X-Ray Diffraction, Section 5.4.3.1. Grazing-incidence X-ray diffraction (GIXRD) edited by C. J. Gilmore, J. A. Kaduk and H. Schenk, https://doi.org/10.1107/97809553602060000115

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Exercise manuals will be available

Topics 6 – Lab 6

1. The subject of the laboratory classes

Investigation of phase transitions initiated by temperature change.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory exercise aims to familiarize students with an advanced measurement technique to study phase transformations occurring in engineering materials initiated by temperature changes. Students will learn how to modify the diffractometer measuring system using a temperature attachment during the exercise. During the exercise, a demonstration measurement will be carried out with the active participation of students. Their participation will consist in optimizing the measurement parameters and conducting a demonstration measurement for the entire group. Based on previously acquired skills, they will learn how to non-destructively study the phase transition related to the reconstruction of the crystal lattice by the influence of temperature change. Working in groups, they will determine the phase transition sequence using computer-aided phase identification. The results obtained by each team will be discussed in the forum of the whole group. This exercise will complete the report preparation.

3. Learning outcomes

After completing the course, students:

• will be aware of the important role of non-destructive methods in characterizing phase transitions,

• acquisition of the ability to analyze phase transformations occurring in crystalline materials and caused by changes in temperature,

• the ability to modify the diffractometer dedicated to temperature tests and to select the appropriate measurement conditions,

• the ability to interpret the results obtained.

4. Necessary equipment, materials, etc

- Laboratory equipped with X-ray diffractometer and temperature attachement.
- Computer labs equipped with the database.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
    a. A brief test on the rules of X-ray technique dedicated to phase transition investigations gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
    a. Introducing the lab's objective and discussing the possibility of X-ray application in the phase transition studies.
    b. Discussing the importance of interplanar determination in determination in the context of crystal lattice changing versus the change of the temperature.
    c. Students will discuss the conditions for carrying out the measurement.
3. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
    d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:

c. For all students, a demonstration measurement will be carried out on a professional diffractometer equipped with the temperature attachement dedicated to the phase transition studiung.
d. Students will actively participate in the show by setting the measurement parameters and observing its progress.

5. Results analysis:
   a. Each team will receive an individual set of defractograms taken at the seperate temperature.
   b. Basing on the caluculated interpenar distances group will carry out identyfication with use of handbook and copmuter support.
   c. Basing on the results students will deduce the sequence of the phases formed during the transition.
   d. Each group will discuss the result obtained, its correctness and sens.
   e. From the summary of all the results, students will draw conclusions regarding sequence of the phases.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the expanding the research possibilities of X-ray techniques with the use of appropriate attachments.
   c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.
The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:
B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, Pearson Education Limited 2014

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Topics 7 – Lab 7

1. The subject of the laboratory classes

Sample preparation in electron microscopy

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory exercise aims to prepare the student to prepare a preparation for research in electron microscopy independently. Students will learn about the stages of sample preparation and the techniques used depending on the specific purpose of the research. These techniques will be dedicated primarily to scanning electron microscopy and transmission microscopy preparations. In the case of scanning electron microscopy will be the standard preparation of surface or cross-sections. In the case of transmission microscopy, students learn how to prepare thin films from the moment of cutting the material, through its thinning, to polishing in specialized ion polishers.

3. Learning outcomes

After completing the course, students:

- will be able to apply the appropriate preparation technique to achieve the assumed research goal effectively.
- is aware of the fact that the method of preparing the material affects its properties and the final test result.
- is prepared to independently perform preparations used for research in a scanning electron microscope.

4. Necessary equipment, materials, etc

- Laboratory equipped with deviced decitated to sample preparation.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:

    a. A brief test on the stages of sample preparation in electron microscopy gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
    a. Introducing the lab's objective and discussing the significance of the sample preparation and its influence on the material properties.
    b. Discussing the importance of the sample prparation in context of goal of the experiment.
3. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
    d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
    a. Students will participate in a demonstration of a laboratory used to prepare samples dedicated to microscopic examination.
    b. Each member of team will prepare one stage in sample preparation.
    c. All prepared samples will be check and its quality will be discuss in audience of whole group.
6. Summary:
    a. Summarizing the lab and reminding of its objectives.
    b. Summarizing the influence of the preparation on the sample.
    c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part.

In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

1. Anwar Ul-Hamid, A Beginners' Guide to Scanning Electron Microscopy, Springer Nature Switzerland AG 2018

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Topics 8 – Lab 8

1. The subject of the laboratory classes

Scanning electron microscopy - types of images and their interpretation

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

This exercise aims to familiarize students with the construction of a scanning microscope and its research capabilities. First of all, students learn about imaging methods used in scanning microscopy obtained with the use of backscattered electrons and secondary electrons. In addition, students will learn about the possibilities of measuring the chemical composition in micrometric areas using the EDS detector. In addition, they will learn about the application of specialized attachments for conducting advanced in-situ studies of phase transitions initiated by temperature and stress change, changes in microstructure caused by external stress, and techniques for determining the crystallographic orientation of micro areas using diffraction of backscattered electrons. They will perform microstructure observations using SE and BSE detectors as part of their individual work. In addition, they will analyze the chemical composition in the micro-area.

3. Learning outcomes

After completing the course, students:
• will know the construction of the scanning electron microscope,
• is aware of the research possibilities related to the characterization of engineering materials using scanning electron microscopy.
• can apply the appropriate technique and attachments to achieve the research goal,
• can perform basic microstructure characterization using backscatter and secondary electron imaging,
• can determine the chemical composition in the appropriate micro-area.

4. Necessary equipment, materials, etc

- Laboratory equipped with scanning electron microscope.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
   a. A brief test on the imaging in the scanning electron microscpe gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
   a. Introducing the lab's objective and discussing the possibility of the imagining in scaning electron microscope.
   b. Discussing the importance of second and back scattered electrons in image formation.
   c. Discussing the importance of the accelerating voltage and size of the beam spot on image formation.
3. Research:
   a. First of all, students will be familiarized with the practical construction of the scanning electron microscope.
   b. For all students, a demonstration will be carried out concerning the second and back scattered electrons imaging as well as the influence of the accelerating voltage and size of the beam spot on image formation.
4. Results analysis:
   a. Students will individually analyze the images obtained in secondary and backscattered electrons.
   b. They will compare the possibilities and benefits of such imaging.
   c. Studnets will measure the chemical composition at selected points.
   d. In the whole grupe there will be discussion on obtained results, their correctness and sens.
5. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the expanding the research possibilities of X-ray techniques with the use of appropriate attachments.
   c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part.

In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001

Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Exercise manuals will be available

Topics 9 – Lab 9

1. The subject of the laboratory classes

Imaging in transmission electron microscopy

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The ongoing development of materials at the nanometric scale requires using an appropriate tool to characterize the structure of materials in areas measured in nanometers. Therefore, the laboratory exercise aims to familiarize the student with the possibilities of conducting observations in such areas using a transmission electron microscope. During the laboratory exercise, students learn about the practical construction of a transmission electron microscope. In addition, they will familiarize themselves with basic imaging techniques, including observation in the bright and dark fields, as well as obtaining high-resolution and diffraction images. Each student will receive an individual electronogram characteristic of polycrystalline material and, based on the acquired knowledge, will learn to solve it by determining the interplanar distances.

3. Learning outcomes

After completing the course, students:

- they will know the construction of the transmission electron microscope,
- is aware of the importance of nano-scale characterization of engineering materials using transmission microscopy techniques,
- can interpret microscopic images and diffraction patterns for monocrystalline and polycrystalline materials.
- can solve electronograms obtained for polycrystalline materials.

4. Necessary equipment, materials, etc

- Laboratory equipped with transmission electron microscope.
- Computer labs equipped with the computer program.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
   a. A brief test on the rules of the imaging in tranmission electron microscpe gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
   a. Introducing the lab's objective and discussing the possibility of the imagining in transmision electron microscope.
   b. Discussing the importance of correlation between microscope image and diffraction image.
   c. Discussing the importance of the current-voltage parameters on image formation.
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
   c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
   d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
   a. First of all, students will be familiarized with the practical construction of the transmission electron microscope.
   b. For all students, a demonstration will be carried out on obtaining dark and bright field images as well as high-resolution and diffraction images.
5. Results analysis:
   a. In group students will be analyzing the images obtained in bright and dark field.

   b. They will compare the possibilities and benefits of such imaging.
   c. In teams, they will solve electronograms received for polycrystalline materials by determination of the microscope constant and interplanar disctances.
   d. In the whole grupe there will be discussion on obtained results, their correctness and sens.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the significance of the transmission electron microscopy in materials characterization.
   c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.
The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:
Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001
Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Exercise manuals will be available

Topics 10 – Lab 10

1. The subject of the laboratory classes

Advanced analysis of the real structure of engineering materials in micro- and nanoscale

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The basic feature of engineering materials is their real structure affecting the properties of these materials. Therefore, the exercise aims to acquire the ability to characterize the real structure of engineering materials by solving electronograms characteristic of monocrystalline materials, determining their crystallographic orientation, and determining the crystallographic orientation of two neighbor grains. An important element of the structure is structural defects occurring in the form of dislocations and affecting the properties of engineering materials. The use of transmission microscopy makes it possible to reveal such defects. Hence, students will learn to identify them on microscopic images and determine their density.

3. Learning outcomes

After completing the course, students:

- are aware of the importance of sustainable development in industry in the context,
- are aware of research opportunities using transmission electron microscopy to characterize the real structure of engineering materials,
- can determine the crystallographic orientation of a single grain as well as the mutual orientation of two grains.
- can characterize the engineering material by determining the density of dislocations.

4. Necessary equipment, materials, etc

- Laboratory equipped with transmission electron microscope.
- Computer labs equipped with the computer program.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
   a. A brief test on the diffraction phenomena in tranmission electron microscpe gathered from the lecture to ensure student is well prepared for the lab.
2. Introduction:
   a. Introducing the lab's objective and discussing the possibility of receiving diffraction image in transmision electron microscope.

   b. Discussing the importance of correlation between microscope image and diffraction image.
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for developing a research plan and determining the role of each team member in the research.
   c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.
   d. Checking and approval of the research plan to ensure that teams are working towards the intended objectives.
4. Research:
   a. Demonstration will be carried out on obtaining microsocpe images of the structural defects.
   b. Demonstration will be carried out on obtaining diffraction images from the single crystalline grain.
5. Results analysis:
   a. In group students will be analyzing the images with disslocation and calculate their denisty.
   b. In teams, they will solve electronograms received for single crytsal and for two crystals the crystallographic correlation will be determined.
   c. In the whole grupe there will be discussion on obtained results, their correctness and sens.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the significance of the diffraction in transmission electron microscopy in nano-scale materials characterization .
   c. All studnets will prepare individual report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject consisting of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the reasonableness of the obtained results and their potential application to the characterization of engineering materials. This part will end with the preparation of a report by the group and its submission.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:
Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001
Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

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8. Optional information

Exercise manuals will be available

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SUSTAINABLE NANOMATERIALS

Code: SN

Course content – lecture

Topics 1

1. The subject of the lecture

NANOTECHNOLOGY AND GREEN MATERIALS: INTRODUCTION, FUNDAMENTALS, AND APPLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, as an introduction to the issue of sustainable nanotechnology, the most important features of nanotechnology will be presented, which indicate that it is considered the technology of the future. The reasons for which it is of great interest in various fields will be indicated. Students will organize their knowledge about the unique properties of nanomaterials that enable their innovative applications in various aspects of everyday life of people and the world of technology, such as: food, production, mechanics, optics, medicine, chemical industry, electronics, energy, catalysis, optoelectronics and photoelectrochemical applications and non-linear optical devices.
During the lecture, students will learn that despite such a rich contribution to the development of science and various applications, nanotechnology unfortunately has a negative impact on our environment and human health.

3. Learning outcomes

Student can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Nanotechnology and green materials, especially: fundamentals, and applications*.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
A. Lecture conducted using multimedia and a traditional blackboard. Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.
B. Discussion - encouraging participants to actively participate in the discussion on the topics discussed
C. Question and answer session - a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading, pre-lesson preparation (required knowledge of students)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 - chapter 1, chapter 2, chapter 13.

Additional, optional literature:

- *An overview on the role of nanotechnology in green and clean technology,* Rani, K., Sridevi, V., 2017. Austin. Environ. Sci. 2, 1026. https://doi.org/10.26420/austinenvironsci.2017.1026.).

6. Additional notes

Topics 2

1. The subject of the lecture

GREEN SYNTHESIS OF NANOMATERIALS

2. Thematic scope of the lecture (abstract, maximum 500 words)

Traditional methods of producing nanomaterials have many disadvantages, such as low production yields, the use of hazardous chemicals such as organic solvents, stabilizing and reducing agents. They also generate high energy consumption because they require high temperature and high pressure. Processes become costly, limiting their use.

Most of the organic solvents used as stabilizers or reducing agents during the synthesis of nanomaterials are hazardous chemicals that threaten fate and limit the application of nanomaterials in various fields. Therefore, there is a need to develop and use safe synthetic techniques that are environmentally friendly, non-toxic, efficient and cost-effective.

During the lecture, students will learn about the possibilities and limitations of biological methods, which are considered green synthesis of nanomaterials. Green synthesis or bio-based process is an environmentally friendly, relatively simple, environmentally friendly, cost-effective and less toxic technique. A biological method uses natural entities such as plants, microbes, bacteria and algae to synthesize nanomaterials of desired shape and size. During the lecture, students will learn about selected methods of using plant materials as a biological unit for the production of nanomaterials.

3. Learning outcomes

Student can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Green synthesis of nanomaterials*.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**

A. Lecture conducted using multimedia and a traditional blackboard. Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

B. Discussion - encouraging participants to actively participate in the discussion on the topics discussed

C. Question and answer session - a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 – chapter 4, chapter 11, chapter 13, chapter 18.

Additional, optional literature:

- *Green Synthesis of Nanomaterials,* Giovanni Benelli, Nanomaterials 2019, 9, 1275; doi:10.3390/nano9091275

6. Additional notes

Topics 3

1. The subject of the lecture

MODERN APPLICATIONS OF GREEN NANOTECHNOLOGIES IN THE ENVIRONMENTAL INDUSTRY

2. Thematic scope of the lecture (abstract, maximum 500 words)

The unique properties of nanomaterials have made them very attractive for many sustainable, innovative and green applications. The lecture will present the applications of nanotechnology from the electronics and biomedical industry, through construction, where nanomaterials are used to improve the properties of building materials, to the food industry, where new packaging films with good barrier, fire-resistant, mechanical and exfoliating properties are created.

Students will learn about examples where the use of green nanotechnology contributes to water purification, removal of pollutants from wastewater and as photocatalysts for the destruction of organic compounds. One of the most important aspects of the use of sustainable nanotechnology will also be presented, which is the way to reduce the global energy crisis with the use of solar energy and the use of various types of energy storage and processing devices.

3. Learning outcomes

Student can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Modern applications of green nanotechnologies in the environmental industry.*

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**

A. Lecture conducted using multimedia and a traditional blackboard. Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

B. Discussion - encouraging participants to actively participate in the discussion on the topics discussed

C. Question and answer session - a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 - chapter 1, chapters 7-9.

6. Additional notes

Topics 4

1. The subject of the lecture

SUSTAINABLE GREEN NANOMATERIALS FOR POTENTIAL DEVELOPMENT IN FUTURE

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture is a continuation of the topic on the use of sustainable green nanomaterials for potential development in environmental industries and an indication of further directions for the development of nanotechnology in the future.

The main challenge facing it today is to replace conventional techniques with greener and more sustainable methodologies for the production of nanomaterials. It is therefore considered necessary to transform these initiatives into industrial and large-scale processes in order to see their environmental benefits. During the lecture, students will learn about the current state of research and projected development of sustainable nanomaterials with potential applications in various aspects of the environmental industry.

3. Learning outcomes

Student can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Sustainable green nanomaterials for potential development in future.*

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**

A. Lecture conducted using multimedia and a traditional blackboard. Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

B. Discussion - encouraging participants to actively participate in the discussion on the topics discussed

C. Question and answer session - a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 - chapter 2, chapters 14, chapter 16.

6. Additional notes

Topics 5

1. The subject of the lecture

THREATS FROM THE USE OF GREEN NANOMATERIALS

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topics of the laboratory classes are related to Threats from the use of green nanomaterials. In the case of nanomaterials, it is still quite difficult to determine the risks arising from their use, however, a risk assessment can be done, which helps to determine the likelihood of adverse effects of nanomaterials on the environment and people. Potential threats to ecosystems and security issues raise serious concerns. During the lecture, students will learn the most important aspects related to the types of threats, sources of threats and the methodology of their detection.

In general, there are two types of potential exposure: a) Chronic: Regular exposure over a long period of time, from several months to several years, and b) Acute: Exposures occur for moderately short periods of time, ranging from minutes to 1-2 days.

Procedures in ecological medical problems that can be minimized by analyzing them in four stages will be discussed: a) problem detection, b) exposure assessment, c) dose assessment and d) risk characterization. Students will also learn the procedures to minimize airborne nanoparticles through: a) engineering controls and b) administrative controls.

3. Learning outcomes

Student can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Threats from the use of green nanomaterials*.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
problem methods - **conversational lecture**

A. Lecture conducted using multimedia and a traditional blackboard. Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

B. Discussion - encouraging participants to actively participate in the discussion on the topics discussed

C. Question and answer session - a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 - chapter 18, chapter 19.

6. Additional notes

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

NANOMATERIAL STRUCTURE CHARACTERIZATION

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During laboratory classes, students' theoretical knowledge of XRD, SEM, TEM methods, will be verified. In order to carry out the structural analysis of nanomaterials, the student will perform selected experiments from the XRD, SEM, TEM methods as part of laboratory exercises. The completed experiment will be the basis for developing a report on the exercises. During laboratory classes, students will work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. The completed experiment will be the basis for developing a report on the exercises.

3. Learning outcomes

Students can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Nanomaterial structure characterization*. Students are able to work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. Thay can prepare a theoretical introduction and final results description to the laboratories on *Nanomaterial structure characterization*, including critical analysis, synthesis and conclusions.

4. Necessary equipment, materials, etc

- X-ray Diffractometer (XRD)
- Scanning Electron Microscope (SEM)
- Transmission Electron Microscope (TEM)
- Computer laboratory

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Classes are held in the following order:
- getting acquainted with the rules of occupational health and safety and laboratory regulations,
- discussion (checking students' knowledge) of methods of materials characterization, especially XRD, SEM, TEM techniques,
- getting acquainted with the research equipment in the laboratory,
- students in groups, students carry out a selected experiment,
- during the experiment, students make observations, record comments and the results of the experiment,
- completion of the experiment and formulation of preliminary conclusions.

Students prepare the final report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 – chapter 3.

Additional, optional literature:
- any textbooks on M*ethods of Structural Analysis of Materials*

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

- ASSESSMENT

They will be assessed:
- substantive preparation (20%),
- the ability to properly plan and execute an experiment (20%),
- the ability to observe, analyze the results and draw appropriate conclusions (20%),
- activity (20%),
- ability to work in a group (20%).

Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+

86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise manuals will be available

Topics 2 – Lab 2

1. The subject of the laboratory classes

GREEN SYNTHESIS OF NANOMATERIALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During laboratory classes, students' theoretical knowledge of the types and possibilities of biological methods that are used for the green synthesis of nanomaterials will be verified. Students will use plant parts (leaves, fruits) to obtain nanoparticles. These types of nanomaterial synthesis techniques are widely used due to their availability in any geographic area, as well as ease of processing and lower cost needed to obtain an extract using a solvent such as ethanol or water. During laboratory classes, students will choose the appropriate method to produce green nanomaterials and design and properly conduct an experiment using plant materials as a biological unit for the production of nanomaterials. The completed experiment will be the basis for developing a report on the exercises.

3. Learning outcomes

Students can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Green synthesis of nanomaterials*. Students are able to work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. Thay can prepare a theoretical introduction and final results description to the laboratories on *Green synthesis of nanomaterials*, including critical analysis, synthesis and conclusions.

4. Necessary equipment, materials, etc

- magnetic stirrer,
- dryer
- etc.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Classes are held in the following order:

- getting acquainted with the rules of occupational health and safety and laboratory regulations,
- discussion (checking students' knowledge) of methods of obtaining green nanomaterials,
- getting acquainted with the research equipment in the laboratory,
- students in groups, prepare an experiment in which they will receive nanomaterials,
- during the experiment, students make observations, record comments and the results of the experiment,
- completion of the experiment and formulation of preliminary conclusions.

Students prepare the final report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 – chapter 4, chapter 11, chapter 13, chapter 18.

Additional, optional literature:

- *Green Synthesis of Nanomaterials,* Giovanni Benelli, Nanomaterials 2019, 9, 1275; doi:10.3390/nano9091275
-*"Green" synthesis of metals and their oxide nanoparticles: applications for environmental remediation* Singh, J., Dutta, T., Kim, K.H., et al., 2018. J. Nanobiotechnol. 16, 1–24. Soares, C., Pereira, R., Fidalgo, F., 2018. Metal-based nanomaterials
- *Rapid synthesis of biocompatible silver nanoparticles using aqueous extract of Rosa damascena petals and evaluation of their anticancer activity*, Balaji Venkatesan, Vimala Subramanian, Anusha Tumala, Elangovan Vellaichamy, Asian Pac J Trop Med 2014; 7(Suppl 1): S294-S300, doi: 10.1016/S1995-7645(14)60249-2

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

- ASSESSMENT

They will be assessed:
- substantive preparation (20%),
- the ability to properly plan and execute an experiment (20%),
- the ability to observe, analyze the results and draw appropriate conclusions (20%),
- activity (20%),
- ability to work in a group (20%).

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise manuals will be available

Topics 3 – Lab 3

1. The subject of the laboratory classes

GREEN NANOMATERIAL CHARACTERIZATION - PROPERTIES

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During laboratory classes, students' theoretical knowledge of UV-Vis spectroscopy (UV-Vis) and Fourier transform infrared spectroscopy (FT-IR) techniques, will be verified. In order to study the optical properties of green nanomaterials, the student will perform selected experiments from UV-Vis Spectroscopy (UV-Vis) and Fourier Transform Infrared Spectroscopy (FT-IR). During laboratory classes, students will work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. The completed experiment will be the basis for developing a report on the exercises.

3. Learning outcomes

Students can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Properties of green nanomaterials*. Students are able to work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. Thay can prepare a theoretical introduction and final results description to the laboratories on *Properties of* green n*anomaterials*, including critical analysis, synthesis and conclusions.

4. Necessary equipment, materials, etc

- UV-Vis spectroscopy (UV-Vis),
- Fourier transform infrared spectroscopy (FT-IR),
- Computer laboratory

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Classes are held in the following order:
- getting acquainted with the rules of occupational health and safety and laboratory regulations,

- discussion (checking students' knowledge) of UV-Vis spectroscopy (UV-Vis), Fourier transform infrared spectroscopy (FT-IR) techniques,
- getting acquainted with the research equipment in the laboratory,
- students in groups, students carry out a selected experiment,
- during the experiment, students make observations, record comments and the results of the experiment,
- completion of the experiment and formulation of preliminary conclusions.

Students prepare the final report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8 – chapter 3.

Additional, optional literature:
- any textbooks on *UV-Vis spectroscopy (UV-Vis), Fourier transform infrared spectroscopy (FT-IR)* techniques

Students should prepare a theoretical introduction to the laboratories.

7. Additional notes

- ASSESSMENT

They will be assessed:
- substantive preparation (20%),
- the ability to properly plan and execute an experiment (20%),
- the ability to observe, analyze the results and draw appropriate conclusions (20%),
- activity (20%),
- ability to work in a group (20%).

Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D

0 - 60 points = F

8. Optional information

Exercise manuals will be available

Topics 4 – Lab 4

1. The subject of the laboratory classes

CONVENTIONAL AND SUSTAINABLE NANOMATERIALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to *Comparison of nanomaterials obtained by conventional methods and using sustainable technologies.* Students working in groups carry out a Team Project, the main title of which is *Comparison of conventional and sustainable nanomaterials*.

3. Learning outcomes

Can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Comparison of nanomaterials obtained by conventional methods and using sustainable technologies*. Students are able to work in a team. Thay can prepare materials to present *Comparison of conventional and sustainable nanomaterials*, including critical analysis, synthesis and conclusions.

4. Necessary equipment, materials, etc

- board, flipcharts, multimedia
- additional materials provided by students

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods - **activating methods: discussion/debate**
- **SWOT analysis**

During laboratory classes, students working in groups develop their own topic or one selected from a sample list of topics:
- economic and environmental consequences of obtaining and using nanomaterials,
- advantages and limitations of conventional and sustainable nanomaterials - comparison,
- properties of nanomaterials versus properties of microcrystalline materials.

During classes, students use available materials from lectures, given literature, data available on the Internet and their own materials.
Students will be tasked with:
- collecting the right content and information related to the analysis of the selected issue,
- development and presentation of the results of work in the form of a synthetic presentation.

The form of the presentation depends on the creativity of the students, it can be a multimedia presentation, poster, staging or other.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- *Green Functionalized Nanomaterials for Environmental Applications.* Edited by Uma Shanker, Chaudhery Mustansar Hussain, Manviri Rani, Elsevier Inc 2022, https://doi.org/10.1016/B978-0-12-823137-1.00017-8

Additional, optional literature:
- *New Insights in Photocatalysis for Environmental Applications,* Muhammad Bilal Tahir, Muhammad Shahid Rafique, Muhammad Sagir, Muhammad Faheem Malik, SpringerBriefs in Applied Sciences and Technology, https://doi.org/10.1007/978-981-19-2116-2

7. Additional notes

- ASSESSMENT

They will be assessed:
- substantive preparation (20%)
- activity/involvement in group work (30%)
- making a presentation (20%)
- giving a presentation (30%)

Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Topics 5 – Lab 5

1. The subject of the laboratory classes

THREATS FROM THE USE OF GREEN NANOMATERIALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the case of nanomaterials, it is still quite difficult to determine the risks arising from their use, however, a risk assessment can be done, which helps to determine the likelihood of adverse effects of nanomaterials on the environment and people. Potential threats to ecosystems and security issues raise serious concerns.
During the classes, students will have the task of leading a debate on the topic "for and against green nanotechnology". Materials from the lecture as well as self-prepared information and examples will be the substantive basis for conducting the debate and resolving threats.

3. Learning outcomes

Can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Threats from the use of green nanomaterials*. Students are able to work in a team, and lead a debate. Thay can prepare materials to discuss on *Threats from the use of green nanomaterials*, including critical analysis, synthesis and conclusions.

4. Necessary equipment, materials, etc

- board, flipcharts, multimedia
- additional materials provided by students

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods - **activating methods: discussion/debate**
- **SWOT analysis**

During the classes, students will have the task of leading a debate on the topic *"For and against green nanotechnology"*. Materials from the lecture as well as self-prepared information and examples will be the substantive basis for conducting the debate.

Classes are held in the following order:
- division of students into two groups: "for" and "against",
- students analyze materials from lectures and other available sources in terms of information needed for the debate,
- students in groups, prepare substantive arguments and construct their position,

- the moderator of the debate changes periodically (the duration of the debate depends on the number of students),
- presentation of the final results and conclusions resulting from the discussed problems (the form of the presentation depends on the creativity of the students),
- conclusion of the debate.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Students are expected to read below texts related to the lecture:
Green Nanomaterials, Processing, Properties, and Applications. Edited by Shakeel Ahmed, Wazed Ali, Springer; Springer Nature Singapore Pte Ltd. 2020, https://doi.org/10.1007/978-981-15-3560-4 - chapter 18, chapter 19.

Additional, optional literature:
- ETAG, 2010. *NanoSafety–Risk Governance of Manufactured Nanoparticles Interim Report - Phase II*. European Technology Assessment Group ETAG, Karlsruhe and Vienna.)

- Students should prepare materials for discussion, from the lecture as well as self-prepared information and examples.

7. Additional notes

ASSESSMENT
They will be assessed:
- substantive preparation (20%),
- the ability to argue and present one's own opinion (20%),
- the ability to conduct a constructive discussion (20%),
- activity (20%),
- the ability to lead the discussion as a leader (20%).
Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

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MATERIALS SCIENCE MASTERS

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SUSTAINABLE COMPOSITE MATERIALS

Code: SCM

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO SUSTAINABILITY IN COMPOSITES

2. Thematic scope of the lecture (abstract, maximum 500 words)

Since sustainability is a global priority with a massive drive for change, the lecture aims to introduce students to the subject of sustainable development and sustainable materials. During the lecture, the basic definitions and concepts related to sustainable development will be discussed, considering the areas of materials engineering and, in particular composite materials. Essential perspectives on sustainable development will also be presented. During the lecture, the three pillars of sustainability, which are: i) circular economy, ii) waste hierarchy, and iii) decarbonisation, will be discussed. Students will have the opportunity to gain knowledge about the meaning of life-cycle analysis (LCA), environmental product declarations (EPDs), or carbon footprint. Also, the issues of planetary resources and limitations, or increasing the lifetime of materials or repairing and reusing devices/materials will be covered. Students will be confronted with different perspectives on sustainability and encouraged to explore the complexities, ambiguities and controversies it entails through an invitation to discussion. It is possible to invite to contribute with a guest lecture an expert(s) on sustainable consumption (e.g. from a university, a company, a NGO, etc.).

3. Learning outcomes

Students can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Introduction to sustainability in composites.*
Students will gain basic knowledge about sustainable development. Students will be able to classify materials used regarding their 'sustainability'. Students will be aware of the rational management of the planet's resources and the reuse of materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture**
a. Lecture conducted with the use of multimedia

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Vijay Kumar Thakur et al., "Handbook of Composites from Renewable Materials," Scrivener Publishing LLC, 2017, ISBN 9781119224365.

Hom Nath Dhakal and Sikiru Oluwarotimi Ismail, “Sustainable Composites for Lightweight Applications”, Woodhead Publishing, 2020, ISBN 978-0-12-818316-8

6. Additional notes

The subject of the lecture covers 2 teaching hours

Topics 2

1. The subject of the lecture

COMPOSITES

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture covers primary and general information in the field of composites. The definition of composites and their classification according to matrix and type of reinforcement will be defined. The lecture will discuss the basic mechanics and some specific aspects of composites. Matrixe and reinforcement materials, their properties and their role in the composite will be discussed in more detail. Topics such as: a review of reinforcing; fibres and matrices; properties and applications; or sandwich constructions will be covered. The lecture will present the principles of designing composite materials and technologies for their production. The lecture will include the briefest references to the sustainability of composite materials. Further lectures will discuss the topic of sustainability in greater detail.

3. Learning outcomes

Students can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Composites.*
Students understand and know the basic terminology related to composites and their manufacturing technology.
Students are able to deal with the mechanics and the design of composite materials.
Students are able to estimate the composite material properties according to the matrix and reinforcement materials.
Students know how to choose the appropriate composite material depending on its application.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
a. Lecture conducted with the use of multimedia.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Xiao-Su Yi Composite Materials Engineering, Volume 1, Chapter: An Introduction to Composite Materials, Springer, ISBN 2018, 978-981-10-5695-6.
Daniel Gay et al., "Composite Materials: Design and Applications," CRC Press, 2002, ISBN 9781420031683.

6. Additional notes

The subject of the lecture covers 2 teaching hours

Topics 3

1. The subject of the lecture

SUSTAINABLE POLYMER MATRIX COMPOSITES

2. Thematic scope of the lecture (abstract, maximum 500 words)

Materials are a significant part of a modern and sustainable society, and polymer-based composites are the largest group of composite materials. Rationalise and sustainable material use is the most challenging aspect of the present day. Composite materials can support sustainable development due to their excellent specific strength, dimensional stability and possibility of recycling. This lecture covers insights into the materials and technology that make sustainability possible, in all aspects of polymer-based composite materials, from material resources to recycling, synthesis, fabrication, and characterisation of green composite materials. The subject of the lecture will focus mainly on polymers and composites from natural and renewable resources, for example, natural, bio-based or biodegradable plastic. Also, reinforcement made of natural or renewable materials that can replace those currently used without compromising the mechanical properties of the composite will be discussed in detail. The fundaments of the various methodologies of preparation/production and processing of composites will also be provided during the lecture. Also, the application areas of sustainable composite materials will be discussed. The lecture will also cover the technologies leading to cleaner production of composites (zero waste) and closing the material chain through the use of recycled raw materials as much as possible.

Due to the dynamically developing technology regarding sustainable materials, the lecture should be updated with current scientific and technological achievements.

3. Learning outcomes

Students can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Sustainable polymer matrix composites.*

Students gain knowledge about the synthesis, fabrication, and characterisation of green composite materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**

a. Lecture conducted with the use of multimedia.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Vijay Kumar Thakur et al., "Handbook of Composites from Renewable Materials," Scrivener Publishing LLC, 2017, ISBN 9781119224365.

Hom Nath Dhakal and Sikiru Oluwarotimi Ismail, "Sustainable Composites for Lightweight Applications", Woodhead Publishing, 2020, ISBN 978-0-12-818316-8
Deepak Verma et al., "Sustainable Biopolymer Composites", Woodhead Publishing, 2020, ISBN 9780128222911

6. Additional notes

The subject of the lecture covers 4 teaching hours

Topics 4

1. The subject of the lecture

SUSTAINABLE METAL MATRIX COMPOSITES

2. Thematic scope of the lecture (abstract, maximum 500 words)

The increasing mindless use of non-renewable materials and the requirements for materials, such as lightness associated with appropriate strength properties, have directed the attention of scientists towards metal matrix composites. The latest trends related to the production of metal matrix composite materials will be discussed during the lecture. Depending on the intended application, the matrix material consists of metal alloys based on aluminium, magnesium, titanium, copper, nickel superalloys and steel. Due to their properties, these alloys are eligible for recycling. Moreover, the extraction of metals is associated with considerable energy expenditure and a high ecological threat. Therefore, it is crucial to recover scrap and waste material in production. The lecture will discuss the issue of recycling metal materials, their sources and processing technologies. Current research on green reinforcement - industrial by-products and agricultural wastes such as basalt fibres or coconut shell ash will also be discussed. The lecture will cover topics related to the mechanical properties of metal matrix composites and the properties of recycled metal matrix composites.

3. Learning outcomes

Students can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Sustainable metal matrix composites.*

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
a. Lecture conducted with the use of multimedia.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Nikhilesh Chawla, Metal Matrix Composites, 2013, Springer, IBSN 1461495474
Sankaranarayanan Seetharaman, Mechanical Properties of Sustainable Metal Matrix Composites: A Review on the Role of Green Reinforcements and Processing Methods, Technologies, 2022, https://doi.org/10.3390/technologies10010032
R.A. Ilyas, Recycling of Plastics, Metals, and Their Composites, Chapter: Recycling for a Sustainable World with Metal Matrix Composites, CRC Press, 2021, ISBN 9781003148760

6. Additional notes

The subject of the lecture covers 2 teaching hours

Topics 5

1. The subject of the lecture

SUSTAINABLE CERAMICS MATRIX COMPOSITES

2. Thematic scope of the lecture (abstract, maximum 500 words)

The following lecture on the sustainability of composite materials will focus mainly on ceramic matrix composite materials - CMC. The latest trends in the matrix and green reinforcement materials will be discussed. This lecture provides information on the chemical composition of CMC and how it influences its physical and mechanical properties. The lecture will focus on the production technologies of ceramics matrix composites that are part of the sustainable development trend, for example, using green cutting fluids while machining hard ceramic composites. Application possibilities of sustainable CMC and sustainable manufacturing technologies will also be discussed.

3. Learning outcomes

Students can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to *Sustainable ceramics matrix composites*.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.
b. During the lecture, there is a discussion with the students.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

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6. Additional notes

The subject of the lecture covers 2 teaching hours

Topics 6

1. The subject of the lecture

CRADLE TO CRADLE

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, a composite material's Life Cycle Assessment (LCA) will be discussed in detail. Information about cradle-to-gate and cradle-to-cradle life cycles will be provided. Computer software which allows determining the material's life cycle will also be presented. The lecture will cover issues regarding the waste hierarchy, and the possibility of recycling composite materials will be presented. Composite recycling is more complex than conventional materials like plastic packaging and metals, which is why the lecture will focus on the newest chemical recycling technologies. The lecture will also address the topic of inherently recyclable composite materials.

3. Learning outcomes

Can use information from lectures, literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to life-cycle analysis of the composite materials and ist recykling.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **informative lecture, monographic lecture, description**
a. Lecture conducted with the use of multimedia.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Vijay Kumar Thakur et al., "Handbook of Composites from Renewable Materials," Scrivener Publishing LLC, 2017, ISBN 9781119224365.

Hom Nath Dhakal and Sikiru Oluwarotimi Ismail, "Sustainable Composites for Lightweight Applications", Woodhead Publishing, 2020, ISBN 978-0-12-818316-8
Deepak Verma et al., "Sustainable Biopolymer Composites", Woodhead Publishing, 2020, ISBN 9780128222911

6. Additional notes

The subject of the lecture covers 2 teaching hours

Course content – laboratory classes - project

Topics 1 – Lab 1

1. The subject of the laboratory classes

DESIGNING A SUSTAINABLE COMPOSITE MATERIAL part 1

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students, based on the knowledge obtained during the lectures and the available literature, under the supervision of a tutor, design their own sustainable composite. They assume the place of application of the material and its properties. Then, they select the appropriate matrix, and reinforcement materials, considering their origin, planetary resources or recycling. They also pay attention to the technology of obtaining the composite, its energy consumption, greenhouse gas emissions, etc. Another essential aspect to consider by students is managing waste generated during material processing and whether the resulting composite is fully or partially recyclable or degradable.

3. Learning outcomes

Students can effectivly search and use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related tot he topic of their project.
Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. Thay can prepare and present a theoretical backgroud for their project.

4. Necessary equipment, materials, etc

- computer with access to online article databases,

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**

During laboratory classes, students work in small group (2-3 people) and plan the course of the experiment. They sharing tasks and working together to establish a work plan, try to predict the results of the project.
Students prepare the final project plan and ist presentation at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students, independently or in small groups, search for literature data.

7. Additional notes

The subject of the lecture covers 2 teaching hours

8. Optional information

Topics 2 – Lab 2

1. The subject of the laboratory classes

DESIGNING A SUSTAINABLE COMPOSITE MATERIAL part 2

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students present their project plan in the form of a presentation to the group. After each presentation, the whole group discusses the advantages and disadvantages of the project. They work together to improve individual projects. Each project must be approved by the teacher before it can be implemented.

3. Learning outcomes

Students can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related tot he topic of their project.
Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. Thay can prepare and present a theoretical backgroud for their project.
Students will be able to:

- present the results of their research in an understandable and transparent way in written form, and oral presentation
- work in a group and independently.

Students will enhance their communication skills.
Students will discover their strengths and weaknesses.

4. Necessary equipment, materials, etc

- computer,
- projector,
- blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate, seminar**
Students present their project plan independently or in a small group; after the presentation, there is a discussion and brainstorming.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

7. Additional notes

The subject of the lecture covers 2 teaching hours

8. Optional information

Topics 3 – Lab 3

1. The subject of the laboratory classes

OBTAINING SUSTAINABLE COMPOSITE MATERIAL

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. They use technologies for obtaining composites described in their project. They produce composites with a different ratio of matrix to reinforcement, which will allow determining their effect on the material's properties. They can use different reinforcement or matrix materials to determine which composition provides the best quality material. They also should use various parameters of the technological process, changing, e.g. time or temperature, to assess their impact on the obtained material.

3. Learning outcomes

Students are able to

- associate the properties of the composite with the used materials and the manufacturing process for its implementation
- work in groups and individually
- design and run an experiment

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- equipment, deescribed in the students project

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,

a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.

b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.

c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Students prepare the partial project report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

7. Additional notes

The subject of the laboratory classes covers 12 teaching hours

8. Optional information

Topics 4 – Lab 4

1. The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION – OPTICAL MICROSCOPE

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students use an optical microscope to characterise their material.

3. Learning outcomes

Students will be able to:
· understand the principles of analysis by using an optical microscopy
· describe the effects of material composition and processing on the microstructure of the composite materials
· appreciate the challenges and limitations associated with optical microscopy
· analyse and interpret experimental results to draw conclusions about obtained composite materials

4. Necessary equipment, materials, etc

- optical microscop

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**
a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.
Students prepare the partial project report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project
instruction prepared by the teacher

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours

8. Optional information

Topics 5 – Lab 5

1. The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION – SEM, EDS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students using a scanning electron microscope equipped with an EDS adapter analyse the morphology and chemical composition of the obtained material.

3. Learning outcomes

Students will be able to:

· understand the principles of analysis by using an SEM and EDS methods

· describe the effects of material composition and processing parameters, such as temperature, heating rate, and holding time, on microstructural development of the composite materials.

· appreciate the challenges and limitations associated with SEM and EDS methods

· analyse and interpret experimental results to draw conclusions about obtained composite materials

4. Necessary equipment, materials, etc

- Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy adapter (EDS)

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,

a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.

b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.

c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Students prepare the partial project report independently at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

instruction prepared by the teacher

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours

8. Optional information

Topics 5 – Lab 6

1.	The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION – X-ray methods

2.	Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students use a X-ray diffraction methods to characterise the structure of the obtained material.

3.	Learning outcomes

Students will be able to:
· understand the principles of analysis by using an X-ray methods
· describe the effects of material composition and processing parameters, on structural development of the composite materials.
· appreciate the challenges and limitations associated with X-ray methods
· analyse and interpret experimental results to draw conclusions about obtained composite materials

4.	Necessary equipment, materials, etc

- X-ray Diffractometer
- Computer laboratory with access to data base

5.	Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Students prepare the partial project report independently at home.

6.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project
instruction prepared by the teacher

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours

8. Optional information

Topics 5 – Lab 7

1. The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION
– mechanical properties tests

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students examine the mechanical properties of the obtained materials, e.g. static tensile test, static compression test or strength, fracture toughness, and static hardness measurements.

3. Learning outcomes

Students will be able to:

- understand the principles of mechanical testing
- to use apriopriate mechanical testing methods
- describe the effects of microstructure and processing conditions on the mechanical properties of the composite materials
- appreciate the challenges and limitations associated with mechanical testing of the composite materials
- analyse and interpret experimental results to draw conclusions about the mechanical properties of composite materials
- apply the knowledge gained from the laboratory class to design and optimize mechanical properties of composite materials for specific applications.

4. Necessary equipment, materials, etc

- universal mechanical testing machine
- hardness tester

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Students prepare the partial project report independently at home.

6.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

literature related to their project
instruction prepared by the teacher

7.	**Additional notes**

The subject of the laboratory classes covers 4 teaching hours

8.	**Optional information**

Topics 5 – Lab 8

1. The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION
– other characterisation methods

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students choose other of material testing methods, selected individually for their material.

3. Learning outcomes

Students will be able to:
· understand the principles of analysis of choosing methods
· describe the effects of material composition and processing parameters, on properties of the composite materials.
· appreciate the challenges and limitations associated with choosen methods
· analyse and interpret experimental results to draw conclusions about obtained composite materials

4. Necessary equipment, materials, etc

- equipment, deescribed in the students project

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**
a. Laboratory classes are carried out with the use of specialist research equipment and specialized software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

Students prepare the final project report at home.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project
instruction prepared by the teacher

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours

8. Optional information

Topics 5 – Lab 9

1. The subject of the laboratory classes

SUSTAINABLE COMPOSITE MATERIAL CHARACTERIZATION – presentation of final results of projects

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students choose other methods of material testing, selected individually for their material.

3. Learning outcomes

Students will be able to:

- present the results of their research in an understandable and transparent way in written form, and oral presentation
- work in a group and independently.

Students will enhance their communication skills.
Students will discover their strengths and weaknesses.

4. Necessary equipment, materials, etc

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods – **problem-based learning, activating methods: discussion/debate, seminar, SWOT analysis**
During classes students present their results in form of presentation (the form of the presentation depends on the creativity of the students). After each presentation, the whole group discusses the advantages and disadvantages of the project results.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours

8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

CERAMIC MATERIALS FOR ENERGY HARVESTING

Code: CMEH

Course content – lecture

Topics 1

1. The subject of the lecture

Introduction to the Ceramics Materials – method of obtaining

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to familiarise the audience with basic concepts related to ceramic materials. The lecture begins with an overview of the history of ceramics, ranging from utility ceramics in the early Iron Age to contemporary functional electroceramics. Next, the classification of ceramic materials will be discussed. Fine ceramics, bioceramics, and technical ceramics will be briefly discussed, particularly on electroceramics. The final part of the lecture will focus on the technology and method of obtaining ceramic materials. Students will learn the details of the methods most commonly used in producing functional electroceramics, including solid-phase synthesis, sol-gel methods, and the Pechini method. Students will become acquainted with ceramic powders' structure and characterisation methods, including concepts such as average grain size, grain shape, and pore distribution. The next part of the lecture will delve into various powder-forming methods, focusing on pressing. The lecture will conclude with a discussion on the processes involved during powder sintering.

3. Learning outcomes

After completing this lecture, students will:

- Understand the fundamental concepts of ceramic materials, including their history and classification.
- Gain insight into the development and significance of electroceramics in modern applications.
- Be able to distinguish between types of ceramic materials, including fine ceramics, bioceramics, and technical ceramics.
- Have knowledge of the technology and methods used in producing ceramic materials, including solid-phase synthesis, sol-gel methods, and the Pechini method.
- Recognize the importance of powder sintering processes in ceramic material production.
- Be able to identify elements of ceramics microstructure (grain, grain boundaries, pores).

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read, related to the lecture, chapter 3 of the following book (related to the lecture): A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003

6. Additional notes

Topics 2

1. The subject of the lecture

Microstructure and its influence on of ceramics properties

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, the basic elements of microstructure, such as grains, grain boundaries, and pores, along with their various types, will be discussed. Students will familiarise themselves with methods for observing microstructure, with particular emphasis on the use of scanning electron microscopy. Consequently, the principles of SEM operation will be revisited in the form of a quiz. Microstructural analysis is often closely associated with X-ray microanalysis, which serves as a tool to confirm the attainment of the assumed theoretical stoichiometry of ceramic materials. Students will learn the basic principles of X-ray microanalysis. Finally, the impact of microstructure - including the shape and size of grains, their orientation, and the number of pores - on the utility properties of ceramic materials will be discussed. Particular emphasis will be placed on the utility properties of electroceramics.

3. Learning outcomes

After completing this lecture, students will:

- Be familiar with methods of studying microstructure, with particular emphasis on the role of scanning microscopy.
- Understand the basic principles of X-ray microanalysis.
- Evaluate the impact of microstructure, including grain shape and size, grain orientation, and pore density, on the functional properties of ceramic materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read, related to the lecture, chapter 3 of the following book (related to the lecture): Joseph Goldstein, Dale E. Newbury, David C. Joy, Joseph R. Michael, Nicholas W. M. Ritchie, John Henry J. Scott, Scanning Electron Microscopy and X-Ray Microanalysis, Springer-Verlag New York Inc., 2017

6. Additional notes

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Topics 3

1.	**The subject of the lecture**
	Crystal structure, defects and electrical conduction of ceramics
2.	**Thematic scope of the lecture (abstract, maximum 500 words)**
	This lecture delves into the intricate relationship between crystal structure, defects, and their impact on electrical conductivity in ceramics. Students with the instructor will delve into the complexities of defect structures in non-stoichiometric and stoichiometric oxides. Various types of defects, including point defects, will be thoroughly discussed. In the next part of the lecture, the role of defects in the process of electrical conductivity, as well as charge transport phenomena, will be elaborated in detail. The lecture ends with discussing the applications of the acquired knowledge in the design of fuel cells and solid oxide fuel cells (SOFC). We will primarily focus on the processing and properties of ceramic-based membranes for fuel cells.
3.	**Learning outcomes**
	After completing this lecture, students will: • Understand the intricate relationship between crystal structure, defects, and electrical conductivity in ceramics. • Be able to classify defects and describe their types. • Be able to explain the role of defects in electrical conductivity. • Understand the principles governing electrical charge transport in ceramic materials. • Be capable of enumerating the principles of design of fuel cells and solid oxi-de fuel cells (SOFC)
4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***
	• Multimedia presentation - using PowerPoint presentations for discussed issues and examples. • Case study - presentation of specific examples of microscopic images of ceramics microstructures. • Discussion - encouraging students to participate in the discussion on the issues actively. • Quiz - summarised the essential information.
5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**
	Students are expected to read, related to the lecture, chapter 4 of the following book (related to the lecture): A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003
6.	**Additional notes**

Topics 4

1. The subject of the lecture

Pyroelectric and piezoelectric properties of ceramics

2. Thematic scope of the lecture (abstract, maximum 500 words)

The first part of the lecture will present primary information regarding the phenomena of direct and inverse piezoelectricity. Coefficients describing the piezoelectric properties of materials will be defined. Students will become familiar with methods for measuring piezoelectric properties. The second part of the lecture will be sacrificing the pyroelectric phenomena. Students will become familiar with the theoretical foundations of the piezoelectric phenomenon and will also learn how to determine the pyroelectric coefficient. The third part of the lecture will encompass discussions on the actual and potential applications of piezoelectric and pyroelectric materials, including sensors and actuators. The lecture will also discuss the general characteristics and differences between lead-based and lead-free piezoelectric materials. Additionally, methods for improving both piezoelectric and pyroelectric properties will be presented. Attendees will also learn how piezoelectric materials can be utilised to harvest energy from various sources, such as human activity, urban infrastructure and transportation, as well as natural phenomena like wind and rain energy.

3. Learning outcomes

After completing this lecture, students will:

- Understand the piezoelectric phenomenon: define direct and inverse piezoelectric effects,
- Be able to calculate coefficients describing the piezoelectric properties of materials and describe methods for measuring these properties.
- Be able to explain the theoretical foundations of pyroelectric phenomena and determine the pyroelectric coefficient.
- Understand how piezoelectric materials can be used to harvest energy from various sources.
- Be able to identify current and potential applications of piezoelectric and pyroelectric materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.

- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read:

- chapters 6 and 7 of the following book A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003
- chapter 2 of the following book: Ling Bing Kong, Tao Li, Huey Hoon Hng, Freddy Boey, Tianshu Zhang, Sean Li, Waste Energy Harvesting, Mechanical and Thermal Energies, Springer, 2014

6. Additional notes

Topics 5

1. The subject of the lecture

Dielectric and ferroelectric properties of ceramics

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the first part of the lecture, the audience will be introduced to the topic of a large group of ceramic materials characterised by dielectric properties. Students will become familiar with the basic properties of dielectric materials, such as dipole moment, polarization, electrical permittivity, and polarisation. During the lecture, polarisation mechanisms will also be discussed. Subsequently, a detailed analysis of dielectric properties for each polarisation mechanism under the influence of varying fields will be conducted, which is essential for understanding the behaviour of these materials under natural conditions. Material dielectric damage may occur in real situations therefore destructive mechanisms will be discussed. At the end of the first part of the lecture, various measurement techniques of dielectric properties will be presented, particularly impedance spectroscopy.

The second part of the lecture will focus on ferroelectricity and ferroelasticity, with particular emphasis on the influence of crystal structure and phase boundaries, the role of domain wall motion and defects, and the impact of stress on phase structural transformations. Measurement techniques will also be presented to characterise the behaviour of the discussed materials in large fields, such as the Sawyer-Tower circuit. Students will be introduced to another class of materials, namely relaxor ferroelectrics. Relaxor ferroelectrics are ferroelectric materials that exhibit high electrostriction. These materials find applications in high-efficiency energy storage and conversion, as they are characterised by high dielectric constants, orders of magnitude higher than those of conventional ferroelectric materials. Like conventional ferroelectrics, relaxor ferroelectrics exhibit permanent dipole moments in domains. However, these domains are on the nanometer scale, whereas domains of classical ferroelectrics are typically on the micrometre scale and require less energy to order. As a result, relaxor ferroelectrics are characterised by high capacitance and have generated interest in energy storage.

3. Learning outcomes

After completing this lecture, students will:

- Understand the basic properties of dielectric materials, including dipole moment, polarisation, and electrical permittivity.
- Identify different polarisation mechanisms in dielectric materials and their behaviour under varying fields.
- Be familiar with various measurement techniques for dielectric properties, especially impedance spectroscopy.
- Comprehend the principles of ferroelectricity and ferroelasticity, including the influence of crystal structure, phase boundaries, and domain wall motion.

- Understand the characteristics and applications of relaxor ferroelectrics in high-efficiency energy storage and conversion.
- Be able to assess the potential of relaxor ferroelectrics for energy storage applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read:

- chapter 5 of the following book A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003
- chapter 3 of the following book: Ling Bing Kong, Tao Li, Huey Hoon Hng, Freddy Boey, Tianshu Zhang, Sean Li, Waste Energy Harvesting, Mechanical and Thermal Energies, Springer, 2014

6. Additional notes

Topics 6

1. The subject of the lecture

Impedance spectroscopy of ceramic materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to acquaint the audience with the fundamental concepts of impedance spectroscopy as a technique enabling the investigation of material properties over a wide frequency range. This method is applied for non-destructive examination of structural and biological objects, monitoring material corrosion, etc. The technique involves exciting the object under investigation with a variable current signal at frequencies that vary widely, usually with a constant, small amplitude, and measuring and analysing the object's response induced by this excitation. Measurement results are typically presented using the admittance or impedance of the object and may depend on external forcing factors, including temperature and pressure, among others. During the lecture, students will become familiar with methods for analysing obtained spectra. They will learn what kind of information, including about the microstructure of ceramic materials, this analysis can provide. At the end of the lecture, participants will learn the basics of operating the ZView program – a tool for analysing impedance measurement results.

3. Learning outcomes

After completing this lecture, students will:

- Understand the fundamental principles of impedance spectroscopy as a technique for investigating material properties across a wide frequency spectrum.
- Students will learn methods for analysing obtained spectra, including extracting information about material microstructure.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read: J.R. MacDonald Impedance spectroscopy, John Wiley&Sons, New York 1987

6. Additional notes

Topics 7

1. The subject of the lecture

Introduction to energy harvesting

2. Thematic scope of the lecture (abstract, maximum 500 words)

In today's world, there is a massive demand for powering small devices such as sensors and mobile biochemical or communication devices. Since users always expect seamless operation of such devices, harvesting energy from the environment has become an essential solution for these systems. This is how the idea of energy harvesting was born. Solutions aimed at harvesting small amounts of energy available in the environment and converting it into electrical energy are the subject of research in many research centres. Power levels required for typical applications can range from microwatts to several watts, and the energy harvested from the environment may be able to recharge or even completely replace the battery, powering autonomous devices continuously. This lecture aims to introduce students to the fundamentals of designing energy-harvesting circuits for autonomous systems. Students will gain an overview of the structure of a typical energy harvesting system, which consists of three main components: (a) an energy transducer, which converts energy from the environment into electrical energy; (b) interface circuits (energy converters); (c) control circuits for output voltage regulation, maximum power tracking, etc. In the final part of the lecture, examples of specific solutions will be presented, including multifunctional nanogenerators.

3. Learning outcomes

After completing this lecture, students will be able:

- explain the concept of energy harvesting and its significance in powering small devices in modern applications.
- eescribe the operation and function of each component in a typical energy harvesting system, including the energy transducer, interface circuits, and control circuits.
- evaluate the performance of energy harvesting systems in terms of power output, efficiency, and reliability.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - using PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of microscopic images of ceramics microstructures.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read:

- Chapters 1,4 and 5 of the following book: Ling Bing Kong, Tao Li, Huey Hoon Hng, Freddy Boey, Tianshu Zhang, Sean Li, Waste Energy Harvesting, Mechanical and Thermal Energies, Springer, 2014

6. Additional notes

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Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

Testing the density, porosity and microstructure of ceramic materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

These exercises aim to familiarise students with obtaining basic information about ceramic materials. Various ceramic materials will be used in the laboratory exercise. Students will determine ceramic samples' real and geometric density and their porosity and water absorption. To do this, they will measure the geometric dimensions of the samples and weigh dry and water-saturated samples. The results obtained will be used for individual analysis, during which students will utilise computer support. In the second part of the exercises, students will prepare metallographic microsections and examine them using a metallographic microscope. Students will become acquainted with the grain structure of ceramic materials. The obtained microscopic images will be used for individual analysis. For this purpose, students will utilise computer support to conduct quantitative analysis of objects, such as crystal grains. They will determine the average grain size. The exercises will conclude with the preparation of a report.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject, which will consist of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the result's reasonableness and their potential application to the characterisation of engineering materials. This part will end with the group preparing a report and its submission.

3. Learning outcomes

By working on this laboratory project, students:

- will gain practical skills in obtaining density, porosity and water absorption
- will learn the difference between theoretical and real density.
- will gain practical skills in preparing non-transparent materials for microscopic examination,
- will gain experience in operating metallographic microscopes
- will learn to interpret the observed microscopic images and use a quantitative approach to analyze the objects.

4. Necessary equipment, materials, etc

The exercise is conducted in two laboratories.

- Laboratory equipped with a device dedicated to sample preparation.
- Laboratory equipped with metallographic microscopes.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge test:

a. A test checking students' preparation for laboratory exercises based on information provi-ded during the lecture and based on the literature resources.

2. Introduction:

a. Presentation of the purpose of the laboratory and discussion of the importance of identify-ing real density, porosity, and water absorption, as well as the microstructure of investigated ceramics.

b. Discuss the experiment stages by describing required calculations and providing a remin-der of the safety rules.

3. The exercise course:

a. Students will be divided into teams.

b. Teams will be responsible for developing a research plan and determining each team member's role in the research.

c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps.

d. The instructor approves the research plan to ensure teams work towards the intended ob-jectives.

4. Research:

a. Teams will prepare ceramics samples: one for density measurements and the second for microstructure observation.

b. Students will be observing the microstructure of the previously prepared samples.

c. Students will measure the geometric dimensions of the sample and determine the dry sample mass, the mass of the sample in water, and the mass of the water-saturated sample.

5. Results analysis:

a. Students will calculate real and geometric density, porosity, water absorption and average grain size.

b. Each team will present the results of their research in a presentation.

c. Teams will discuss and compare their results to those received from others.

d. Students will create conclusions regarding the observation.

6. Summary:

a. Summarizing the lab and reminding of its objectives.

b. Summarizing the experience and identify the importance of density and porosity measu-rements for the preliminary characterisation of materials.

c. In teams, students will prepare reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

7. Additional notes

8. Optional information

Exercise manuals will be available
Students should prepare a theoretical introduction to the laboratories

Topics 2 – Lab 2

1. The subject of the laboratory classes

Microstructure images

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory is to investigate the influence of various sintering conditions on the microstructure of perovskite ceramics, as well as to familiarize students with the basics of operating a scanning electron microscope (SEM). Students will be provided with several samples of the same material sintered under different conditions for examination. Their task will be to obtain images of the obtained samples and analyze the microstructure. Since various signals are produced as a result of the interaction between electrons and matter, each carrying useful information about the sample, students will analyze two types of images characteristic of the scanning electron microscope. The first type will be images generated using backscattered electrons (BSE), and the second type using secondary electrons (SE). It should be noted that BSE originate from deeper areas of the sample, while SE originate from the surface areas. Therefore, both signals carry different types of information. BSE images show high sensitivity to differences in atomic number; the higher the atomic number, the brighter the material appears in the image. SE imaging can provide more detailed information about the surface being examined. Additionally, students will conduct qualitative and quantitative X-ray microanalysis of the examined samples.

Laboratory exercises will be divided into three parts. The first part will include an introduction to the course subject, which will consist of checking the prepared knowledge and the developed theoretical introductions.

The second part concerns conducting an experiment in which each of the students takes an active part. Group leaders divide activities and control their course. In the third part of the laboratory, there will be a discussion on the obtained results. Students will compare and discuss the result's reasonableness and their potential application to the characterisation of engineering materials. This part will end with the group preparing a report and its submission.

3. Learning outcomes

By working on this laboratory project, students:

- will gain practical skills in operating a scanning electron microscope (SEM).
- will understanding of the influence of various sintering conditions on the microstructure of perovskite ceramics
- will distinguish between backscattered electron (BSE) and secondary electron (SE) images and will understand their respective contributions to microstructural analysis.
- will learn to conduct qualitative and quantitative X-ray microanalysis to determine the chemical composition of examined samples.
- will develop critical thinking and problem-solving skills through hands-on laboratory activities.

4. Necessary equipment, materials, etc

The exercise is conducted in two laboratories.

- Laboratory equipped with a device dedicated to sample preparation.
- Laboratory equipped with scaning electronmicroscopes.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge test:
   a. A test checking students' preparation for laboratory exercises based on information provi-ded during the lecture and based on the literature resources.
2. Introduction:
   a. Presentation of the purpose of the laboratory and discussion of the sintering conditions' influence on the microstructure of investigated ceramics.
   b. Discuss the experiment stages with a particular emphasis on sample preparation for mi-croscopic examination and reminding of the safety rules.
3. The exercise course:
   a. Students will be divided into teams.
   b. Teams will be responsible for developing a research plan and determining each team member's role in the research.
   c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps.
   d. The instructor approves the research plan to ensure teams work towards the intended ob-jectives.
4. Research:
   a. Familiarization with the structure, operation, and handling of the microscope.
   b. Preparation of the sample for microscopic examination.
   c. Conducting imaging of the microstructure using secondary electron (SE) and backscatte-red electron (BSE) detectors,
   d. Performing qualitative and quantitative analysis of the chemical composition from mi-croareas (point analysis, line analysis) using EDS technique.
5. Results analysis:
   a. Each team will present the results of their research in a presentation.
   b. Teams will discuss and compare their results to those received from others.
   c. Students will create conclusions regarding the observation.
6. Summary:
   a. Summarizing the lab and reminding of its objectives.
   b. Summarizing the experience and identifying the difference in the microstructure of sam-ples obtained in the different sintering conditions.
   c. In teams, students will prepare reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Joseph Goldstein, Dale E. Newbury, David C. Joy, Joseph R. Michael, Nicholas W. M. Ritchie, John Henry J. Scott, Scanning Electron Microscopy and X-Ray Microa-nalysis, Springer-Verlag New York Inc., 2017

7. Additional notes

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8. Optional information

Exercise manuals will be available
Students should prepare a theoretical introduction to the laboratories.

Topics 3 – Lab 3

1. The subject of the laboratory classes

Determination of piezoelectric coefficients

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory aims to familiarise Students with the piezoelectric coefficient investigation method. At present, the measurement of this value is mostly realized using three techniques: the frequency method, the laser interferometer technique, and the quasi-static method. In the present laboratory, the first method will be used. Students will learn how to prepare samples for measurement with this method and haw to conduct the process of polarization. Then, they will measure the Z modulus and the phase shift angle. Based on the obtained results and using the forced harmonic oscillator model, they will find characteristic piezoelectric frequencies and determine the piezoelectric parameters on their basis.

3. Learning outcomes

By working on this laboratory project, students:

- will gain practical skills in preparing samples for piezoelectric measurements.
- will gain practical skills in the process of samples polarisation
- will gain familiarity with the three primary techniques used for measuring the piezoelectric coefficient, especially the frequency method.
- will develop proficiency in interpreting data to determine piezoelectric parameters based on the measured values.
- will enhance problem-solving skills through practical application of theoretical concepts.
- will foster critical thinking by analyzing discrepancies and uncertainties in the measurement process.

4. Necessary equipment, materials, etc

The exercise is conducted in two laboratories.

- Laboratory equipped with a device dedicated to sample preparation.
- Laboratory equipped with scaning electronmicroscopes.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge test:

    a. A test checking students' preparation for laboratory exercises based on information provi-ded during the lecture and based on the literature resources.

2. Introduction:
    a. Presentation of the purpose of the laboratory and discussion of the piezoelectric coefficient measurements method.
    b. Discuss the experiment stages by describing the manner of sample preparatios, measure-ment technique and required calculations.
3. The exercise course:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining each team member's role in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps.
    d. The instructor approves the research plan to ensure teams work towards the intended ob-jectives.
4. Research:
    a. Familiarization with the a computerized automatic system based on the Agilent E4980A impedance analyzer within a frequency range spanning from f=0.02 kHz to f=2000 kHz.
    b. Preparation of the sample for piezoelectric measurements.
    c. Conducting measurements in the range of temperaturę from room temperaturę up to 200^{o}C (in the ferroelectric phase).
    d. Performing calculation of piezoelectric coefficients
5. Results analysis:
    a. Each team will present the results of their research in a presentation.
    b. Teams will discuss and compare their results to those received from others.
    c. Students will create conclusions regarding the observation.
6. Summary:
    a. Summarizing the lab and reminding of its objectives.
    b. Summarizing the experience in piezoelectric coefficients calculations.
    c. In teams, students will prepare reports.

6.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

chapter 6 of the following book A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003

7.	**Additional notes**

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8.	**Optional information**

Exercise manuals will be available
Students should prepare a theoretical introduction to the laboratories.

Topics 4 – Lab 4

1. The subject of the laboratory classes

Measurements of pyroelectric current and calculation of the pyroelectric coefficient

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The first part of the laboratory will be sacrificed for sample polarisation. The process of polarisation can take place in several different ways. Students will discuss the method and conditions of sample polarisation. The process of polarisation is a necessary procedure before testing pyroelectric properties. The pyroelectric effect can be tested using a static, quasi-static or dynamic method. Students will learn the details of each technique, their advantages and disadvantages. In the second part of the laboratory, the quasi-static method will be used to measure the pyroelectric current in the PBZT 25/70/30 ceramics. In this method, the electrodes of previously polarised samples are short-circuited with a resistor R with a resistance much lower than the resistance of the sample. The changes in the current generated by the increasing temperature are then measured. Based on the obtained dependence and knowing the rate of temperature changes, the Students' task will be to calculate the pyroelectric coefficient. The measured ceramics were selected in such a way that on the determined I(T) characteristic, the thermally stimulated depolarization (TSDC) currents are visible - the origin of the currents will be discussed.

3. Learning outcomes

By working on this laboratory project, students:

- will gain practical skills in sample polarization proces
- will calculate the pyroelectric coefficient based on the obtained temperature dependence of pyroelectric current and the known rate of temperature changes.
- will identify the I(T) characteristic thermally stimulated depolarisation currents (TSDC) and discuss the mechanism of their appearance.

4. Necessary equipment, materials, etc

Laboratory Equipment for Pyroelectric Testing

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge test:
   a. A test checking students’ preparation for laboratory exercises based on information provi-ded during the lecture and based on the literature resources.
2. Introduction:
   a. Presentation of the purpose of the laboratory and discussion of the pyroelectric coefficient measurements method.

b. Discuss the experiment stages by describing the manner of sample preparatios, measure-ment technique and required calculations.

3. The exercise course:

a. Students will be divided into teams.

b. Teams will be responsible for developing a research plan and determining each team member's role in the research.

c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps.

d. The instructor approves the research plan to ensure teams work towards the intended ob-jectives.

4. Research:

a. Familiarization with the a computerized automatic system based on the picoamperometer Keithley 6485.

b. Preparation of the sample for pyroelectric measurements.

c. Conducting measurements in the range of temperaturę from room temperaturę up to 450°C.

d. Performing calculation of piezoelectric coefficients

5. Results analysis:

a. Each team will present the results of their research in a presentation.

b. Teams will discuss and compare their results to those received from others.

c. Students will create conclusions regarding the observation.

6. Summary:

a. Summarizing the lab and reminding of its objectives.

b. Summarizing the experience in piezoelectric coefficients calculations.

c. In teams, students will prepare reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

chapter 6 of the following book A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003

7. Additional notes

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8. Optional information

Exercise manuals will be available

Students should prepare a theoretical introduction to the laboratories.

Topics 5 – Lab 5

1. The subject of the laboratory classes

Impedance spectroscopy - the key to investigations electric properties of grains and grains boundary

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In this laboratory, Students will be familiarized with impedance spectroscopy. The method is used to measure the impedance of the system for a selected discrete set of frequencies covering a wide frequency range from f=(10-30)Hz to frequencies of several hundred kHz. The essence of this measurement is to determine the dependence of the impedance on the frequency of the excitation voltage. The obtained results are most often presented in the form of the dependence of the imaginary component of the impedance as a function of the real component. They take the shape of characteristic semicircles, which are called Nyquist plots. The main difficulty in the analysis of test results lies in the selection of an equivalent circuit. Students will learn the principles that should be followed in the selection of such a circuit. Examples of equivalent circuits describing various ceramic materials will be presented. The Students will be acquainted with the basic functions and operation of the ZView program used to determine the values of parameters describing the components of the selected equivalent circuit. Finally, based on the obtained results, the Students will attempt to determine the values of the parameters using the aforementioned program.

3. Learning outcomes

By working on this laboratory project, students:

- will learn the principles of selecting an electrical equivalent circuit.
- will gain practical skills in impedance measurement results analysing.
- will calculate the grains and grains boundary resistivity.

4. Necessary equipment, materials, etc

Laboratory Equipment for Impedance Spectroscopy

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge test:
    a. A test checking students' preparation for laboratory exercises based on information provi-ded during the lecture and based on the literature resources.
2. Introduction:
    a. Presentation of the purpose of the laboratory and discussion of the pyroelectric coefficient measurements method.
    b. Discuss the experiment stages by describing the manner of sample preparatios, measure-ment technique and required calculations.

3. The exercise course:
    a. Students will be divided into teams.
    b. Teams will be responsible for developing a research plan and determining each team member's role in the research.
    c. The instructor will serve as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps.
    d. The instructor approves the research plan to ensure teams work towards the intended ob-jectives.
4. Research:
    a. Familiarization with the a computerized automatic system based on the picoamperometer Keithley 6485.
    b. Preparation of the sample for pyroelectric measurements.
    c. Conducting measurements in the range of temperaturę from room temperaturę up to 450°C.
    d. Performing calculation of piezoelectric coefficients
5. Results analysis:
    a. Each team will present the results of their research in a presentation.
    b. Teams will discuss and compare their results to those received from others.
    c. Students will create conclusions regarding the observation.
6. Summary:
    a. Summarizing the lab and reminding of its objectives.
    b. Summarizing the experience in piezoelectric coefficients calculations.
    c. In teams, students will prepare reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read the following book: J.R. MacDonald Impedance spectroscopy, John Wiley&Sons, New York 1987

7. Additional notes

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8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MATERIALS FOR HYDROGEN ENERGY

Code: MHE

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

Introduction to Hydrogen Energy: The role of hydrogen as an alternative fuel in the climate neutrality strategy

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to present the theoretical basics and the results of the latest scientific research as well as the practical approach to the design and engineering of materials for hydrogen energy. It serves as an introduction to the carbon neutral hydrogen technologies that can prevent climate change and ensure the sustainable development of the economy in the future. This lecture shows how to maximize hydrogen production for the hydrogen economy needs in a clean and effective way. The lecture presents current trends and future directions of development of hydrogen-based technologies. It addresses issues related to renewable energy sources and explains the role of renewable hydrogen and hydrocarbon fuels. The lecture discusses the requirements for the fuels of the future. It includes the characteristics of hydrogen as an alternative and environmentally friendly energy carrier, which is crucial for the successful transformation to green energy. The lecture presents the advantages and disadvantages of hydrogen as the fuel. It discusses the tasks undertaken as part of the hydrogen economy, which concern the search for effective methods of hydrogen production, hydrogen purification and transmission, methods of hydrogen storage, and conversion of hydrogen chemical energy into electricity using fuel cell technology. It highlights the current challenges of hydrogen technologies and the fundamental importance of scientific research in overcoming barriers to the development of the hydrogen economy.

3. Learning outcomes

- **Knowledge:** The student will be able to define hydrogen as an energy carrier
- **Comprehension:** The student will be able to describe the factors driving the interest in hydrogen
- **Application:** The student will be able to choose learned materials in new and concrete situations associated with the hydrogen economy
- **Analysis:** The student will be able to discuss the role of hydrogen as an alternative fuel in the climate neutrality strategy
- **Synthesis:** The student will be able to infer the barriers to overcome in the future development of hydrogen economy
- **Evaluation:** The student will be able to judge the value of material for a given purpose of hydrogen economy

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:

The skeleton for the lecture is the introduction, the body, and the conclusion.

The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

The organizational outline provides a general outline of the main points (only) of the lecture on the board, on an overhead or slide, or in a handout. An outline will ensure that students are following the logical flow. It also highlights new terms that are introducing. Students still have to take notes because the process of note taking has learning and retention benefits.

In addition, the learning aids are integrated:

- *Visuals*

When planning the material, it is considered how to convey or repackage it visually - in pictures, photographs, slides, graphic metaphors, diagrams, graphs, and concept or mind maps (spatial arrangements of concepts or stages linked by lines or arrows). These graphics for presentation to the class are prepared. While such visual aids facilitate almost everyone's learning, they can be critical for students with a visual learning style.

- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Wijk, Ad van. "Hydrogen key to a carbon-free energy system". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 43-104. https://doi.org/10.1515/9783110596250-005
- Iaquaniello, Gaetano, Palo, Emma and Salladini, Annarita. "1 An overview of today's industrial processes to make hydrogen and future developments' trend". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 137-170. https://doi.org/10.1515/9783110596250-009

6. Additional notes

The topics will be covered in one lecture

Topics 2

1. The subject of the lecture

Materials used in the hydrogen production

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to discuss the requirements for hydrogen production materials, methods of their synthesis and ways of modifying them to increase hydrogen production efficiency and stability. The lecture shows the technological challenges related to the production of hydrogen on an industrial scale and provides an understanding of them. The lecture introduces the methods of hydrogen production, especially low- or zero-emission methods. The lecture presents the classification of hydrogen based on the extraction/production technology. It characterizes black, brown, grey, blue, green and pink hydrogen, with particular emphasis on green hydrogen produced by electrolysis of water using electricity generated by renewable energy sources as solar energy, wind energy and others. The lecture discusses possible ways to solve the problem of high energy consumption in industrial water electrolysis by improving the design of hydrogen generators and reducing overpotentials of hydrogen and oxygen gas evolution using electrode materials with increased electrocatalytic properties. It shows how to determine the kinetics and mechanism of electrolytic evolution of hydrogen and oxygen and how to increase the activity of electrodes using electrochemical methods.

3. Learning outcomes

- **Knowledge:** The student will be able to identify hydrogen color depending on the extraction/production technology
- **Comprehension:** The student will be able to indicate technological challenges regarding industrial hydrogen production
- **Application:** The student will be able to choose learned materials in new and concrete situations associated with the hydrogen production
- **Analysis:** The student will be able to compare the effectiveness of methods of hydrogen production
- **Synthesis:** The student will be able to discuss possible ways to solve the problem of high energy consumption in the water electrolysis process
- **Evaluation:** The student will be able to assess the activity of the electrode material for the production of green hydrogen

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:
Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:

The skeleton for the lecture is the introduction, the body, and the conclusion.

The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

The organizational outline provides a general outline of the main points (only) of the lecture on the board, on an overhead or slide, or in a handout. An outline will ensure that students are following the logical flow. It also highlights new terms that are introducing. Students still have to take notes because the process of note taking has learning and retention benefits.

In addition, the learning aids are integrated:

- *Visuals*

When planning the material, it is considered how to convey or repackage it visually - in pictures, photographs, slides, graphic metaphors, diagrams, graphs, and concept or mind maps (spatial arrangements of concepts or stages linked by lines or arrows). These graphics for presentation to the class are prepared. While such visual aids facilitate almost everyone's learning, they can be critical for students with a visual learning style.

- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Giaconia, Alberto, Della Pietra, Massimiliano, Monteleone, Giulia and Nigliaccio, Giuseppe. "5 Development perspective for green hydrogen production". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 251-278. https://doi.org/10.1515/9783110596250-013
- Paidar, Martin and Bouzek, Karel. "8 Water electrolysis as an environmentally friendly source of hydrogen". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 331-358. https://doi.org/10.1515/9783110596250-016

6. Additional notes

The topics will be covered in one lecture.

Topics 3

1. The subject of the lecture

Materials used in the hydrogen storage and transport

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to present the latest developments in hydrogen storage technologies. It shows technologically advanced materials used to store hydrogen, methods of their production and kinetic and thermodynamic aspects. The lecture discusses the nanomaterials as hydrogen storage, which are produced using top-down and bottom-up approach. The lecture introduces the issues of light hydrogen storage and long-distance transport of pure hydrogen, especially for applications in the automotive industry and transport. The lecture explains the limitations of current renewable hydrogen storage methods, such as geological hydrogen storage, hydrogen liquefaction, pressurized hydrogen storage, and solid-state hydrogen storage. The lecture discusses physically bound hydrogen storage on the example of zeolites, carbon nanostructures, and metal-organic framework materials. It focuses on new hydrogen storage and transport technologies based on light materials. It enables learning the principles of designing solid-state hydrogen storages. The lecture explains chemically bound hydrogen storage on the example of intermetallics, magnesium hydrides, alanates, borohydrides, imides, amides, and multicomponent hydrogen systems. The lecture discusses the possibility of using organic liquid carriers for hydrogen storage and indirect hydrogen storage in metal ammines. The lecture introduces the basics of the methods used to determine the content of stored hydrogen and presents new concepts of hydrogen storage.

3. Learning outcomes

- **Knowledge:** The student will be able to define hydrogen storage, transmission and distribution
- **Comprehension:** The student will be able to describe the trends in hydrogen storage technologies
- **Application:** The student will be able to choose learned materials in new and concrete situations associated with the hydrogen storage and transport
- **Analysis:** The student will be able to compare the effectiveness of methods of hydrogen storage and transport
- **Synthesis:** The student will be able to predict the limitations of renewable hydrogen storage methods
- **Evaluation:** The student will be able to judge the value of a given material in terms of application for hydrogen storage and transport

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:
Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:
The skeleton for the lecture is the introduction, the body, and the conclusion.
The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

The organizational outline provides a general outline of the main points (only) of the lecture on the board, on an overhead or slide, or in a handout. An outline will ensure that students are following the logical flow. It also highlights new terms that are introducing. Students still have to take notes because the process of note taking has learning and retention benefits.
In addition, the learning aids are integrated:

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- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Jurczyk, Mieczyslaw and Nowak, Marek. "3 Materials overview for hydrogen storage". *Volume 2 Hydrogen Storage for Sustainability*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 195-212. https://doi.org/10.1515/9783110596281-011
- Zhang, Zhao, Li, Xianda and Elkedim, Omar. "8 Methods of preparing hydrogen storage materials". *Volume 2 Hydrogen Storage for Sustainability*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 303-322. https://doi.org/10.1515/9783110596281-016

6. Additional notes

The topics will be covered in one lecture

Topics 4

1. The subject of the lecture

Fundamentals and principles of water electrolysis

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to discuss hydrogen as an opportunity to balance an unstable energy system based on renewable energy sources. It places special emphasis on the application of water electrolysis method to produce green hydrogen in the future with zero net worth. The lecture discusses the theoretical basis of water electrolysis, construction and principle of operation of electrochemical cells for water splitting, cell efficiency, and related thermodynamic aspects. The lecture introduces the history of water electrolysis over the years with particular emphasis on new renewable energy markets. It presents electrolysis in alkaline solutions, the current state and prospects of its applications in hydrogen energy, physico-chemical principles of alkaline electrolysis, principle of operation of alkaline electrolysers, materials used in alkaline electrolyzers and the effects of their degradation, and characteristics of anion-exchange membrane electrolysis. The lecture shows the electrolysis of water using a proton exchange membrane (PEM), the principle of PEM operation, cell and stack materials available, efficiency of the cell, degradation and lifetime of cell materials, financial aspects, latest technological developments and concepts. The lecture discusses the principles of high-temperature steam electrolysis, chlor-alkali electrolysis, seawater electrolysis and regenerative fuel cells that use PEM technology. The lecture covers the economic conditions of hydrogen production with particular emphasis on PEM electrolysis. It discusses the new principles of electrolyzers dedicated for separated photoelectrochemical and photocatalytic water splitting.

3. Learning outcomes

- **Knowledge:** The student will be able to define water electrolysis process
- **Comprehension:** The student will be able to grasp the meaning of electrode material for the efficiency of green hydrogen production
- **Application:** The student will be able to choose learned materials in new and concrete situations related to various types of water electrolysis
- **Analysis:** The student will be able to discuss the use of hydrogen for balancing an unstable energy system based on renewable energy sources
- **Synthesis:** The student will be able to discuss advantages and disadvantages of alkaline electrolysis, anion-exchange membrane electrolysis, high-temperature steam electrolysis, chlor-alkali electrolysis, and seawater electrolysis
- **Evaluation:** The student will be able to assess the usefulness of electrode material for the hydrogen production by separated photoelectrochemical and photocatalytic water splitting

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:

The skeleton for the lecture is the introduction, the body, and the conclusion.
The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

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In addition, the learning aids are integrated:

- *Visuals*

When planning the material, it is considered how to convey or repackage it visually - in pictures, photographs, slides, graphic metaphors, diagrams, graphs, and concept or mind maps (spatial arrangements of concepts or stages linked by lines or arrows). These graphics for presentation to the class are prepared. While such visual aids facilitate almost everyone's learning, they can be critical for students with a visual learning style.

- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- Paidar, Martin and Bouzek, Karel. "8 Water electrolysis as an environmentally friendly source of hydrogen". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 331-358. https://doi.org/10.1515/9783110596250-016
- Ciambelli, Paolo, Sarno, Maria and Scarpa, Davide. "11 Photoelectrocatalytic H_2 production: current and future challenges". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 401-426. https://doi.org/10.1515/9783110596250-019

6. Additional notes

The topics will be covered in one lecture

Topics 5

1. The subject of the lecture

Fuel cells: From fundamentals to applications

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to present key information on the use of hydrogen to power fuel cells for emission-free electricity generation. The lecture explains the construction and testing methods of fuel cells, the assessment of operation and cell lifetime, and the concepts of hydrogen production. It shows the history of fuel cell development. The lecture familiarizes with the thermodynamic and electrochemical basis of fuel cell operation and chemical reactions taking place in a fuel cell. It explains what fuel cell efficiency is and what factors limit it. The lecture discusses the criteria for classifying fuel cells, such as operating temperature, type of electrolyte and fuel. The lecture presents the advantages and disadvantages of technologies based on fuel cells. It presents the technological and material requirements for fuel cells, including high-performance polymer electrolyte membrane fuel cell (PEMFC), reversible fuel cell (RFC), direct methanol fuel cell (DMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC), and latest types of fuel cells as redox flow cells, biological fuel cells, semi-fuel cells, and direct carbon fuel cells. The lecture discusses the environmental aspects of fuel cells and the perspectives of fuel cell applications in the near and distant future.

3. Learning outcomes

- **Knowledge:** The student will be able to define fuel cell
- **Comprehension:** The student will be able to describe the factors driving the interest in fuel cell technologies
- **Application:** The student will be able to choose learned materials in new and concrete situations related to various types of fuel cells
- **Analysis:** The student will be able to classify given fuel cell as high-performance polymer electrolyte membrane fuel cell, reversible fuel cell, direct methanol fuel cell, alkaline fuel cell, phosphoric acid fuel cell, molten carbonate fuel cell or solid oxide fuel cell
- **Synthesis:** The student will be able to discuss the most important differences between latest types of fuel cells as redox flow cells, biological fuel cells, semi-fuel cells, and direct carbon fuel cells
- **Evaluation:** The student will be able to assess the value of a given material from the view-point of the applying possibility in fuel cells

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:
Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:
The skeleton for the lecture is the introduction, the body, and the conclusion.
The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

The organizational outline provides a general outline of the main points (only) of the lecture on the board, on an overhead or slide, or in a handout. An outline will ensure that students are following the logical flow. It also highlights new terms that are introducing. Students still have to take notes because the process of note taking has learning and retention benefits.
In addition, the learning aids are integrated:

- *Visuals*

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- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- Mitzel, Jens and Friedrich, K. Andreas. "11 Hydrogen fuel cell applications". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 367-398. https://doi.org/10.1515/9783110596274-019
- Coutanceau, Christophe, Chatenet, Marian, Jones, Deborah and Maranzana, Gael. "12 Materials for proton-exchange fuel cell for mobility and stationary applications". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 399-432. https://doi.org/10.1515/9783110596274-020

6. Additional notes

The topics will be covered in one lecture

Topics 6

1. The subject of the lecture

Use of hydrogen in industry, energy and transport

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to familiarize students with current trends in the development of the hydrogen economy, with particular emphasis on applications. It presents the possibilities of using hydrogen in transport to power cars and trucks, trains, as well as water, air and space ships. The lecture discusses the materials used in the use of hydrogen for the transport and production of electricity. The lecture presents examples of innovative materials and electrolytes proposed for use in fuel cell technology. It raises issues related to the mobility of vehicles based on fuel cells, such as fuel station network, safety, risk assessment for infrastructure and transport. The lecture addresses the commercialization of fuel cells for applications in large and small stationary power plants, transportation, portable devices, military applications and technological barriers to the wide commercialization of fuel cells. It discusses the possibilities of using PEFC in the transportation and aerospace industries. The lecture presents examples of AFC applications in transport, power engineering of vehicles and boats. The lecture introduces commercialized fuel cells in the form of PAFC, which have been used as a source of electricity and heat in public facilities. It outlines plans to use SOFC in high-power installations. The lecture explains the limitations of MCFC in applications for heating needs and technological processes.

3. Learning outcomes

- **Knowledge:** The student will be able to list examples of hydrogen use in industry, energy and transport
- **Comprehension:** The student will be able to describe technological challenges of hydrogen use in industry, energy and transport
- **Application:** The student will be able to choose learned materials in new and concrete situations associated with the use of hydrogen in industry, energy and transport
- **Analysis:** The student will be able to discuss trends in the development of the hydrogen economy in terms of industrial applications
- **Synthesis:** The student will be able to infer technological barriers to the wide commercialization of fuel cells
- **Evaluation:** The student will be able to assess the usefulness of a given fuel cell for application in industry, energy and transport

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:
Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

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- *Examples*

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- *Restatements*

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The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- Centi, Gabriele and Perathoner, Siglinda. "1 Applications of hydrogen technologies and their role for a sustainable future". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 137-156. https://doi.org/10.1515/9783110596274-009
- Allidières, Laurent. "4 Introduction to hydrogen energy: from applications to technical solutions". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 195-218. https://doi.org/10.1515/9783110596274-012

6. Additional notes

The topics will be covered in one lecture

Topics 7

1. The subject of the lecture

Safety of hydrogen use

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to present the risks resulting from the use of flammable and explosive hydrogen fuel. It describes the principles of safe use of hydrogen, which relate to the safe generation, handling and use of hydrogen as a fuel in gaseous and liquid form. It characterizes actions taken to create a secure chain of technical connections throughout the logistics process, from production, through storage, to delivery of hydrogen to recipients. The lecture describes the fire hazards caused by a hydrogen explosion and how to conduct a risk analysis of hydrogen systems. It presents certification and legal regulations in the field of hydrogen energy. The lecture acquaints with detailed information contained in the certification of hydrogen technologies, hydrogen sources, transport and storage equipment and systems in land and water transport, and certification of electrolysers. The lecture introduces hydrogen codes and standards developed for hydrogen fuel cell vehicles, stationary and portable fuel cell applications.

3. Learning outcomes

- **Knowledge:** The student will be able to define safety of hydrogen use
- **Comprehension:** The student will be able to describe the risk factors resulting from the use of hydrogen
- **Application:** The student will be able to apply certification and legal regulations in in new and concrete situations associated with safety of hydrogen use
- **Analysis:** The student will be able to analyze the risk of hydrogen systems
- **Synthesis:** The student will be able to formulate the principles of safe use of hydrogen
- **Evaluation:** The student will be able to judge the usefulness of a given hydrogen code and standard in terms of application for hydrogen fuel cell vehicles, stationary and portable fuel cells

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:
Lecture with two- to fifteenminute breaks for student activities (such as answering a multiple-choice objective item, solving a problem, comparing and filling in lecture notes, debriefing a minicase, doing a thinkpair-share exercise, or a small-group discussion) every twelve to twenty minutes.

The internal organization of lecture:
The skeleton for the lecture is the introduction, the body, and the conclusion.
The introduction has three parts: (1) a statement that frames the lecture in the context of the course objectives, (2) a statement reviewing and transitioning from the material covered in

the previous class period, and (3) an attention grabber for the new material. Effective attention grabbers include an intriguing question the lecture will answer, a story or parable that illustrates the new subject matter of the day, a demonstration of a nonobvious phenomenon, a reference to a current event or movie, a case or a problem that requires the lecture's information to solve, or a strong generalization that contradicts common thought. The idea is to draw in the class with surprise, familiarity, curiosity, or suspense.

The body is a presentation and explication of new material. Within this section the major topic is subdivided into minilectures, each of which should revolve around only one major point. To keep organization of a minilecture simple, an array of options is used: deduction (theory to phenomena/examples); induction (phenomena/examples to theory); hypothesis testing (theory to hypothesis to evidence); problem to solution; cause to effect; concept to application; familiar to unfamiliar; debate to resolution; a chronology of events (a story or process) - to name just some common possibilities. To appeal to different learning styles, the organization from one minilecture to another is varied.

The organizational outline provides a general outline of the main points (only) of the lecture on the board, on an overhead or slide, or in a handout. An outline will ensure that students are following the logical flow. It also highlights new terms that are introducing. Students still have to take notes because the process of note taking has learning and retention benefits.
In addition, the learning aids are integrated:

- *Visuals*

When planning the material, it is considered how to convey or repackage it visually - in pictures, photographs, slides, graphic metaphors, diagrams, graphs, and concept or mind maps (spatial arrangements of concepts or stages linked by lines or arrows). These graphics for presentation to the class are prepared. While such visual aids facilitate almost everyone's learning, they can be critical for students with a visual learning style.

- *Examples*

Illustrating abstract concepts and relationships with examples are used. These examples are striking, vivid, current, common in everyday life, and related to students' experiences (past, present, or future). Making them humorous also helps students remember them.

- *Restatements*

Each important point is restated in two or three different ways - in scholarly terms, lay formal language, and informal language. Restatements not only demystify the material, making it more comprehensible, but they also build students' vocabulary and encourage their own paraphrasing of the material.

The conclusion is a two- to five-minute recap of the most important points in the lecture for learning purposes. The lecturer plans and directs the recap activity, but the students should do it. The recap activity takes the form of an oral summary presented by one or more students, a free-recall writing exercise, a classroom assessment technique such as a one-minute paper, or a quiz.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- Caliendo, Ciro, Russo, Paola and Ciambelli, Paolo. "13 Hydrogen safety, state of the art, perspectives, risk assessment, and engineering solutions". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 433-450. https://doi.org/10.1515/9783110596274-021
- Dodds, Paul E., Scamman, Daniel and Ekins, Paul. "16 Hydrogen distribution infrastructure". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 491-510. https://doi.org/10.1515/9783110596274-024

6. Additional notes

The topics will be covered in one lecture

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

Electrodeposition of nickel electrocatalysts

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to determine the impact of electrodeposition parameters on the quality of nickel electrocatalysts (color, gloss, texture, homogeneity, compactness, adhesion, thickness) using the Hull cell. Production of nickel electrocatalysts on metallic substrates will be carried out by controlling electrodeposition parameters, such as the chemical composition of the galvanic bath, current and time. The laboratory classes allows students to understand how to select preliminary conditions for electrodeposition nickel coatings on metallic substrates. They allow students to understand how to optimize electrodeposition parameters in a new galvanic bath, electrodeposit metallic coatings using the Hull cell, and determine the current efficiency in the process of cathodic deposition of metallic coatings.

3. Learning outcomes

- **Knowledge:** The student will be able to select preliminary conditions for electrodeposition of metallic electrocatalysts from a galvanic bath using the Hull cell
- **Comprehension:** The student will be able to explain the experimental results carried out in the Hull cell
- **Application:** The student will be able to make use of the Hull cell in new and concrete situations associated with the electrodeposition of metallic electrocatalysts
- **Analysis:** The student will be able to determine the cathodic current efficiency of metal deposition from a given galvanic bath using the Hull cell
- **Synthesis:** The student will be able to produce the metallic electrocatalysts with a thickness assumed using the Hull cell
- **Evaluation:** The student will be able to assess the quality of metallic electrocatalysts produced using the Hull cell

4. Necessary equipment, materials, etc

- Electrodes: carbon steel plates (100 x 60 x 2 mm), nickel plates (60 x 60 x 2 mm), abrasive papers
- Apparatus: caliper, analytical balance, magnetic stirrer, DC power supply with cables
- Laboratory glassware: Hull cells with a volume of 267 cm^3, beakers
- Solutions for cleaning the electrodes
- Galvanic baths for electrodeposition of nickel electrocatalysts
- Metalographic microscope

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students doing an exercise activity or creating a product in small groups of two to six in laboratory; exercise is carefully managed by the lecturer.

Case method: Students applying course knowledge to devise one or more solutions or resolutions to problems or dilemmas presented in a realistic story or situation.

Project-based learning: Students (as individuals or in groups) applying course knowledge to produce a written report, process or product design, research or program proposal; often paired with cooperative learning.

Laboratory course outline:

1. Introduction
• Presentation of rules of Occupational Health and Safety (OHS) at the hydrogen technology laboratory. Each student signs the OHS work regulations.
• Introduction to the topic of the laboratory.
• A short test or colloquium to see how well students understood the content of previous lectures and prepared for the laboratory. Questions may apply to both theory and practical aspects related to the experiment.
• Presentation of goals, procedures and expected results of the exercise.
• Division of students into groups and assigning appropriate positions. Individual groups are responsible for developing a research plan and determining the role of each group member in the exercise.

2. Course of exercise
• Presentation of instructions on the use of equipment.
• Execution of a series of experiments on the subject of laboratory exercise:
  - Measuring the geometrical dimensions of the steel substrate and the nickel electrode using a caliper.
  - Cleaning the electrode surface with abrasive paper and then rinsing the electrodes several times with distilled water and washing with alcohol.
  - Cleaning chemically the surface of the steel electrode. Rinsing the electrode with distilled water.
  - Cleaning electrochemically the steel cathode surface. Rinsing the electrode with distilled water.
  - Weighing the dried electrodes on an analytical balance.
  - Preparing the Hull cell with a cathode of carbon steel plate and an anode of nickel plate.

- After placing the electrodes in the respective positions, pouring the nickel bath into the electrolyzer. Setting the power supply to the nickel deposition current and conducting the electrolysis successively from baths I, II, III and IV.
- Writing the reactions occurring on the electrodes during electrodepsoition of nickel.
- After finished electrodepsoition, removing the steel cathode coated with nickel from the Hull cell, rinsing with distilled water and weighing on analytical balance after drying.
- Visual assessment of the obtained nickel coatings. Describing the quality of coatings (color, gloss, texture, homogeneity, compactness, adhesion, thickness). Comparing the quality of coatings obtained from the nickel plating bath I-IV using a suitable current scale. Selection of the optimum nickel deposition currents from bath I-IV to obtain good quality coatings. Calculation of the electrodeposited nickel mass from difference of the cathode mass before and after deposition from bath I-IV.
- Calculation of the cathodic current efficiency of nickel deposition.
- Explaining the importance of using nickel electrocatalysts, and provide examples of uses.
- Explaining the purposefulness of use a bath of different compositions to coat the metal.

• Monitoring by the lecturer of the work progress and providing the necessary assistance. The lecturer serves as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.

3. Data analysis and interpretation
• Groups analyze the collected data and prepare appropriate charts, tables or reports.
• The lecturer conducts a discussion on the results received and helps students interpret the data obtained. It is important to maintain a balance between student activity and the lecturer's role to ensure interactivity and effective knowledge assimilation.

4. Summary and conclusions
• A joint discussion about the results obtained and conclusions drawn.
• Comparison of experimental results with theoretical expectations or earlier results.
• Discussion of the relationship between theory and practice and the importance of results for materials engineering.

5. Organizing positions and ending
• Tips for organizing work stations and proper storage of materials and chemical reagents used.
• End of the laboratory. The lecturer reminds students about the next date of laboratory classes.

6. Preparing a report
• The lecturer discusses the requirements and rules for assessing the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

- Szklarska Magdalena, Smołka Agnieszka, Popczyk Magdalena, Łosiewicz Bożena. *Characteristics of the Galvanic Baths for Electrodeposition of Nickel Coatings Using the Hull Cell.* Solid State Phenomena, 2015, 228, 79–88. doi: 10.4028/www.scientific.net/ssp.228.79

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT

They will be assessed:

- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 2 – Lab 2

1. The subject of the laboratory classes

Production of green hydrogen by electrolysis of water

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to the study of the impact of various galvanic baths used for the electrodeposition of nickel electrocatalysts on their activity in the production of green hydrogen by water electrolysis method. The impact of operational parameters, such as the chemical composition of the galvanic bath and the overpotential of electrolytic hydrogen evolution, will be examined experimentally. The electrocatalytic properties of nickel electrodes obtained in various electrodeposition conditions will be assessed in electrochemical measurements. By changing the parameters of the water electrolysis process and analyzing their impact on the evolution of gas hydrogen, students will be able to understand how to produce green hydrogen and determine the activity of metallic cathodes in the hydrogen evolution reaction in aqueous electrolytes.

3. Learning outcomes

- **Knowledge:** The student will be able to choose the galvanic bath for electrodeposition of metallic electrocatalysts used in electroevolution of hydrogen
- **Comprehension:** The student will be able to explain the impact of galvanic baths and overpotentials on the activity of metallic coatings in hydrogen electroevolution
- **Application:** The student will be able to apply the water electrolysis process to produce green hydrogen on a laboratory scale
- **Analysis:** The student will be able to determine the electrochemical parameters of hydrogen evolution reaction in aqueous electrolytes on a given electrode material
- **Synthesis:** The student will be able to produce the metallic electrocatalysts with an electrocatalytic properties assumed in the water electrolysis process
- **Evaluation:** The student will be able to assess the activity of metallic electrocatalysts produced in the water electrolysis process

4. Necessary equipment, materials, etc

- Electrodes: working electrode in the form of carbon steel (10 x 10 x 2 mm), reference electrode, counter electrode, abrasive papers
- Apparatus: analytical balance, magnetic stirrer, DC power supply with cables, potentiostat
- Laboratory glassware: thermostated electrolytic cells, beakers
- Solutions for cleaning the electrodes
- Galvanic baths for electrodeposition of nickel electrocatalysts
- Electrolytes for water electrolysis
- Argon bottle

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students doing an exercise activity or creating a product in small groups of two to six in laboratory; exercise is carefully managed by the lecturer.

Case method: Students applying course knowledge to devise one or more solutions or resolutions to problems or dilemmas presented in a realistic story or situation.

Project-based learning: Students (as individuals or in groups) applying course knowledge to produce a written report, process or product design, research or program proposal; often paired with cooperative learning.

Lab course outline:

1. Introduction
• Introduction to the topic of the laboratory.
• A short test or colloquium to see how well students understood the content of previous lectures and prepared for the laboratory. Questions may apply to both theory and practical aspects related to the experiment.
• Presentation of goals, procedures and expected results of the exercise.
• Division of students into groups and assigning appropriate positions. Individual groups are responsible for developing a research plan and determining the role of each group member in the exercise.

2. Course of exercise
• Presentation of instructions on the use of equipment.
• Execution of a series of experiments on the subject of laboratory exercise:
  - Washing with distilled water and alcohol the nickel electrocatalysts electrodeposited at various galvanic baths.
  - Washing with distilled water and alcohol the platinum anodes.
  - Connection of the electrochemical system for measuring the potential of electrodes.
  - Measurement of the potential of the tested electrode relative to the saturated calomel electrode in the system, in which current does not flow from an external source.
  - Measurement of the potential of the tested electrode relative to the saturated calomel electrode in the system included in the electrolysis current system. Setting the current values in the range from 0 to 1.5 A, every 0.1 A using a DC power supply. After each change of current, waiting a minute and reading the values of the potential of the electrodes relative to the saturated calomel electrode. Noticing measurement

results. Measurements should be made for all electrodes in 0.5 M or 1 M sulphuric acid solution with and without the use of electrolyte mixing.

- Converting the value of the electrode potential relative to the normal hydrogen electrode.
- Graphical presentation of the obtained results on polarization curves. Graphical determination of b coefficients in the Tafel equation.
- Discussion of the effect of the type of substrate, current density, electrolyte pH and mixing on the overpotential of hydrogen electrolytic evolution.

• Monitoring by the lecturer of the work progress and providing the necessary assistance. The lecturer serves as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.

3. Data analysis and interpretation

• Groups analyze the collected data and prepare appropriate charts, tables or reports.

• The lecturer conducts a discussion on the results received and helps students interpret the data obtained. It is important to maintain a balance between student activity and the lecturer's role to ensure interactivity and effective knowledge assimilation.

4. Summary and conclusions

• A joint discussion about the results obtained and conclusions drawn.

• Comparison of experimental results with theoretical expectations or earlier results.

• Discussion of the relationship between theory and practice and the importance of results for materials engineering.

5. Organizing positions and ending

• Tips for organizing work stations and proper storage of materials and chemical reagents used.

• End of the laboratory. The lecturer reminds students about the next date of laboratory classes.

6. Preparing a report

• The lecturer discusses the requirements and rules for assessing the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

- Paidar, Martin and Bouzek, Karel. "8 Water electrolysis as an environmentally friendly source of hydrogen". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 331-358. https://doi.org/10.1515/9783110596250-016

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT

They will be assessed:

- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 3 – Lab 3

1. The subject of the laboratory classes

Hydrogen storage in metals by electrochemical methods

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to the study of the impact of different parameters of hydrogen electrosorption on hydrogen storage into metals. The impact of operational parameters such as the chemical composition of the electrolyte, potential and time of hydrogen electrosorption on the amount of hydrogen accumulated into metals will be investigated. The ability of selected metals for storage of hydrogen will be evaluated using electrochemical methods. By changing the parameters of electrosorption and analyzing their impact on hydrogen storage, students will be able to understand how to accumulate hydrogen electrochemically and how to determine the amount of hydrogen stored into metals and kinetics of diffusion and desorption of hydrogen.

3. Learning outcomes

- **Knowledge:** The student will be able to choose the operational parameters of hydrogen electrosorption into metals
- **Comprehension:** The student will be able to explain the impact of hydrogen electrosorption parameters on hydrogen storage into metals
- **Application:** The student will be able to apply the hydrogen electrosorption process to accumulate hydrogen into metals on a laboratory scale
- **Analysis:** The student will be able to determine the electrochemical parameters of hydrogen electrosorption in aqueous electrolytes into a given electrode material
- **Synthesis:** The student will be able to estimate the metal ability to accumulate hydrogen through the electrosorption
- **Evaluation:** The student will be able to assess the amount of hydrogen electrosorbed into metals and kinetics of diffusion and desorption of hydrogen

4. Necessary equipment, materials, etc

- Electrodes: working electrode of metal under investigation, reference electrode, counter electrode, abrasive papers
- Apparatus: analytical balance, magnetic stirrer, potentiostat, frequency response analyzer
- Laboratory glassware: thermostated electrolytic cells, beakers
- Solutions for cleaning the electrodes
- Electrolytes for electrosorption
- Argon bottle

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students doing an exercise activity or creating a product in small groups of two to six in laboratory; exercise is carefully managed by the lecturer.

Case method: Students applying course knowledge to devise one or more solutions or resolutions to problems or dilemmas presented in a realistic story or situation.

Project-based learning: Students (as individuals or in groups) applying course knowledge to produce a written report, process or product design, research or program proposal; often paired with cooperative learning.

Lab course outline:

1. Introduction
• Introduction to the topic of the laboratory.
• A short test or colloquium to see how well students understood the content of previous lectures and prepared for the laboratory. Questions may apply to both theory and practical aspects related to the experiment.
• Presentation of goals, procedures and expected results of the exercise.
• Division of students into groups and assigning appropriate positions. Individual groups are responsible for developing a research plan and determining the role of each group member in the exercise.

2. Course of exercise
• Presentation of instructions on the use of equipment.
• Execution of a series of experiments on the subject of laboratory exercise:
  - Washing with distilled water and alcohol the metallic cathodes.
  - Washing with distilled water and alcohol the platinum anodes.
  - Connection of the electrochemical system for measuring the potential of electrodes.
  - Measurement of hydrogen electrosorption for each tested electrode in electrolytes with various chemical composition using cyclic voltammetry and chronoamperometry methods.
  - Measurement of hydrogen electrosorption for each tested electrode at various potential of hydrogen accumulation using cyclic voltammetry and chronoamperometry methods.
  - Measurement of hydrogen electrosorption for each tested electrode at various time of hydrogen accumulation using cyclic voltammetry and chronoamperometry methods.

- Quantitative determination of stored hydrogen in metallic electrodes depending on the conditions of electrosorption.

• Monitoring by the lecturer of the work progress and providing the necessary assistance. The lecturer serves as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.

3. Data analysis and interpretation

• Groups analyze the collected data and prepare appropriate charts, tables or reports.

• The lecturer conducts a discussion on the results received and helps students interpret the data obtained. It is important to maintain a balance between student activity and the lecturer's role to ensure interactivity and effective knowledge assimilation.

4. Summary and conclusions

• A joint discussion about the results obtained and conclusions drawn.

• Comparison of experimental results with theoretical expectations or earlier results.

• Discussion of the relationship between theory and practice and the importance of results for materials engineering.

5. Organizing positions and ending

• Tips for organizing work stations and proper storage of materials and chemical reagents used.

• End of the laboratory. The lecturer reminds students about the next date of laboratory classes.

6. Preparing a report

• The lecturer discusses the requirements and rules for assessing the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

- Zhang, Zhao, Li, Xianda and Elkedim, Omar. "8 Methods of preparing hydrogen storage materials". *Volume 2 Hydrogen Storage for Sustainability*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 303-322. https://doi.org/10.1515/9783110596281-016

7. Additional notes

The topics will be covered in one laboratory classes

8. Optional information

Exercise instruction will be available

Topics 4 – Lab 4

1. The subject of the laboratory classes

Construction and testing of electrochemical properties of a polymer electrolyte membrane fuel cell

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to the ability to practical use of green hydrogen for drive a car model with hydrogen cell, in which traditional fuels as gasoline, diesel oil or petroleum can be replaced by pro-ecological hydrogen fuel. Before starting a car model with a reversible fuel cell driven by hydrogen, a distilled water electrolysis will be carried out. An external power source and solar panel will be used for the production of green hydrogen. The produced gaseous hydrogen and oxygen will be stored separately in the fuel cell tanks with a polymer membrane (PEM). The flammability test of accumulated hydrogen will be carried out. In the next stage, PEM will be installed with a hydrogen and oxygen tanks on the car chassis. The vehicle will start as a result of hydrogen combustion in oxygen, and heat and water will be released as the only and non-emission combustion product. The water created as a combustion product will be reused for electrolysis and re-production of hydrogen and oxygen.

3. Learning outcomes

- **Knowledge:** The student will be able to choose the operational parameters of a reversible fuel cell for production of green hydrogen
- **Comprehension:** The student will be able to explain the principle of polymer electrolyte membrane fuel cell used to power the vehicle
- **Application:** The student will be able to apply green hydrogen for driving a car model with a polymer electrolyte membrane fuel cell
- **Analysis:** The student will be able to determine the amount of gas hydrogen and oxygen accumulated separately in the fuel cell tanks
- **Synthesis:** The student will be able to estimate the efficiency of an external power source and solar panel for the production of green hydrogen
- **Evaluation:** The student will be able to assess the electrochemical properties of a polymer electrolyte membrane fuel cell for mobile applications

4. Necessary equipment, materials, etc

- Apparatus: reversible fuel cell with a polymer electrolyte membrane, solar panel, UV lamp, DC power supply with cables, hydrogen-powered car model
- Laboratory glassware: beakers, cylinders
- Distilled water

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students doing an exercise activity or creating a product in small groups of two to six in laboratory; exercise is carefully managed by the lecturer.

Case method: Students applying course knowledge to devise one or more solutions or resolutions to problems or dilemmas presented in a realistic story or situation.

Project-based learning: Students (as individuals or in groups) applying course knowledge to produce a written report, process or product design, research or program proposal; often paired with cooperative learning.

Lab course outline:

1. Introduction
• Introduction to the topic of the laboratory.
• A short test or colloquium to see how well students understood the content of previous lectures and prepared for the laboratory. Questions may apply to both theory and practical aspects related to the experiment.
• Presentation of goals, procedures and expected results of the exercise.
• Division of students into groups and assigning appropriate positions. Individual groups are responsible for developing a research plan and determining the role of each group member in the exercise.

2. Course of exercise
• Presentation of instructions on the use of equipment.
• Execution of a series of experiments on the subject of laboratory exercise:
- Conducting a distilled water electrolysis using an external power source (direct current power supply) or a solar panel.
- Separate storage of gas hydrogen (12 ml) and oxygen (12 ml) in fuel cell tanks with polymer membrane.
- Carrying out the flammability of the collected hydrogen.
- Installation of PEM fuel cell with gas tanks on the car chassis.
- Starting a vehicle as a result of hydrogen burning in the presence of oxygen with simultaneous evolution of heat and water as a combustion product.
- The use of a combustion (water) product for re-electrolysis and obtaining gas hydrogen and oxygen.

• Monitoring by the lecturer of the work progress and providing the necessary assistance. The lecturer serves as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.

3. Data analysis and interpretation
• Groups analyze the collected data and prepare appropriate charts, tables or reports.
• The lecturer conducts a discussion on the results received and helps students interpret the data obtained. It is important to maintain a balance between student activity and the lecturer's role to ensure interactivity and effective knowledge assimilation.

4. Summary and conclusions
• A joint discussion about the results obtained and conclusions drawn.
• Comparison of experimental results with theoretical expectations or earlier results.
• Discussion of the relationship between theory and practice and the importance of results for materials engineering.

5. Organizing positions and ending
• Tips for organizing work stations and proper storage of materials and chemical reagents used.
• End of the laboratory. The lecturer reminds students about the next date of laboratory classes.

6. Preparing a report
• The lecturer discusses the requirements and rules for assessing the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:
- Coutanceau, Christophe, Chatenet, Marian, Jones, Deborah and Maranzana, Gael. "12 Materials for proton-exchange fuel cell for mobility and stationary applications". *Volume 3 Utilization of Hydrogen for Sustainable Energy and Fuels*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 399-432. https://doi.org/10.1515/9783110596274-020

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT
They will be assessed:
- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+

86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 5 – Lab 5

1. The subject of the laboratory classes

Destructive effect of hydrogen electroevolution on metallic electrodes

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The topics of the laboratory classes are related to the study of the impact of hydrogen evolution reaction to micromechanical properties and corrosion resistance of metallic electrodes in aqueous electrolytes. The impact of operating parameters, such as the chemical composition and concentration of electrolyte, overpotential and time of hydrogen electrolytic evolution, will be investigated. To assess the micromechanical properties of selected metallic electrodes before and after the process of electrolytic hydrogen evolution, the Vickers microhardness tests will be used. The effect of electrolytic hydrogen evolution on corrosion resistance of metallic electrodes will be determined using electrochemical methods. Controlling the parameters of water electrolysis and analyzing their impact on the microhardness and corrosion resistance of metallic electrodes, students will be able to better understand how to determine the destructive effect of hydrogen by measuring microhardness and parameters of corrosion resistance of electrode materials in aqueous electrolytes.

3. Learning outcomes

- **Knowledge:** The student will be able to choose the operational parameters of hydrogen electroevolution to reduce the destructive effect of hydrogen on electrode material
- **Comprehension:** The student will be able to explain the impact of hydrogen evolution reaction to micromechanical properties and corrosion resistance of metallic electrodes in aqueous electrolytes
- **Application:** The student will be able to apply the properly selected electrode material in new and concrete situations to avoid the destructive effect of hydrogen electroevolution
- **Analysis:** The student will be able to determine the Vickers microhardness and parameters of corrosion resistance for a given cathode material used in hydrogen electroevolution
- **Synthesis:** The student will be able to estimate the degree of degradation of electrode materials caused by hydrogen electroevolution
- **Evaluation:** The student will be able to assess the destructive effect of hydrogen electroevolution on metallic electrodes

4. Necessary equipment, materials, etc

- Electrodes: working electrode of metal under investigation, reference electrode, counter electrode, abrasive papers
- Apparatus: analytical balance, magnetic stirrer, potentiostat, frequency response analyzer
- Laboratory glassware: thermostated electrolytic cells, beakers
- Solutions for cleaning the electrodes

- Electrolytes
- Argon bottle
- Vickers microhardness testing machine

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students doing an exercise activity or creating a product in small groups of two to six in laboratory; exercise is carefully managed by the lecturer.

Case method: Students applying course knowledge to devise one or more solutions or resolutions to problems or dilemmas presented in a realistic story or situation.

Project-based learning: Students (as individuals or in groups) applying course knowledge to produce a written report, process or product design, research or program proposal; often paired with cooperative learning.

Lab course outline:

1. Introduction
• Introduction to the topic of the laboratory.
• A short test or colloquium to see how well students understood the content of previous lectures and prepared for the laboratory. Questions may apply to both theory and practical aspects related to the experiment.
• Presentation of goals, procedures and expected results of the exercise.
• Division of students into groups and assigning appropriate positions. Individual groups are responsible for developing a research plan and determining the role of each group member in the exercise.

2. Course of exercise
• Presentation of instructions on the use of equipment.
• Execution of a series of experiments on the subject of laboratory exercise:
  - Washing with distilled water and alcohol the metallic electrocatalysts electrodeposited at various galvanic baths.
  - Washing with distilled water and alcohol the platinum anodes.
  - Connection of the electrochemical system for measuring the potential of electrodes.
  - Measurement of the polarization curves for each tested electrode in electrolytes with various chemical composition and concentration, overpotential and time of the electrolytic hydrogen evolution.
  - Determining the micromechanical properties of the tested electrodes before and after the electrolytic hydrogen evolution in the measurements of microhardness using the Vickers method.

- Determining the electrochemical properties of the tested electrodes before and after the electrolytic hydrogen evolution in the measurements of corrosion resistance using the open circuit potential method and polarization curves.
- Determining the corrosion resistance parameters of the tested electrodes based on the polarization curves using the extrapolation method of Tafel lines.

• Monitoring by the lecturer of the work progress and providing the necessary assistance. The lecturer serves as a mentor, supporting teams in developing their research plan and pointing out any errors or gaps in the plan.

3. Data analysis and interpretation
• Groups analyze the collected data and prepare appropriate charts, tables or reports.
• The lecturer conducts a discussion on the results received and helps students interpret the data obtained. It is important to maintain a balance between student activity and the lecturer's role to ensure interactivity and effective knowledge assimilation.

4. Summary and conclusions
• A joint discussion about the results obtained and conclusions drawn.
• Comparison of experimental results with theoretical expectations or earlier results.
• Discussion of the relationship between theory and practice and the importance of results for materials engineering.

5. Organizing positions and ending
• Tips for organizing work stations and proper storage of materials and chemical reagents used.
• End of the laboratory. The lecturer reminds students about the next date of laboratory classes.

6. Preparing a report
• The lecturer discusses the requirements and rules for assessing the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:
- Paidar, Martin and Bouzek, Karel. "8 Water electrolysis as an environmentally friendly source of hydrogen". *Volume 1 Hydrogen Production and Energy Transition*, edited by Marcel Van de Voorde, Berlin, Boston: De Gruyter, 2021, pp. 331-358. https://doi.org/10.1515/9783110596250-016

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT

They will be assessed:

- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:
96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

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UNIVERSITY OF SILESIA IN KATOWICE
UNIVERSITY OF ŽILINA

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

POWDER METALLURGY

Code: PM

Co-funded by the European Union
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UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO POWDER METALLURGY: HISTORY; ADVANTAGES AND LIMITATIONS OF POWDER METALLURGY; APPLICATIONS OF POWDER METALLURGY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This course provides an introduction to the fundamental principles of powder metallurgy. The student will gain an understanding of basic science and engineering as they relate to this technology. During the lecture, Students should be introduced to powder metallurgy technology, learn the basic terms, and differentiate manufacturing methods for producing metal powders and concepts of powder metallurgy and why we use powders; example processes, examples of products, and some references.

Moreover, the lecture should include a quick overview of the most important aspects that will be covered in the lectures, including discussing particle morphology: size, shape, characterization, requirements of lubricants and binders, describing common consolidation/shaping processes including, discussing sintering furnaces and atmospheres, describe post-sintering operations.

In addition, the lecture should provide an opportunity to learn about the history of this method, from its origins to current industrial applications. Milestones for the method should be discussed, including metallurgy of tungsten powders for fiber production, sintered metal-carbon-based compounds, composite materials known as "sintered alloys or carbides," metal oxide-based composites, so-called cermets, used for special high-temperature purposes.

Moreover, the most important properties of various powder metallurgy technologies, including their advantages and disadvantages, should also be presented. Also, the lecture should compare the advantages and disadvantages of PM technology to other methods of synthesizing materials, including induction melting and casting into molds.

Moreover, students should be known for recognizing management issues, including safety, health, cost, efficiency, markets, and applications.

3. Learning outcomes

Students can use information from lectures, literature, and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to powder metallurgy. Students understand and know the basic terminology related to materials manufacturing by powder metallurgy technology. Students can deal with the mechanics and the design of materials by powder metallurgy. Students know how to choose the appropriate material prepared by powder metallurgy technology depending on its application. Also, Students know the most important properties of various powder metallurgy technologies, including their advantages and disadvantages.

Moreover, students are known for recognizing management issues, including safety, health, cost, efficiency, markets, and applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, to visualize the discussed issues.
Case study - presentation of powder metallurgy technology and learning the basic terms, history, and concepts of powder metallurgy, examples of the use of powder metallurgy in various fields, such as aviation, automotive, biomedical applications, advantages and disadvantages of PM technology to other methods of synthesizing materials
Discussion - encouraging participants to participate in the discussion on the discussed issues actively
Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Treatise on Powder Metallurgy – C. Goetzel, vol. 1&2.
4. Powder Metallurgy Practice and Applications – R.L. Sands & C.R. Shakespeare.
5. Handbook of Powder Metallurgy – H. H. Hausner & M.Mal- 2nd Ed.

6. Additional notes

The subject of the lecture covers 3 teaching hours.

Topics 2

1. The subject of the lecture

POWDER PRODUCTION METHODS AND THEIR CHARACTERISTICS

2. Thematic scope of the lecture (abstract, maximum 500 words)

In this lecture, a description of the most important principles and processes for powder manufacturing that are of technological significance should be given. The student will gain an understanding of the significant powder manufacturing methods, mainly the mechanical, physical-mechanical, physical-chemical, physical, and chemical methods. In particular, students should be introduced to powder fabrication approaches; mechanical techniques - milling, grinding, attritioning, impaction; electrolytic techniques; chemical techniques - decomposition, precipitation, reduction, and reaction. Also, atomization of melts: gas and water atomization principles, centrifugal atomization, plasma and special atomization, comparison of powders, typical characteristics, and nanoscale powders should be given.

During the lecture, students should also be introduced to the dependencies of how the powder production method affects their chemical composition and particle structure, in addition to the exact nature of the particle size distribution and how these properties also influence the behavior of the powder during compaction and sintering, and on the composition, structure, and properties of the sintered material.

Also, the success of any powder metallurgical process depends significantly on the complete characterization and control of the metal powders. Therefore, during this lecture, students should learn about powders' properties and selected study methods: size, shape, and structure of powder particles, the specific surface area of powders, and technological properties.

Also, during this lecture, students should learn about powders' properties and selected study methods: size, shape, and structure of powder particles, the specific surface area of powders, and technological properties.

Students should be introduced to the principles of laser measurement of particle size and distribution and interpretation of results from such measurements. In addition, students should be introduced to the possibilities offered by optical analysis of powders using optical microscopy and scanning electron microscopy, and they should learn the principles of creating histograms for assessing the particle size of powders.

3. Learning outcomes

Students can use information from lectures, literature, and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to powders manufacturing techniques using the PM method.

Students understand and know the basics of mechanical, physical-mechanical, physical-chemical, physical, and chemical methods for powder preparation.

Also, Students know the most important properties of powders and selected methods of their study: size, shape, and structure of powder particles, the specific surface area of powders, and technological properties.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, to visualize the discussed issues.

Case study - presentation of powders production methods and their characteristics

Discussion - encouraging participants to participate in the discussion on the discussed issues actively

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Treatise on Powder Metallurgy – C. Goetzel, vol. 1&2.
4. Powder Metallurgy Practice and Applications – R.L. Sands & C.R. Shakespeare.
5. Handbook of Powder Metallurgy – H. H. Hausner & M.Mal- 2nd Ed.

6. Additional notes

The subject of the lecture covers 3 teaching hours.

Topics 3

1. The subject of the lecture

COMPACTION OF POWDERS

2. Thematic scope of the lecture (abstract, maximum 500 words)

The compaction of metal powders has the following primary functions: to consolidate the powder into the desired shape, to impart, to as high a degree as possible, the desired final dimensions with due consideration to any dimensional changes resulting from sintering, to impart the desired level and type of porosity and to impart adequate strength for subsequent handling.

In this lecture, a description of the most important principles and processes for metal or ceramic powder compaction, especially the basic functions: to consolidate the powder into the desired shape, to impart, to as high a degree as possible, the desired final dimensions with due consideration to any dimensional changes resulting from sintering, to impart the desired level and type of porosity and to impart adequate strength for subsequent handling. During the lecture, Students should be introduced to the issues of mixture preparation methods and the conditions for introducing slip agents and porogens.

In addition, the most important concepts connected with powder compacting should also be presented, including the phenomena occurring during compacting, the mechanism of powder compaction, the role of friction, the role of material and powder characteristics, ejection pressure, and the expansion of green compacts.

In addition, pressure and non-pressure powder compaction techniques should be discussed, e.g., methods without the application of pressure (loose powder sintering in mould, vibratory compaction, slip casting, slurry casting, and injection moulding) and methods with applied pressure (cold die compaction with single action pressing or double action pressing or floating die pressing, isostatic pressing, powder rolling, powder extrusion, and explosive compaction)

Moreover, students should be presented with powder rolling, powder forging, explosive forming, and the cost of compaction.

The lecture should also review high-temperature compaction methods: Hot Pressing, Hot Extrusion, Spark Plasma Sintering, and HIP.

In addition, the lecture should include various factors that can affect the density of green compacts. The mold design principles and presses used in powder metallurgy technology will be explained at the end of the lecture.

3. Learning outcomes

Students can use information from lectures, literature, and other sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to powder compacting in powder metallurgy techniques.

Students understand and know the most important concepts connected with powder compacting.

Also, Students know the most important phenomena occurring during the mechanism of powder compaction, the role of friction, ejection pressure, and the expansion of green compacts.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, to visualize the discussed issues.
Case study - presentation of compacting of powders techniques and their characteristics
Discussion - encouraging participants to participate in the discussion on the discussed issues actively
Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Treatise on Powder Metallurgy – C. Goetzel, vol. 1&2.
4. Powder Metallurgy Practice and Applications – R.L. Sands & C.R. Shakespeare.
5. Handbook of Powder Metallurgy – H. H. Hausner & M.Mal- 2nd Ed.

6. Additional notes

The subject of the lecture covers 3 teaching hours.

Topics 4

1. The subject of the lecture

PRINCIPLES AND PRACTICE OF SINTERING

2. Thematic scope of the lecture (abstract, maximum 500 words)

Sintering may be considered the process by which an assembly of particles, compacted under pressure or confined in a container, chemically bond themselves into a coherent body under the influence of an elevated temperature. The temperature is usually below the melting point of the major constituent. The difficulty in defining and analyzing sintering is based on the many changes within the material that may occur simultaneously or consecutively. Sintering is a complex process, and for any given metal and set of sintering conditions, there are likely to be different stages of driving forces and material transport mechanisms associated with the process.

Definitions of sintering, mechanisms of sintering, stages of sintering, driving forces of the process, and mechanisms of matter transport should be presented. In addition, the lecture should also discuss the principles of sintering single and multi-component materials, and the Lecturer should explain the phenomena occurring during sintering.

During the lecture, Students should be introduced to the issues of single and mixed-phase sintering. Methods for powders and green compacts, In particular, should concern single-phase sintering, mainly: mix powders to form alloy composites; enhanced and novel sintering – activated, liquid phase, supersolidus; microstructure variants and rules; computer simulations. In the part of the lecture on mixed-phase sintering, individual aspects of the mix powders to form alloys and composites; enhanced and novel sintering – activated, liquid phase, super solidus; microstructure variants and rules; computer simulations should be discussed.

Students should also be introduced to sintering furnaces and cycles during the lecture. In particular, it should concern heating technology - heat transfer, temperature generation, temperature measurement, batch versus continuous, furnace types, styles, cycles, microstructures, and problems. Moreover, the sintering atmospheres and practice, mainly basic reaction thermodynamics, atmosphere options, dimensional control, substrates, and supports, should be discussed. Also, the rules of sintering furnaces in air and protective atmospheres should be explained, including a discussion of the different types of protective atmospheres used in green compacts.

During the lecture, explaining the full density concepts, especially combined effects of temperature and pressure; amplified stress (effective pressure versus applied pressure); processes - yielding, plastic flow, diffusion, creep, and densification options is important.

3. Learning outcomes

Students can use information from lectures, literature, and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to the sintering of green compacts in the powder metallurgy technique.
Students understand and know the most important concepts connected with the sintering of green compacts.
Also, Students know the most important phenomena occurring during the mechanisms of sintering, stages of sintering, driving forces of the process, and mechanisms of matter transport.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, to visualize the discussed issues.
Case study - presentation of sintering of green compacts and their characteristics
Discussion - encouraging participants to participate in the discussion on the discussed issues actively
Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Handbook of Powder Metallurgy – H. H. Hausner & M.Mal- 2nd Ed.

6. Additional notes

The subject of the lecture covers 3 teaching hours.

Topics 5

1. The subject of the lecture

FINISHING TREATMENT AND APPLICATION OF COMPONENTS PREPARED BY POWDER METALLURGY TECHNOLOGY

2. Thematic scope of the lecture (abstract, maximum 500 words)

In practice, powder metallurgy components may require closer tolerances, increased mechanical properties, and less possible features by simply sintering. Most operations that accomplish these processes are performed on powder metallurgy components in the same manner as on cast or wrought components. However, porosity frequently imposes limitations on some secondary operations.

In this lecture, various types of secondary post-consolidation treatments should be described. Even though such treatments increase the cost, the process can prove economical in many cases compared to other competing technologies.

During the lecture, Students should be introduced to finishing topics, including a detailed presentation of the secondary operations and finishing, mainly steps after sintering, densification, adding value, and meeting specifications; traditional manufacturing; difficulties from pores – contaminants, cutting tool wear.

In addition, the lecture should also discuss property measurements, especially standard tests, unique tests involving porosity, mechanical properties, surface, related properties, corrosion, wear, magnetic properties, and other properties.

It is important to explain some problems about the cost, efficiency, health, safety, and quality, mainly overview process costs, component rationalization to process, feature-based decisions, material, energy, time, and other metrics, health and safety comments, and quality programs.

In addition, the lecture should also discuss the principles of sinter property testing, including porosity, microstructure, phase composition, and mechanical properties.

In addition, at the end of the lecture, the concept of obtaining composites by powder metallurgy should be explained, as well as the definition of components and their classification.

In addition, in the lecture, the Lecturer should present examples of properties, structures, and applications of various composite components produced by powder metallurgy technology.

The lecture should also discuss the process and design trends, especially overview directions, show growth examples – materials, applications, and processes; and quickly examine properties, performance, and cost.

3. Learning outcomes

Students can use information from lectures, literature, and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to the finishing treatment and application of components prepared by powder metallurgy technology.

Students understand and know the most important concepts connected to principles of sinter property testing, including porosity, microstructure, phase composition, and mechanical properties.

Also, Students know the most important phenomena occurring in obtaining composites by powder metallurgy will be explained, as well as the definition of composites and their classification.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, to visualize the discussed issues.

Case study - presentation of different types of finishing treatment and application of components prepared by powder metallurgy technology

Discussion - encouraging participants to participate in the discussion on the discussed issues actively

Quiz - conducting a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Treatise on Powder Metallurgy – C. Goetzel, vol. 1&2.
4. Powder Metallurgy Practice and Applications – R.L. Sands & C.R. Shakespeare.
5. Handbook of Powder Metallurgy – H. H. Hausner & M.Mal- 2nd Ed.

6. Additional notes

The subject of the lecture covers 3 teaching hours.

Course content – laboratory classes - project

Topics 1 – Lab 1

1. The subject of the laboratory classes

PROJECT OVERVIEW, TECHNOLOGICAL ANALYSIS, SELECTION OF TECHNOLOGICAL ALLOWANCES, SELECTION OF GREEN COMPACTS TECHNOLOGY.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the course, students, based on the knowledge gained in lectures and available literature, design the chemical and phase composition of their metallic components under the teacher's guidance. They assume the potential application site of the material and its properties, perform technological analysis, selection of technological accessories. In addition, the student will analyze phase diagrams and productivity and develop a set of design features for a particular component that will allow it to be produced easily under given production conditions.

They will then select appropriate powder materials, taking into account their source, planetary resources or recycling, and potential application area. They also look at powder metallurgy technology as a method of obtaining the component, energy consumption for its preparation, GHG emissions, etc. Another important aspect for students to consider is the management of waste generated during the processing of materials by powder metallurgy and whether the resulting component is fully or partially recyclable.

During the lab, students will work in a group, sharing tasks and jointly establishing a work plan, analyzing results, and drawing conclusions. The completed experiment will form the basis of the laboratory report.

3. Learning outcomes

Students can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to their project topic.

Students work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group.

Students will enhance their communication skills.

Students will discover their strengths and weaknesses.

4. Necessary equipment, materials, etc

- a computer with access to online article databases,

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing - reading,
Problem methods - problem-based learning, activating methods: discussion/debate
During laboratory classes, students work independently or in small groups (2-3 people) and plan the course of the experiment. They share tasks and work together to establish a work plan and try to predict the project's results.
Students prepare the final project plan and its presentation at home.

Lab course outline:
1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction: Introduce the purpose of the laboratory and discuss the importance of adequately selecting powder materials for the planned application and powder metallurgy manufacturing technology.
3 Course of the exercise:
   a) Students will be divided into teams (2-3 people).
   b) Teams develop a research plan and define all necessary activities to achieve the relevant work results. Teams define the role of each team member.
   c) The instructor continuously checks and supports the teams in developing the research plan, pointing out any shortcomings, and finally approves the correct research plan.
4 Research:
   a) Based on its knowledge and available technical literature, each team determines the component it plans to fabricate.
   b) Based on the powders currently available in the laboratory, each team proposes the chemical and phase composition of the planned components based on phase diagrams.
   c) Based on powder material specification datasheets, each team proposes a method for manufacturing the component, including homogenization, consolidation, sintering, and finishing processing.
5 Analysis of the results:
   a) Each team will present the results of their research in the form of a presentation.
   b) Teams will discuss their conclusions regarding the potential effects of different powder materials and methods for preparing components by powder metallurgy. They will ultimately propose an appropriate procedure for each of the planned components.
6 Summary:
   a) Summarizing the lab and recalling its objectives.

b) Discuss the results obtained and determine the potentially optimal materials and methods for preparing components by powder metallurgy.
c) Summarize the experience and identify possible future activities, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students, independently or in small groups, search for literature data.
Recommended literature:

- Massalski, T.B. Binary Alloy Phase Diagrams. ASM International, Metals Park., 1990
- G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997
- DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
- ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 2 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

"Binary Alloy Phase Diagrams" books will be available prior to the laboratory classes.

Topics 2 – Lab 2

1. The subject of the laboratory classes

STUDY OF PHYSICAL AND TECHNOLOGICAL PROPERTIES OF POWDERS. POWDER PROPERTIES: DETERMINATION OF BULK DENSITY AND FLOWABILITY OF METAL POWDERS. PREPARATION OF POWDER SAMPLES.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the course, students carry out projects under the supervision of a research supervisor. They use various methods to study powders' physical and technological properties, mainly determining the bulk density and particle size of metal powders.

Students learn how to measure the particle size of powders, which should be determined using a laser particle size analyzer.

Students also learn how to operate analytical programs for particle size measurement. Moreover, Students weigh appropriate amounts of powders to prepare powder green samples.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the properties of a component to the materials used and the manufacturing process for its implementation.
- They can use various methods to study powders' physical and technological properties, mainly powder properties, which determine the bulk density particle size of metal powders.
- They will be able to prepare powder samples.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.
- Students will discover their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Fritsch Analysette 22 NeXT laser particle size analyzer,
- Measuring cylinder,
- Analytical balance with accuracy of at least 0.1g,
- Computer,
- Projector,

- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test student's preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the purpose of the laboratory and discuss the importance of the appropriate selection of methods to study powder's physical and technological properties, mainly the determination of bulk density and particle size of metal powders in powder metallurgy technology.

3 Course of the exercise:

a) Students will be divided into teams (2-3 persons or independently).
b) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.
c) The instructor will constantly check and support the teams in developing the research plan, pointing out any shortcomings, and finally approving the correct research plan.

4 Research

a) After developing and approving the plan for manufacturing the component by powder metallurgy, each team proceeds to prepare and conduct tests of physical and technological parameters and receive a set of powders to test the:
    - bulk density of metal powders
    - particle size of metal powders
b) Students conduct tests of the density of metal powders using the available equipment, observe the process of measuring the particle size of metal powders, and record their observations.
c) Using the available software, students determine the parameters related to particle size, particularly the particle size distribution, and determine the parameters D_{10} and D_{50}.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding different physical and technological parameters and choose the most advantageous one that meets the assumptions for green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods for testing powders in the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students, independently or in small groups, search for literature data.

Recommended literature:

- Manual of Fritsch Analysette 22 NeXT laser particle size analyzer
- G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997
- DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
- ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 2 teaching hours.

Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 3 – Lab 3

1. The subject of the laboratory classes

POWDER HOMOGENIZATION (MIXING IN A PLANETARY MILL, MECHANICAL SYNTHESIS)

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor.

They use technologies for the homogenization mixture of the powder described in their project. Students will learn the practical basics of powder homogenization methods. Powders widely dissimilar, particularly in terms of particle size and density, poor flowability, or cohesive, are often mixed in planetary or drum-type ball mills (shaker-type powder dry mixers, the V-shaped tumble blender, planetary mill), often with some added processing agent to improve homogenization. Purity concerns (due to possible powder contamination) and hardness must be considered while selecting the materials that come into contact with the powders. In addition, the student will be able to learn about the mixing or mechanical synthesis process in a ball mill. Students should also apply various process parameters, such as the mixing time or speed, to evaluate their effect on the obtained quality of powder homogenization.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the homogenization of used powders to the materials used and the manufacturing process for its implementation.
- They will be able to use various methods of homogenization.
- They will be able to prepare powder samples.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students will discover their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Manual of Planetary Micro Mill PULVERISETTE 7 premium line
- Sieve set,
- Analytical balance with accuracy of at least 0.1g,
- Computer,
- Projector, Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the purpose of the laboratory and discuss the importance of the homogenization methods

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) After developing and approving a plan for producing a component by powder metallurgy, each team proceeds to homogenize the prepared powders using a planetary mill.
b) Students select the appropriate ratio of mixing balls to powder and select a protective atmosphere during mixing in the mill.
c) Students carry out homogenization of metal powders using the available equipment, observe the mixing process, and record their observations.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding powder homogenization in the green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods of powders homogenization in the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

- Manual of analytical laboratory balance,
- Manual of Planetary Micro Mill PULVERISETTE 7 premium line
- G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997

– DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
– ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 4 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 4 – Lab 4

1. The subject of the laboratory classes

PRESSING OF POWDERS: CALCULATION OF POWDER MASS, SELECTION OF POWDER FORMING, AND COMPACTION TECHNOLOGY

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. They use pressing technology to obtain components described in their project. The student will calculate the powder's mass considering the results of the technological analysis. In addition, the student will select the molding technology, the possible use of porogen's, and powder compaction.

They also should use various parameters of the technological process, changing, e.g., powder pressing pressure, to assess their impact on the obtained material.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the pressing of powders to manufacturing green compacts and components for its implementation.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Isostatic press and press dies,
- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the purpose of the laboratory and discuss the importance of the pressing technologies

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) After developing and approving a plan to produce a component by powder metallurgy, each team proceeds to fabricate green compacts using an isostatic press.
b) Students prepare green compacts from homogenized metal powders and select the appropriate pressing pressure to produce material of different strengths, porosity, and dimensions.
c) Students perform isostatic pressing of mixed metal powders using available equipment, observe the pressing process, and record their observations.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding powder homogenization in the green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods for pressing technologies in the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

- Manual of isostatic press,
- G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997
- DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
- ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 2 teaching hours.

Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 5 – Lab 5

1. The subject of the laboratory classes

SINTERING OF GREEN COMPACTS, SELECTION OF TEMPERATURE AND SINTERING TIME

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. They use sintering technologies to obtain components described in their project. In addition, the student will select the sintering time and temperature, considering the powders' properties. The completed experiment will be the basis for preparing the exercise report.

They also should use various parameters of the technological process, changing, e.g., time or temperature, to assess their impact on the obtained material.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the sintering of green compacts and the manufacturing of green compacts and components for their implementation.
- They will be able to use various types of sintering.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- SNOL 6.4l induction furnace,
- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the purpose of the laboratory and discuss the importance of the sintering technologies

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) After developing and approving a plan to produce a component by powder metallurgy, each team proceeds to make sintered green compacts using an induction furnace.
b) Students choose the sintering time and temperature, considering the powders' properties to produce a material with different strength, porosity, and dimensions.
c) Students carry out the sintering of green metal compacts using available equipment, observe the sintering process, and record their observations.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding powder sintering in the green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods for sintering technologies in the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

– Manual of induction furnace,
– G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997
– DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
– ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 2 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 6 – Lab 6

1. The subject of the laboratory classes

PROPERTIES OF SINTERED PRODUCTS: EFFECT OF SINTERING AND PRESSING PRESSURE ON THE PROPERTIES AND DIMENSIONS OF SINTERED PRODUCTS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. The Laboratory aims to present the student with a practical basis for assessing the quality and properties of the obtained sinters. The student will analyze the effect of sintering and pressing pressure on the properties and dimensions of sinters by measuring the mass, volume, and dimensions of the sinters obtained. The completed experiment will be the basis for preparing the exercise report.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the effect of sintering and pressing pressure on the properties and dimensions of sinters by measuring the obtained components' mass, volume, and dimensions.
- They can use various measurement methods: mass, volume, and dimensions.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Analytical weighing scale with an accuracy of at least 0.1g,
- Caliper with an accuracy of at least 0.1mm,
- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the laboratory's purpose and discuss the effect of sintering and pressing pressure on the properties and dimensions of sinters by measuring the obtained components' mass, volume, and dimensions.

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) After developing and approving a plan to produce a component by powder metallurgy, each team proceeds to analyze the effect of sintering and pressing pressure on the properties and dimensions of sinters.
b) Using available equipment, students measure the sinter by measuring mass, volume, and dimensions to evaluate the material, observe the measurement process, and note their observations.5 Results analysis:

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding green compact sintering in green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods for a measure of the obtained component's mass, volume, and dimensions in the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

– Manual of the clipper,
– Manual of analytical laboratory balance,
– G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997
– DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008

– ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 2 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 7 – Lab 7

1. The subject of the laboratory classes

METALLOGRAPHIC PREPARATION OF SINTERED MATERIALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. The Laboratory aims to present the student with the practical basics of preparing research materials. During the lab, students can work independently by selecting the appropriate grinding and/or polishing process to obtain a surface for qualitative research. For this purpose, they will use papers with appropriately selected grain.

The student will use the university infrastructure to prepare a metallographic microsection and etch the sinter. The completed experiment will be the basis for preparing the exercise report. Students will gain experience in preparing surfaces for testing - will be able to select a grinding procedure depending on the material being tested, and will operate a grinder/polisher.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the effect of preparing a metallographic microsection and etching the sinter on the surface quality for the testing.
- Depending on the material being tested, they can use a grinding procedure and will operate a grinder/polisher.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Automatic and manual grinders and polishers,
- Kit and appropriate reagent for sample digestion
- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the laboratory's purpose and discuss the effect of preparing a metallographic microsection and etching the sinter on the surface quality for the testing.

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) Each team receives its set of samples after sintering, which they grind and polish using appropriately sized sandpaper and polishing wheels (if necessary).
b) Students control the positioning of the samples and the appropriate pressure to achieve a flat surface.
c) After the grinding and polishing process is complete, each team performs etching with a chemical reagent selected appropriately for the tested metallic material.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding the metallographic preparation of samples for testing in the green powder metallurgy.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the best methods for preparing a metallographic sample and etching on the surface quality for the surface testing in the powder metallurgy method
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

– P. G. Ormandy, An Introduction to Metallurgical Laboratory Techniques, Pergamon, 1968
– G. S. Upadhyaya, Powder Metallurgy Technology Cambridge Int Science Publishing, 1997

– DeGarmo, E. P. Materials and Processes in Manufacturing (10th ed.). Wiley, 2008
ASM Handbook Vol. 7: Powder Metal Technologies and Applications, ASM International/Warrendale (1998)

7. Additional notes

The subject of the lecture covers 4 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 8 – Lab 8

1. The subject of the laboratory classes

TESTING OF SINTERED MATERIALS - SEM AND OM MICROSCOPIC EXAMINATIONS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Using the university's infrastructure, the student will measure the surface of metallographic specimens.

Laboratory exercises aim to acquaint students with surface quality testing using microscopic methods (OM and SEM) - getting to know the device's software, preparation of the stand, and proper placement of samples.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the effect of preparing components on the microstructure.
- Describe the material's composition and processing influence on the components' microstructure.
- Appreciate the challenges and limitations of optical and scanning microscopy.
- Analyze and interpret the results of experiments to conclude the microstructure of the obtained materials.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Optic Microscopy
- Scanning Electron Microscopy
- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the laboratory's purpose and discuss the effect of composition and processing on the microstructure of components.

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) Each team receives its set of samples as metallographic specimens (after polishing and etching in chemical reagents), which Students will individually analyze using a scanning electron microscope and optical microscope. Students will compare the capabilities and benefits of imaging.
b) Students will individually analyze images obtained in secondary and backscattered electrons.
c) Students will measure chemical composition in selected points and areas.
d) Students will individually analyze images obtained on their samples using an optical microscope using bright and dark fields and phase contrast.

5 Results analysis:

a) Each team will present the results of their research in the form of a presentation.
b) The teams will discuss their conclusions regarding the results obtained, their correctness, and meaning.

6 Summary:

c) Summarizing the lab and recalling its objectives.
d) Discussing the results obtained and determining the microstructure of components prepared by the powder metallurgy method.
e) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

- Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013

- Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001
- Anwar Ul-Hamid, A Beginners' Guide to Scanning Electron Microscopy, Springer Nature Switzerland AG 2018

7. Additional notes

The subject of the lecture covers 4 teaching hours.
Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 9 – Lab 9

1. The subject of the laboratory classes

TESTING OF SINTERED MATERIALS - XRD, POROSIMETER, MICROHARDNESS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor. The laboratory aims to present the student with practical physical and mechanical properties research knowledge. The student will perform selected XRD experiments to carry out the structural analysis of nanomaterials. To analyze the basic mechanical properties, the student will conduct microhardness tests. However, to assess the porosity, the Student will perform analyses based on the results from stereometrics and experiment on a porosimeter. The completed experiment will be the basis for preparing the exercise report.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present a theoretical background for their project.

Students will be able to:

- Relate the effect of preparing components on the XRD, porosimeter, and microhardness.
- Describe the influence of the composition and processing of the material on the phase composition, porosity, and microhardness of the components.
- Appreciate the challenges and limitations of XRD, porosimeter, and microhardness tester.
- Analyze and interpret the results of experiments to conclude the XRD, porosimeter, and microhardness of the obtained materials.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Philips X'Pert XRD diffractometer,
- Porosimeter,
- Mitutoyo Microhardness tester,
- Computer,
- Projector,Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory class outline:

1. Knowledge test: A quiz to test students' preparation for laboratory exercises based on the information provided during the lecture.

2. Introduction: Introduce the laboratory's purpose and discuss the effect of the components' phase composition, porosity, and microhardness.

3 Course of the exercise:

a) Laboratory classes are carried out using specialist research equipment and specialized software.
b) During laboratory classes, students in small groups plan the course of the experiment and perform it on their own
c) Students will be divided into teams (2-3 persons or independently).
d) Teams will develop a research plan and define all necessary activities to achieve appropriate work results. Teams will define the role of each team member.

4 Research

a) Each team receives its set of samples as metallographic specimens (after polishing and etching in chemical reagents), which Students will individually analyze using XRD, porosimeter, and microhardness. Students will compare the possibilities and benefits of such measurements.
b) Students analyze the phase composition based on the obtained X-ray diffractograms of their samples,
c) Students analyze the degree of porosity of their samples using a porosimeter
d) Students analyze the microhardness of their samples

5 Results analysis:

f) Each team will present the results of their research in the form of a presentation.
g) The teams will discuss their conclusions regarding the results obtained, their correctness, and meaning.

6 Summary:

a) Summarizing the lab and recalling its objectives.
b) Discussing the results obtained and determining the phase composition, porosity, and microhardness of components prepared by the powder metallurgy method.
c) Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

– B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, Pearson Education Limited 2014

- P. KlobesPorosity and Specific Surface Area Measurements for Solid Materials U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, 2006
- K. Herrmann, Hardness Testing: Principles and Applications, ASM International, 2011

7. Additional notes

The subject of the lecture covers 6 teaching hours.

Students are obliged to prepare a theoretical background as the introduction part of the laboratory report.

8. Optional information

Exercise manuals and equipment manuals will be available prior to the laboratory classes.

Topics 10 – Lab 10

1. The subject of the laboratory classes

FINAL EXERCISES: PRESENTATION OF RESULTS, DEBATE, TEST

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the classes, students carry out their projects under the supervision of a tutor.
The Laboratory aims to present the results of the project. The student will present the results of his research. In addition, based on the results obtained from the presentation, a debate among students will be held.
The final stage will be passing by the Student written test of knowledge from the Powder Metallurgy laboratory.

3. Learning outcomes

Students can work in a group, sharing tasks and working together to establish a work plan, predict the results, and draw conclusions. They can prepare and present the results of the project.
Students will be able to:

- Relate the analysis of the effect of technology on the properties of components.
- Describe the influence of the composition and processing on the properties of the final components.
- Appreciate the challenges and limitations of tested methods
- Analyze and interpret the results of experiments to conclude the properties of the obtained materials.
- Present the results of their research understandably and transparently in written form and oral presentation.
- Work in a group and independently.
- Students will enhance their communication skills.

Students know their strengths and weaknesses.

4. Necessary equipment, materials, etc

- Computer,
- Projector,
- Blackboard.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Students will be able to:

- present the results of their research understandably and transparently in written form and oral presentation
- work in a group and independently.

Students will enhance their communication skills.

Students will discover their strengths and weaknesses.

Summarizing the lab and recalling its objectives.

Discussing the results obtained of components prepared by the powder metallurgy method.

Summarize the experience and identify possible future activities, including further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

literature related to their project

7. Additional notes

The subject of the laboratory classes covers 2 teaching hours.

8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MODERN METALLIC MATERIALS FOR SUSTAINABLE INDUSTRY

Code: MMMSI

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

METALLIC MATERIALS: INTRODUCTION AND FUNDAMENTALS

2. Thematic scope of the lecture (abstract, maximum 500 words)

A comprehensive and in-depth introduction to the structure and diverse properties of metallic materials will be presented during the lectures. The primary focus of the lecture will be centred on investigating the multifaceted realm of metallic bonds and their profound influence on shaping the fundamental properties exhibited by these commonly used materials. By exploring this interesting topic, Students will gain insights into the interatomic forces that govern the behaviour of metallic elements and compounds, unravelling the secrets behind their exceptional strength, ductility, and electrical conductivity.

In addition to elucidating metallic bonds, this discourse will also examine the fundamental crystal structure types that define the essence of metallic materials. Students will be able to understand the basic crystal lattice types and their influence on the mechanical properties at the heart of the most prevalent groups of metals. Students will be introduced to solid solutions, intermetallic phases, and the conditions governing their creation. Moreover, the lecture will expound upon the intricacies of basic alloy types, delving into the amalgamation of different metallic elements and their remarkable ability to alter the properties of the resulting material. From enhancing strength to bestowing corrosion resistance, alloys have played an indispensable role in transforming the possibilities of engineering and manufacturing. Furthermore, the conditions for successfully creating these alloyed wonders will be meticulously outlined, granting attendees a profound understanding of the intricate processes involved in achieving the desired material characteristics.

3. Learning outcomes

Students understand and know the basic terminology related to metals and their structure.
Students will gain basic knowledge about the basic structure of metallic materials.
Students will know the mechanism of metallic bond creation and their influence on basic metals properties (like transport properties and mechanic properties).
Students will be able to recognise basic crystal structures of metallic materials and will understand the basic alloy types (like solid solution, interstitial alloys and intermetallic phases).

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture, discussion**

a. Lecture conducted with the use of multimedia
b. Discussion and brainstorming

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Fundamentals of the Theory of Metals* by A. A. Abrikosov, Dover Publications Inc. 2017, ISBN: 9780486819013;
2. *Metals and Alloys: Industrial Applications* by M. A. Benvenuto, De Gruyter, 2016, https://doi.org/10.1515/9783110441857;

6. Additional notes

The subject of the lecture covers 2 teaching hours.

Topics 2

1. The subject of the lecture

STEEL AND ITS VARIOUS TYPES FOR ADVANCED APPLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to provide a thorough understanding of steel and its various types. The lecture will be focussed on how steel is used in advanced industries and its contributions to sustainability. Steel is a mixture of iron, carbon, and other alloying elements, known for its strength, versatility, and recyclability. It has been used for a long time and remains crucial in sustainable industries like construction, transportation, energy, and manufacturing.

Throughout the lecture, Students will be introduced to various aspects of steel. The lecture will explore carbon steels, which have specific properties like strength and hardness due to their carbon content. During the lecture, basic concepts of seel formation will be provided. The Fe-C phase diagram will be studied in detail, and the basic types of steel microstructures will be introduced and discussed. The lecture will also be focused on alloy steels, where different elements come together to provide steel-improved qualities such as higher tensile strength, better resistance to wear, and good thermal conductivity. The analysis of the role of alloying elements, like chromium, manganese, and nickel, in shaping steel's properties will be provided. Chromium, for example, provides corrosion resistance, manganese adds toughness, and nickel enhances thermal stability. Students will delve into the classification of steel based on its chemical composition, microstructure, and mechanical properties (carbon steels, alloy steels, stainless steels, and advanced high-strength steels, among others). The focus will be on understanding each type's unique characteristics and suitability for different advanced applications. The lecture will showcase the extensive use of steel in advanced industries. Students will explore how different types of steel contribute to sustainability in sectors such as automotive manufacturing, aerospace engineering, renewable energy, infrastructure development, and sustainable construction. Case studies and examples of innovative steel applications will be presented to highlight the role of steel in achieving sustainable industry objectives. Moreover, the lecture will consider steel's significance in sustainability efforts. Its inherent properties, long lifespan, and recyclability make it valuable for responsible resource management and environmental conservation. Basic steel manufacturing techniques will be introduced, and the methods to shape steel properties will be provided. A crucial aspect of steel's sustainability is its recyclability. The lecture will delve into the recycling process of steel and its environmental benefits, including reduced energy consumption and greenhouse gas emissions. The lecture will also focus on emerging technologies and practices that aim to enhance the sustainability of steel production. Students will explore topics such as energy-efficient steelmaking processes, carbon capture and utilisation techniques, and the use of alternative feedstocks.

3. Learning outcomes

Students understand and know the basic terminology related to steel and their manufacturing technology.

Students will understand the influence of carbon content on the steel microstructure and properties.

Students will know the various seel types and could propose specific steel types for selected applications.

Students will know the influence of selected alloying elements on the steel properties and know basic steel manufacturing methods.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture, discussion**

a. Lecture conducted with the use of multimedia
b. Discussion and brainstorming

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Basic Concepts of Iron and Steel Making* by S. K. Dutta and Y. B. Chokshi, Springer Nature Singapore, 2020, ISBN: 9789811524363;
2. *Introduction to Steels: Processing, Properties, and Applications* by P.C. Angelo, B. Ravisankar, Springer Nature Singapore, 2020, ISBN: 9780367731045;
3. *Steels: Microstructure and Properties, 4th Edition* by H. Bhadeshia, R. Honeycombe, Butterworth-Heinemann, 2017, ISBN: 9780081002704;

6. Additional notes

The subject of the lecture covers 2 teaching hours.

Topics 3

1. The subject of the lecture

ALUMINIUM ALLOYS FOR AUTOMOTIVE AND AEROSPACE APPLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lectures central objective is to give students a comprehensive understanding of aluminium alloys and their significance within the automotive and aerospace sectors. A particular emphasis will be placed on their contribution to sustainable practices in these industries. The advent of aluminium alloys has wrought a transformative impact on both sectors, attributed to their extraordinary attributes, notably their lightweight nature and remarkable properties. Such attributes have facilitated manufacturing process advancements and sparked a revolution in the quest for sustainable solutions. The lecture will provide an overview of aluminium alloys' properties, characteristics, and advantages. The lecture will focus on understanding the influence of alloying elements and their effects on the properties of aluminium alloys. The strategic incorporation of alloying elements, such as silicon (Si), magnesium (Mg), or lithium (Li), has played a crucial role in amplifying the potential applications of aluminium alloys. The impact of weight reduction on greenhouse gas emissions and overall sustainability in transportation will be discussed. High-strength aluminium alloys stand at the forefront of this development, representing a significant leap in material engineering. As industries seek to enhance the efficiency and performance of their products, the demand for lightweight yet robust materials has intensified. High-strength aluminium alloys provide an optimal solution, offering a delicate balance between weight reduction and mechanical strength. These alloys have extensive applications in aerospace, automotive, and transportation industries, where their adoption has increased fuel efficiency, higher load-bearing capacities, and improved structural integrity. Corrosion-resistant alloys have also emerged as a formidable response to the challenge posed by environmental degradation. Exposure to harsh atmospheric conditions, moisture, and chemical environments necessitates the development of alloys that can withstand the corrosive forces encountered in various applications. These alloys demonstrate exceptional corrosion resistance, prolonging the lifespan of critical components and structures. Industries such as marine, petrochemical, and infrastructure have reaped the benefits of corrosion-resistant alloys, witnessing reduced maintenance costs and enhanced durability. Simultaneously, alloys engineered with enhanced heat resistance have opened new frontiers in industries with elevated temperature environments. The demand for materials capable of withstanding extreme temperatures, thermal shocks, and prolonged exposure to heat has driven researchers to explore innovative alloy compositions and processing techniques. These advanced alloys find applications in gas turbines, jet engines, nuclear reactors, and industrial furnaces, where they serve as the backbone of reliable and efficient operations. The lecture will also provide knowledge regarding the processing techniques to optimise the properties of aluminium alloys. Advanced techniques such as rapid solidification, severe plastic deformation, and powder metallurgy have emerged as transformative methodologies for achieving refined microstructures and enhanced mechanical characteristics. These techniques boost the performance of aluminium alloys and facilitate more efficient material usage and waste reduction.

3. Learning outcomes

Students understand and know the basic terminology related to aluminium alloys and their manufacturing technology.
Students know the properties of aluminium alloys and their beneficial influence on the aerospace and automotive industry.
Students will know the various aluminium alloy types and could propose specific alloy types for selected applications.
Students will know the influence of selected alloying elements on the aluminium alloys properties and know basic manufacturing methods.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture, discussion**

a. Lecture conducted with the use of multimedia
b. Discussion and brainstorming

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *The Complete Technology Book On Aluminium And Aluminium Products* Edited by NPCS Board of Consultants & Engineers, NIIR Project Consultancy Services, 2007, ISBN: 9788178330150;
2. *Aluminum Alloys: For Transportation, Packaging, Aerospace and other Aplication* by S.K. Das and W.Yin, Wiley, 2010, ISBN: 978-0873396622;
3. *Aluminum Alloys: Preparation, Properties, and Applications* by E.L. Persson, Nova Science, 2011, ISBN: 9781611223118;

6. Additional notes

The subject of the lecture covers 2 teaching hours.

Topics 4

1. The subject of the lecture

HIGH-ENTROPY ALLOYS AS A NEW CONCEPT FOR THE PRODUCTION OF NOVEL ALLOYS FOR VARIOUS APPLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

The main focus of the lecture will be on high-entropy alloys (HEA) and their properties and applications. These special alloys comprise five or more elements mixed together in almost equal amounts. This unique combination leads to the creation of solid solutions with extraordinary properties. HEAs represent a whole new way of designing alloys, offering exciting possibilities to achieve better mechanical, physical, and functional qualities. What makes them even more appealing is their potential to reduce the negative impact on the environment compared to traditional alloy production methods. By mixing multiple elements in nearly equal proportions, materials with exceptional strength, hardness, and even resistance to wear and corrosion can be created. This opens up doors for applications in various industries, from aerospace to electronics, where high-performance materials are highly sought after. Furthermore, HEAs offer a more sustainable alternative to alloy production. Traditional methods often require much energy and resources, increasing environmental pollution. However, HEAs can potentially reduce such negative effects by using less energy and producing less waste during manufacturing. This makes them an attractive option for industries striving to become more eco-friendly. During the lecture, students will be introduced to the concept of entropy and its role in creating novel alloy compositions. Further, the analysis of the benefits of multicomponent alloying in terms of properties and sustainability will be discussed. The lecture will focus on the strategies employed in designing high-entropy alloys (HEAs) with specific desired properties. Students will explore the methods used to carefully select suitable elements and their precise compositions tailored to meet the requirements of targeted applications. Additionally, the lecture will investigate the critical process of evaluating how the alloying elements impact the microstructure and overall performance of HEAs. This lecture will comprehensively assess the sustainability aspects associated with high-entropy alloy (HEA) production. The focus will be on evaluating each approach's environmental, economic, and social implications. When analysing the environmental impact, it is crucial to consider resource consumption and waste generation during manufacturing. Conventional alloy production often entails extensive energy usage and raw material extraction, leading to a significant carbon footprint and depletion of natural resources. In contrast, HEA production has the potential to mitigate these adverse effects by employing a more streamlined process that requires fewer raw materials and consumes less energy. As a result, the environmental burden of HEA production might be notably reduced. Economically, HEA production offers promising advantages. Due to its unique composition and exceptional properties, HEAs may enable the design of high-performance materials with enhanced longevity and reduced maintenance requirements. These factors can lead to cost savings in the long run, making HEAs economically appealing, particularly in industries where efficiency and durability are critical. HEA production is still a developing field, and its scalability and applicability to various industries need further exploration.

3. Learning outcomes

Students understand and know the basic terminology related to high-entropy alloys and their manufacturing technology.
Students know the concept of entropy and high-entropy alloys. Students understand the influence of high entropy on basic alloy properties.
Students can provide benefits of the high-entropy alloys on the current industrial applications.
Students can provide examples of selected high entropy alloys and suggest their applications.
Students can provide high entropy alloys for selected applications.
Students know basic manufacturing methods of high entropy alloys.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture, discussion**

a. Lecture conducted with the use of multimedia
b. Discussion and brainstorming

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *High-Entropy Alloys: Fundamentals and Applications* Edited by J.-W. Yeh, M. C. Gao, P. K. Liaw, Y. Zhang, Springer International Publishing, 2016, ISBN:9783319270135;
2. *Structure and Properties of High-Entropy Alloys* by V. E. Gromov , S. V. Konovalov , Yu. F. Ivanov , K. A. Osintsev, Springer, 2021, ISBN: 978-3-030-78363-1;
3. *High-Entropy Alloys, 2nd Edition* by B.S. Murty, Jien-Wei Yeh, S. Ranganathan, P. P. Bhattacharjee, Elsevier, 2019, ISBN: 9780128160671

6. Additional notes

The subject of the lecture covers 2 teaching hours.

Topics 5

1. The subject of the lecture

SHAPE MEMORY METALS FOR VARIOUS APPLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

The primary objective of this lecture is to provide students with a comprehensive understanding of shape memory metals and their versatile applications in the sustainable industry. Shape memory metals are a special group of materials known for their unique ability to "remember" their original shape and effortlessly return to it after being bent or deformed. This fascinating property has captured significant attention, making these materials extremely valuable in various industries seeking sustainable solutions. Sometimes shape memory materials are called intelligent materials due to their ability to react to external stimuli such as temperature, magnetic field or stress. The lecture will examine the diverse applications of shape memory metals in the context of sustainability. These materials have shown promise in areas such as energy-efficient buildings, eco-friendly transportation, and renewable energy technologies. Their capacity to respond to changing conditions with shape recovery makes them ideal candidates for various smart and adaptive systems, reducing waste and conserving resources. The lecture will commence with an overview of shape memory metals, including their characteristics, properties, and underlying mechanisms. Students will gain insights into martensitic transformation and the thermomechanical behaviour that enables the shape memory effect. Students will be introduced to various shape memory materials focusing on NiTi shape memory alloys due to their most common applications. The lecture will introduce sustainable manufacturing processes involving shape memory metals. Students will explore environmentally friendly techniques such as additive manufacturing (3D printing), which allows for precise and resource-efficient production of complex shapes, minimising waste and optimising material usage. The lecture will also emphasise the importance of recycling and reusing shape memory metals to reduce environmental impact. The lecture will highlight the role of shape memory metals in advancing sustainable transportation. Students will discover how these materials are employed in the aerospace industry, where lightweight shape memory alloys contribute to fuel efficiency and reduce emissions. Furthermore, the lecture will discuss shape memory alloy actuators used in automotive applications to enhance fuel economy and improve safety through active control systems. Shape memory metals have found extensive applications in the medical field, contributing to sustainable healthcare practices. Students will explore how shape memory alloys are used in orthopaedic implants, stents, and surgical instruments, providing minimally invasive and long-lasting solutions. The lecture will emphasise the importance of biocompatibility, durability, and the recyclability of shape memory materials in the medical sector.

3. Learning outcomes

Students understand and know the basic terminology related to shape memory alloys and their manufacturing technology.
Students know the concept of shape memory effects and related phenomena.
Students understand the influence of martensitic transformation and the alloys structures on the shape memory effects.
Students can provide benefits of the shape memory alloys on the current industrial applications with a focus on sustainability.
Students can provide examples of shape memory alloys and suggest their applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing and problem methods - **informative lecture, monographic lecture, description, problem-based lecture, conversational lecture, discussion**

a. Lecture conducted with the use of multimedia
b. Discussion and brainstorming

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Shape Memory Alloys: Manufacture, Properties and Applications* by H. R. Chen, Nova Science Publishers, 2010, ISBN: 9781607417897;
2. *Shape Memory Alloys* by M. Fremond and S. Miyazaki, Springer Vienna, 2014, ISBN: 9783709143483;

6. Additional notes

The subject of the lecture covers 2 teaching hours.

Course content – laboratory classes - project

Topics 1 – Lab 1

1. The subject of the laboratory classes

METALLIC MATERIALS: INTRODUCTION AND FUNDAMENTALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During laboratory classes, students, based on the knowledge obtained during the lectures and the available literature, will analyse the basic crystal structures of the selected metallic materials. Based on the crystal structure model, Students will discuss the differences and similarities between cubic close-packed and hexagonal close-packed structures and the stacking sequences. Further, Students will analyse the octahedral and tetrahedral voids present in the crystal structure and discuss what influences the metals properties that may have. The next activity will focus on analysing the crystal structure of some common metallic materials and intermetallic phases. Based on the provided models, the defect structure of the metallic materials will be discussed. Students will practise the recognition and proper description (e.g. Burgers vector) of defects in the crystal lattice. Students will also analyse the selected phase diagram and discuss what are the proposed properties of the various alloys phases. Based on the phase diagrams, phase contribution and phase composition will be calculated. Further, Students will analyse phase transitions that occur in the provided binary systems. The last part of the classes will focus on applying TEM to analyse the structure of alloys with precipitates and their defect structure. Based on the performed observations and analysed models, the discussion regarding real crystal structure and its influence on materials properties will be performed.

3. Learning outcomes

Students understand and can use in practice the basic terminology related to metals and their structure. Students will gain basic knowledge about the basic structure of metallic materials. Students will be able to practically recognise the basic crystal structures of metallic materials and intermetallic phases. Students can recognise and describe defects of crystal structure. Students can interpret microstructure images recorded using TEM. Students understand the concept of phase diagrams and can calculate basic information about selected binary systems. Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. They can prepare and present a theoretical background for their project.

4. Necessary equipment, materials, etc

- basic crystal structures models of metallic materials and intermetallic phases,
- models of defects in the crystal lattice of metallic materials,
- phase diagrams of selected binary systems,
- Transmission Electron Microscope (TEM),
- various metallic samples for TEM observations.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialised software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyse the results and draw conclusions.

Students present their project plan and laboratory reports independently or in small groups;

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Lectures of the MMMSI*
2. *Fundamentals of the Theory of Metals* by A. A. Abrikosov, Dover Publications Inc. 2017, ISBN: 9780486819013;
3. *Metals and Alloys: Industrial Applications* by M. A. Benvenuto, De Gruyter, 2016, https://doi.org/10.1515/9783110441857;

7. Additional notes

The subject of the lecture covers 4 teaching hours.

8. Optional information

Topics 2 – Lab 2

1. The subject of the laboratory classes

STEEL AND ITS VARIOUS TYPES FOR ADVANCED APPLICATIONS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

These laboratory classes aim to thoroughly understand steel and its structure, microstructure, different types and basic properties. During laboratory classes, students will discuss the steel structures and the influence of carbon on the microstructure. Fe-C phase diagram will be studied, and observed phases and phase transitions will be discussed. Further, Students work will be focused on the practical aspect of the characterisation of the microstructure of selected steel types after selected thermomechanical processing. Students will prepare metallographic specimens themselves from various steel types and observe the microstructure using light microscopy. The grinding, polishing and etching process of the metallic samples will be presented, and Students will independently prepare the selected steel samples for further microscopic observations. Further, during the classes, Students will observe and record images of the resulting microstructures. Based on the performed observations, they will discuss the microstructures within themselves and discuss the predicted materials properties. In the final stage of the laboratory classes, students will observe, using optical microscopes, the microstructures of selected steel types. They will learn how to recognise the steel type based on the performed observations.

3. Learning outcomes

Students understand and can use in practice the basic terminology related to steel and their structure. Students will gain basic knowledge about the basic microstructures of steel. Students will be able to practically recognise the basic steel microstructures based on optical microscopy observations. Students will understand the influence of carbon content on the steel microstructure and properties. Students will be able to prepare the metallographic specimens by themselves. Students will be able to perform optical microscopy observations by themselves.

Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. They can prepare and present a theoretical background for their project.

4. Necessary equipment, materials, etc

- optical microscopes,
- metallographic sample in preparation tools – grinding/polishing machines, set of sand papers, polishing cloths and etching ingredients,
- various steel samples for metallographic specimen preparation,
- various steel types in the form of metallographic specimens for optical microscopy observations.
- a computer connected to the optical microscopes to record observed images.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialised software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyse the results and draw conclusions.

Students present their project plan and laboratory reports independently or in small groups;

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Lectures of the MMMSI*
2. *Basic Concepts of Iron and Steel Making* by S. K. Dutta and Y. B. Chokshi, Springer Nature Singapore, 2020, ISBN: 9789811524363;
3. *Introduction to Steels: Processing, Properties, and Applications* by P.C. Angelo, B. Ravisankar, Springer Nature Singapore, 2020, ISBN: 9780367731045;
4. *Steels: Microstructure and Properties, 4th Edition* by H. Bhadeshia, R. Honeycombe, Butterworth-Heinemann, 2017, ISBN: 9780081002704;

7. Additional notes

The subject of the lecture covers 5 teaching hours.

8. Optional information

Topics 3 – Lab 3

1. The subject of the laboratory classes

ALUMINUM ALLOYS - MICROSTRUCTURE AND SELECTED MECHANICAL PROPERTIES

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

This laboratory classes central objective is to give students a comprehensive understanding of aluminium alloys structure and properties and their indispensable significance within the automotive and aerospace sectors. During the laboratory classes, students will be tasked with analysing the microstructure of the proposed aluminium alloys (for example Al-Si alloys) using light microscopy and scanning electron microscopy. Based on this, students will investigate the Al-Si phase diagram and will try to predict the possible microstructure of the final Al-Si alloys. Based on the performed observations, students will determine the microstructure of the selected Al-Si alloys and compare the observations with the theoretical predictions performed based on the studied phase diagrams. Students will analyse the relative phase composition and the size distribution of silicon phase hardening precipitates. Further, during the classes, students will determine the hardness of the alloy using Vickers (micro)hardness tests and compare the results with the observed microstructure.

3. Learning outcomes

Students understand and can use in practice the basic terminology related to aluminium alloys and their structure.

Students will gain basic knowledge about the basic microstructures of aluminium alloys. Students will understand the influence of silicon content on the Al-Si alloys microstructure and properties. Students will be able to analyse, using SEM, the metallographic specimens by themselves. Students will be able to perform relative phase composition and determine the size distribution of precipitates based on the recorded SEM images. Students will be able to perform Vickers (micro)hardness tests and understand the influence of the precipitates on the measured (micro)hardness.

Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. They can prepare and present a theoretical background for their project.

4. Necessary equipment, materials, etc

- optical microscopes,
- Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy detector(EDS),
- a computer with particle analysis software (like ImageJ),
- aluminium alloys samples for optical and scanning electron microscopy observations,
- Vickers (micro)hardness tester.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialised software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyse the results and draw conclusions.

Students present their project plan and laboratory reports independently or in small groups;

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Lectures of the MMMSI*
2. *The Complete Technology Book On Aluminium And Aluminium Products* Edited by NPCS Board of Consultants & Engineers, NIIR Project Consultancy Services, 2007, ISBN: 9788178330150;
3. *Aluminum Alloys: For Transportation, Packaging, Aerospace and other Aplication* by S.K. Das and W.Yin, Wiley, 2010, ISBN: 978-0873396622;
4. *Aluminum Alloys: Preparation, Properties, and Applications* by E.L. Persson, Nova Science, 2011, ISBN: 9781611223118;

7. Additional notes

The subject of the laboratory classes covers 5 teaching hours

8. Optional information

Topics 4 – Lab 4

1. The subject of the laboratory classes

HIGH-ENTROPY ALLOYS - PRODUCTION AND CHARACTERISATION

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The main focus of the laboratory classes will be on high-entropy alloys (HEA) and their properties and applications. These special alloys comprise five or more elements mixed together in almost equal amounts. This unique combination leads to the creation of solid solutions with extraordinary properties. HEAs represent a whole new way of designing alloys, offering exciting possibilities to achieve better mechanical, physical, and functional qualities.

During the laboratory classes, students will be tasked with preparing selected high-entropy alloy and characterising its microstructure. This task will be conducted in the form of a teamwork project. Each group of students will choose its own chemical composition of the alloy (from proposed chemical elements). Students will prepare weightings of the selected alloy from elemental powders and will prepare green compacts using a laboratory press. The next step will be alloy manufacturing using the vacuum arc melting technique performed after the classes by a tutor or technical worker. The last part of the assignment will be metallographic sample preparation and microstructure characterisation using light microscopy and scanning electron microscopy. Students will prepare a report based on their work, present it to other groups, discuss the obtained results, and compare them to the results of other groups.

3. Learning outcomes

Students understand and can use in practice the basic terminology related to high entropy alloys and their structure. Students will gain basic knowledge about the basic microstructures of high entropy alloys. Students will be able to calculate the weightings of the selected alloy from elemental powders. Students will be able to prepare green compacts from selected powders using a laboratory press. Students will be able to analyse and interpret SEM images of the microstructures.

Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. They can prepare and present a theoretical background for their project.

4. Necessary equipment, materials, etc

- laboratory balance,
- powders of selected chemical elements,
- laboratory press,
- vacuum arc-melting furnace,
- metallographic sample preparation tools and consumables,
- optical microscope,

- Scanning Electron Microscope (SEM) with an Energy Dispersive X-ray Spectroscopy detector(EDS),

5.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialised software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyse the results and draw conclusions.

Students present their project plan and laboratory reports independently or in small groups;

6.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

1. *Lectures of the MMMSI*
2. *High-Entropy Alloys: Fundamentals and Applications* Edited by J.-W. Yeh, M. C. Gao, P. K. Liaw, Y. Zhang, Springer International Publishing, 2016, ISBN:9783319270135;
3. *Structure and Properties of High-Entropy Alloys* by V. E. Gromov , S. V. Konovalov , Yu. F. Ivanov , K. A. Osintsev, Springer, 2021, ISBN: 978-3-030-78363-1;
4. *High-Entropy Alloys, 2nd Edition* by B.S. Murty, Jien-Wei Yeh, S. Ranganathan, P. P. Bhattacharjee, Elsevier, 2019, ISBN: 9780128160671

7.	**Additional notes**

The subject of the laboratory classes covers 10 teaching hours

8.	**Optional information**

Topics 5 – Lab 5

1. The subject of the laboratory classes

SHAPE MEMORY METALS

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The primary objective of these laboratory classes is to provide students with a comprehensive understanding of shape memory metals and their versatile applications in the sustainable industry. Shape memory metals are a special group of materials known for their unique ability to "remember" their original shape and effortlessly return to it after being bent or deformed. During the laboratory classes, students will be tasked with analysing the microstructure of the proposed shape memory material (for example Nitinol) and determining the characteristic temperatures of the martensitic transformation using DSC (Differential Scanning Calorimetry) method. The martensitic transformation is essential to the presence of the shape memory effects, and the characteristic temperatures govern the possible application of obtained alloys. The range of the martensitic transformation characteristic temperatures can be tailored by the variation of chemical composition of fourther thermomechanical treatment of the alloys. The crucial task before the application is the characterisation of the characteristic temperatures. The DSC method is very convenient in such experiments due to its fast and reliable analysis. In the las part of the laboratory classes, Students will also be involved in the induction of a two-way shape memory effect by thermos-mechanical cycling. Students will be provided with Nitinol wires, and by repeated thermomechanical cycling (liquid nitrogen bath →, bending of the wire→heating the wire in boiling water), two shape memory effect can be achieved.

3. Learning outcomes

Students understand and can use in practice the basic terminology related to shape memory effects and alloys. Students will gain basic knowledge about the basic microstructures of Nitinol. Students will be able to analyse and DSC measurement results. Students will be able to determine characteristic phase transition temperatures based on the DSC measurements. Students are able to induction of a two-way shape memory effect by thermos-mechanical cycling of nitinol wire.

Students are able to work in a group, sharing tasks and working together to establish a work plan, predict the results and draw conclusions. They can prepare and present a theoretical background for their project.

4. Necessary equipment, materials, etc

- Differential Scanning Calorimetry system (DSC),
- Nitinol wires,
- Dewar with liquid nitrogen,
- Boiling water,

- pliers,
- protection gloves and glasses.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

assimilation methods/providing - **reading**,
problem methods **- problem-based learning, activating methods: discussion/debate**
a set of practical methods - **laboratory exercise/experiment; observation**

a. Laboratory classes are carried out with the use of specialist research equipment and specialised software.
b. During laboratory classes, students in a small group plan the course of the experiment and perform it on their own.
c. During laboratory classes, students work in a group, sharing tasks and working together to establish a work plan, analyse the results and draw conclusions.

Students present their project plan and laboratory reports independently or in small groups;

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. *Lectures of the MMMSI*
2. *Shape Memory Alloys: Manufacture, Properties and Applications* by H. R. Chen, Nova Science Publishers, 2010, ISBN: 9781607417897;
3. *Shape Memory Alloys* by M. Fremond and S. Miyazaki, Springer Vienna, 2014, ISBN: 9783709143483;

7. Additional notes

The subject of the laboratory classes covers 6 teaching hours.

8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MODERN KNOWLEDGE ABOUT POLYMERS

Code: MKP

Course content – lecture

Topics 1

1. The subject of the lecture

General characteristics of polymer materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

Today, life on Earth is not possible without polymer and biopolymer materials. They form the basis for the development of areas such as construction, the automotive industry, food production, the manufacture of medicines and protective components or implants. Starting with the first attempts by the German chemist Simon, who isolated styrene (1839), through to nitrocellulose obtained by Alfred Nobel (1868) and phenol-formaldehyde resins synthesised by L.H. Baekeland (1909), the plastics industry developed. It allowed the production of new types of polymeric materials, with characteristic properties that form the basis for the preparation of the classification we use. At the same time, there are a number of basic characteristics attributed to this group of materials, allowing them to be distinguished among the basic material groups. The lecture aims to introduce basic information and terminology typical for polymeric materials. Classification criteria will be stressed and basic types of polymers will be presented with core properties typical for each group. Groups will be distinguished according to their origin, such as natural polymers (called biopolymers), synthetic polymers and modified polymers. Another criterion for the division is the chemical structure (polymers with homo- and heterogeneous chains), the physical structure (thermoplastic polymers, thermosets, chemosets (duroplastics) or the rheological properties (elastomers, plastomers including thermoplastics and duroplastics). The term plastic will be introduced as a term commonly used and associated with the modification of the properties of the basic component of the mass by the introduction (usually dispersion) of specific substances, known as additives or auxiliaries. This group includes: fillers, carriers, stabilisers, softeners (plasticisers), antioxidants, photo-stabilisers, dyes, pigments, counter-statics, flame retardants, flame retardants, flame retardants (porophores). The basic functions and purpose of these additives will be discussed. Recommendations of the International Union of Pure and Applied Chemistry (IUPAC) for the correct nomenclature of polymeric materials will be presented, as well as the customary nomenclature used in polymeric materials chemistry and processing technology. Students will be introduced to the symbolism of the abbreviations used, as well as to recycling designations. In the active discussion with the students examples of everyday items will be pointed out to familiarise them with the typical properties and behaviour of each group. The elementary discussion about international signs and code belonging to the most common material will also be included.

3. Learning outcomes

Student will gether the basic properties characterictic to polymeric materials and will be eligible to distinguish them from the other engeneering materials. They will also be equipped with the ability to find the identification information based on the codes provided by the manufacturers. Moreover, they are able to properly name the common polymeric materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a traditional interactive board along with the use of multimedia. During the lecture, different items (e.g. different polymer granules) will be shown to present physical forms and their diversities. The topic will be realized within 2 h of classes.

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning general characteristics of polymer materials with examples in the fields like automotive, biomedical applications, building

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560

6. Additional notes

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Topics 2

1. The subject of the lecture

Structure of polymer materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

For understanding the knowledge of polymer materials it is crucial to be aware of the inner structure of the material. Depending on the layer of organization various factors influence on the macroscopic behavior of the polymers. Hence in the lecture the information about molecular structure and its influence on materials properties will be presented. Gradual stages of ordering starting from composition of the macromolecule, its mer structure will be described. The basis for the preparation of polymers are monomers, hence the conditions that a chemical compound must fulfil to act as a monomer (valence, thermodynamic, kinetic conditions) will be discussed. The change of the meric unit occurring during the reaction will be discussed. Monomers undergo polymerisation reactions, thus the basic mechanisms of the polymerisation process will be discussed (chain polymerisation, polycondensation, polyaddition) with assignment of groups of polymeric materials obtained according to the mentioned mechanisms. Depending on the type and number of constitutional units, it is possible to obtain homopolymeric systems (for 1 type unit) or mulitipolymeric systems (for 2 or more units). Their basic types, i.e. co-, ter- and caterpolymeric systems will be discussed. The manner and order of coupling of the meric units affect the macroscopic properties of the material hence the concepts of statistical, block, alternating copolymers will be introduced. These properties are also influenced by the presence of oligomeric fractions, which are transition compounds in the processes of addition and step polymerisation.
In terms of first-order structure (configuration), the covalent bond-fixed conformation of the polymer chain is considered. It leads to a tactical configuration associated with a head-to-tail, head-to-head, tail-to-tail meringue sequence. In addition, the presence of an unsaturated double bond in the main chain leads to cis-tactic and trans-tactic configurations. Often used mono-substituted olefins belong to the prochiral monomers, and thus, as a result of the polymerisation reaction, chiral centers are generated, which are the reason for the formation of spherical isomerism. It results in the appearance of atactic, isotactic and syndiotactic configurations. The tacticity of the chain influences the properties of the polymer material, such as the ability to form a crystalline phase, static strength and density. In terms of the second-order structure (conformation), the mobile shaping of the polymer chain that takes place solely by rotating the individual bonds in the main chain, but without affecting the angles between the bonds, is considered. There are six conformational forms of polymer chains (conformers): upright chain, globular form (cluster), rectal form (zigzag), foliated form (lamellar), helical form (helical), and cyclic form. Their formation depends on the energy of intra- and intermolecular interactions, as well as the energy barriers of rotation around the covalent bond, and whole segments. In terms of the III-order structure (aggregation), we are referring to the fixed interconnection of multiple macromolecules into complex spatial structures. Third- to fourth-order structures include clusters of polymers forming apparent

cells, randomly entangled macromolecules forming spaghetti structures, fringed micelles, lamellar lamellar structures, superhelical structures.

3. Learning outcomes

Student understand and can describe the influence of othe basic molecular composition of macromolecules on properties of polymer. Moreover, he / she provides rational explanation of the crystallinity of polymeric material with its origin. He / she can prove the relationship between molecular ordering of the macrochain and its macroproperties.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a traditional interactive board along with the use of multimedia. During the lecture, discussion with the participants will be conducted to engage them into the subject. The topic will be realized within 2 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning inner structure of polymer materials with

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, "Polymer chemistry" Springer-Verlag (Berlin), 2017, ISBN: 9783662492772

6. Additional notes

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Topics 3

1. The subject of the lecture

The thermo-mechanical behavior aspect

2. Thematic scope of the lecture (abstract, maximum 500 words)

Amorphous polymers can be in one of three physical states, i.e. glassy (brittle), elastic or plastic (liquid). Each physical state of the polymer is characterized by a specific way in which the sample deforms under an applied force. In the glassy state, the sample undergoes irreversible deformation, in the elastic state, elastic-type deformation is observed, and in the plastic state, plastic-type deformation is observed above the flow temperature. The transitions of a polymer from one state to another are II-type transitions and occur at a specific temperature characteristic of the polymer. The brittleness temperature (Tk - transition temperature from the brittle glassy state to the glassy state with forced elasticity), the glass transition temperature (Tg - transition temperature from the glassy to the elastic state), the flow temperature (Tf - transition temperature from the elastic to the plastic state) will be discussed. Specifically for crystalline polymers, instead of the flowing temperature Tf, the melting temperature (Tm - temperature at which the last crystal melts, as crystal melting occurs over a certain time interval) is determined. The physical and mechanical properties of amorphous polymers are largely determined by the degree of confinement of the molecular motions of the macromolecules relative to each other. Between the glass transition temperature Tg and the melting temperature Tm in the elastic state, segmental motions occur, involving the mutual displacement of macromolecules relative to each other. Below the glass transition temperature, amorphous polymers are compact, hard and brittle, as in the glassy state all macromolecules remain fixed in position relative to each other. Polymers with a high degree of crystallinity are robust and mechanically resistant. Semicrystalline polymers with a low degree of crystallinity below the melting point are stiff and rather brittle. Above the glass transition temperature (Tg, elastic state), the polymer becomes transparent, and flexible. Within the scope of the lecture, the concept of free volume according to Fox and Flory's theory will be addressed. The melting process takes place within a certain temperature range dependent on factors such as degree of crystallinity, size of crystallites, content of defects in the crystal lattice, ordering of macromolecules, molar mass of the polymer, heating rate, superheating (related to the rate of heat transfer into the polymer mass), ability to recrystallize crystallites.

The changes of material properties in course heating or cooling will be explained in reference to the both molecular level and macroscopic one. During the transition from the glassy to the plastic state, large step changes in certain physical and mechanical properties are observed, such as specific volume (v), coefficient of thermal expansion (α), specific heat (cp), thermal conductivity (λ), Young's modulus (In G), diffusion coefficient (D), electrical permeability (ε), tangent of dielectric loss angle (tg δ), and refractive index. Industry standard methods for the determination of Tg include measurements of softening point, hardness point, hardness, modulus of elasticity, mechanical dynamic properties, differential thermal analysis and inversion chromatography.

3. Learning outcomes

Student can point the effect of temperature impact on polymer material with understanding phenomena occurring within the heat flow through the sample. He / she understand short / long term thermal exposure impact and is able to point proper technique to detect the changes. The student is capable to perform simple analysis of the thermal changes occurring in polymeric material.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a interactive board supported with the use of multimedia. During the lecture simple experiment will be taken to picture the feature described in theoretical part. Also discussion with the participants will be encouraged to support the remembering process. The topic will be realized within 2 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning thermo-mechanical behavior aspect

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Charles E. Carraher, "Polymer chemistry", CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388

6. Additional notes

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Topics 4

1. The subject of the lecture

Ageing and stabilisation

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the lecture the focus will be pointed at stability of polymer material in various aspects. During processing and use, polymers are subjected to physical factors such as mechanical stress, temperature, solar radiation, ultrasound, electrical discharges, ionising radiation. As a result of these interactions, the chemical and physical structure of polymers undergoes destructive changes, leading to degradation, a decrease in molar mass as a result of chain scission and the formation of macromolecules of shorter length, crosslinking as a result of recombination of free macroradicals, the formation of branched structures, changes in the number and position of bonds, and cyclization processes. These reactions proceed simultaneously, often independently of each other. The physical effects are usually accompanied by chemical effects, e.g. oxidation of the polymer if the reactions were carried out in an environment containing air. Polymer ageing is the breakdown of polymers and plastics under the influence of the sum of all the chemical and physical factors that interact with them during use and storage. Polymers with a saturated structure (e.g. vinyl polymers) are more resistant to ageing processes than polymers containing double bonds in the main chain (unsaturated polymers, polydienes). The thermostability of polymers depends primarily on their chemical and molecular structure, i.e. the type of atoms present in the molecule: C, F, Cl, O, S, the type of interatomic bonds present in the molecule: C-C, C=C, C=C, the presence of specific chemical groups, e.g. - Cl, - OH, -COOH, the type of aromatic and heterocyclic rings present in the main chain, the type of intermolecular bonds: hydrogen, ionic, ionic, metallic, - CO - Cl, - OH, -COOH, type of aromatic and heterocyclic rings present in the main chain, intermolecular bonds: hydrogenous, ionic, metallic, linear, branched, cross-linked, stereoregular structure. The higher the dissociation energy of the interatomic bonds, the higher the thermostability of the polymer. The thermochemical decomposition temperature is determined by the lowest value of the dissociation energy of the interatomic bonds in the polymer chain. Thermal stability (thermostability) is determined by the temperature at which the test sample begins to undergo thermochemical decomposition. The thermochemical decomposition temperature is defined as the temperature at which the first signs of chemical decomposition (thermodissociation) begin to be observed. The stability of the material is also affected by its susceptibility to thermal depolymerisation, which is a chain radical process. This is particularly true for polymers containing two substituents, R1 and R2, at one carbon atom in the main chain. Stability at the use stage is also determined by flammability, i.e. the rapid thermal oxidation of polymers with high heat release and weight loss. Materials are characterised in this respect by their oxygen index (LOI), a measure of the polymers' flammability. The basic mechanism observed during aging will be described in relation to core groups of polymers. The process aimed at withdrawing or slowing down aging namely stabilisation will be presented with basic groups of stabiliser description like flame retardants (flame retardants), photostabilisers, antioxidants, antiozonants.

3. Learning outcomes

Student can provide information about aging process of polymers with proper identification of crucial factors responsible for obtaining stable system both internal like structural one, presence of additives and external one like the environmental condition of usage of material. She / he is capable to discuss basic paths of degradation with prediction of its influence on macroscopic properties.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realised with a board supported with the use of multimedia. During the lecture reference to own experience of the students will be recall to strengthen the understanding of the presented material. The topic will be realised within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning ageing and stabilisation

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560

6. Additional notes

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Topics 5

1. The subject of the lecture

Degradation and recycling opportunities

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the lecture degradation process will be presented with description of the main mechanisms. The possible paths of materials disruption will be discussed pointing its undesired side (instability of the materials' properties) but also desired one. Degradation (decomposition) of polymers occurs under the influence of a number of physical, chemical and biological factors: increased temperature (thermodegradation), the presence of air (oxygen) (thermo-oxidative degradation), sunlight (UVvis radiation) (photodegradation), ionising radiation (y-rays, X-rays, electrons) (radiation degradation), mechanical forces (rolling, grinding, stress) (mechanodegradation), ultrasound (ultrasonic degradation), oxygen (molecular, atomic, singlet oxygen), ozone (oxidative degradation), water, acids, bases (hydrolytic degradation), corrosive agents (acids, alkalis, strong oxidisers, chemical compounds) (corrosive degradation), atmospheric agents (wind, rain, snow, frost, smog) (atmospheric degradation), biological agents (bacteria, enzymes, fungi) (biodegradation). The term degradation encompasses both processes that result in a decrease in molar mass and processes that result in crosslinking, or the formation of branched structures. The general mechanism of radical decomposition of polymers is the same for different physical agents, but the mechanisms of its initiation vary depending on the degradation triggers. Individual bonds in a macromolecule can dissociate into free radicals when sufficient energy is supplied to them in the form of heat, electromagnetic radiation, ionising radiation or mechanical stress in excess of the critical binding energy, known as the bond dissociation energy (Ed). Knowledge of these values is also the basis for the production of materials with a programmed degradation pathway (biodegradable materials), which have found applications in medicine.

Knowing the inevitable perspective of materials degradation the main recycling pathways will be disussed. The strategies of materials collection, sorting and recovery in respect to material, social and economic aspects will be proposed. Plastic materials can be recycled in a variety of ways and the ease of recycling varies among polymer type, package design, and product type. Thermoplastic is a class of polymer, which can be easily melted or softened by providing heat in order to recycle the material. Therefore, these polymers are generally produced in one step and then converted into the required article at a subsequent process. Unlike thermoplastics, thermosetting plastics have strong cross-linked structure that shows resistance to higher temperature, which provides greater thermal stability. Therefore, these materials cannot be recycled, remolded, or reformed upon heating. Recycling of plastics should be carried in such a manner to minimize the pollution during the process and as a result to enhance the efficiency of the process and conserve the energy. Plastics recycling technologies have been historically divided into four general types: primary, secondary, tertiary, and quaternary. Primary recycling involves processing of a waste/scrap into a product with characteristics similar to those of original product. Secondary recycling involves processing of waste/scrap plastics into materials that have characteristics different from those of original plastics product. Tertiary recycling involves the production of basic chemicals and fuels from plastics waste/scrap as part of the municipal waste stream or as a segregated waste. Quaternary recycling retrieves the energy content of waste/scrap plastics by burning/incineration

3. Learning outcomes

Student can identify the degradation process and its accompanying processes with basic prediction of changes in properties of material. He / she is aware of the impact of the environmental factors on the (in)stability of the polymer material. Moreover, the student knows basic recycling paths with awareness of their prons and cons.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realised with a board supported with the use of multimedia. During the lecture, discussion with the participants will be conducted to engage them into the subject. The topic will be realised within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning degradation and recycling opportunities

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, “Polymer chemistry” Springer-Verlag (Berlin), 2017, ISBN: 9783662492772

6. Additional notes

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Topics 6

1. The subject of the lecture

Market assessment - technical developments and new developments in plastics

2. Thematic scope of the lecture (abstract, maximum 500 words)

The final lecture will provide insight into economic outlook to polymeric material. The information will be presented on the life cycle of a polymeric material in a closed loop economy. In respect to this information the current image of plastics will be deliberated with both positive and negative perspective. Examples of successful strategies for reusing plastics will be presented, but also risks and unresolved issues will be discussed with cautious proposals for their overcoming. Most of our knowledge is around plastic waste in the marine environment, although there is research that indicates that plastic waste in landfill and in badly managed recycling systems could be having an impact, mainly from the chemicals contained in plastic. In the marine environment, the most well documented impacts are entanglement and ingestion by wildlife. One of the most concerning is the impact of chemicals associated with plastic waste. There are several chemicals within plastic material itself that have been added to give it certain properties such as Bisphenol A, phthalates, and flame retardants. These all have known negative effects on human and animal health, mainly affecting the endocrine system. There are also toxic monomers, which have been linked to cancer and reproductive problems. The actual role of plastic waste in causing these health impacts is uncertain. This is partly because it is not clear what level of exposure is caused by plastic waste, and partly because the mechanisms by which the chemicals from plastic may have an impact on humans and animals are not fully established. The most likely pathway is through ingestion, after which chemicals could bioaccumulate up the food chain, meaning that those at the top could be exposed to greater levels of chemicals. Two key economic drivers influence the viability of thermoplastics recycling. These are the price of the recycled polymer compared with virgin polymer and the cost of recycling compared with alternative forms of acceptable disposal. There are additional issues associated with variations in the quantity and quality of supply compared with virgin plastics. Lack of information about the availability of recycled plastics, its quality, and suitability for specific applications can also act as a disincentive to use recycled material. Historically, the primary methods of waste disposal have been by landfill or incineration. Costs of landfill vary considerably among regions according to the underlying geology and land-use patterns and can influence the viability of recycling as an alternative disposal route. High disposal costs are an economic incentive towards either recycling or energy recovery. As the quality of recovered plastic is typically lower than that of virgin plastics, the price of virgin plastic sets the ceiling for prices of recovered plastic. Hence, although higher oil prices also increase the cost of collection and reprocessing to some extent, recycling has become relatively more financially attractive. Technological advances in recycling can improve the economics in two main ways - by decreasing the cost of recycling and by closing the gap between the value of recycled resin and virgin resin.

3. Learning outcomes

Student is capable to point threats and opportunities provided by the use of plastic material. He / she is aware of the environmental issues as well as technological capabilities to recycle or reuse plastics. The student knows and understand the idea of closed loop economy.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realised with a board supported with the use of multimedia. During the lecture with the use of personal equipment like smartphones various recycling strategies will be sought in situ to attract students' attention to the issue. The topic will be realised within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning market assessment - technical developments and new developments in plastics

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their friends.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Charles E. Carraher, "Polymer chemistry", CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388

6. Additional notes

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Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

Characteristic of polymers by flame analysis

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Laboratory topics are related to basic polymer identification methods. For the analysis different types of polymeric materials will be taken. Environmental regulations require the labelling of plastic products with plastic products with internationally standardized symbols. These symbols allow the material to be identified. If the product is not marked, an attempt can be made to determine the type of plastic by means of a combustion test or sensitivity to selected reagents. The analysis of polymers differs significantly from the typical analysis of organic compounds. This is due to their characteristic physical properties such as high molecular weight, polydispersity, varying degrees of crystallinity, varying degrees of branching, etc. The type of plastic is important from recycling point of view but also from practical one as e.g. it determines the choice of solvent, glue or varnish that can be used. The basic analysis involves observing changes in the behavior of the material when exposed to a flame with detection of changes in color and consistency, presence of bubbles, odor, flame quenching, combustion residues. The test is valid for pure polymers only as the presence of additives may false the results. In addition, a density-based test will be carried out with water and a salt solution of a certain concentration as a reference subjected to flame analysis, which is a basic, simple but still instructive technique for the initial characterization. Finally, after completion the informative part of the classes the students will receive comoditive materials sample (e.g. PVC glove, PA strip, PS food container) and are asked to identify its main polymeric component. The studied samples shall be formed with one of the previously identified materials.

3. Learning outcomes

The student is aware of the variety of polymeric materials characterised by distinct properties that can be used for identification purposes. He/she is able to identify the basic techniques of differentiation together with the criteria for division.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with a fume hood to remove fumes and smoke generated by the experiment. No special advanced device is used during the test. The exercise takes place in laboratory equipped with a distilled water supply and personal protective equipment.

Necessary materials

Materials for the classes involves:

- polymers samples in a pure form (composite are not convenient for the analysis),
- chemical compounds like sodium chloride, calcium chloride, distilled water as solvent,
- chemical laboratory burner,
- copper wire for Beilstein test,
- laboratory glass items e.g. beakers, spatulas, glass rod, gas burner, test tubes, test tube holder.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of identification of polymer materials in regards to recycling issues, material selection.
   - Discuss the stages of experiment with description of required calculations, principle of burner operation, safety rules reminder.
3. The course of the exercise:
   - Students will be divided into working teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a set of samples and prepare the solution needed for the immersion test.
   - Students start with the immersion test in water.
   - Students control place the samples one by one in the test vial trying to sink it; test is repeated at least 3 times for 3 different pieces of the same sample. The students observe behaviour and make notes.
   - They repeat immersion test in the saline solution – they observe behaviour of the samples and make notes.
   - The next step involves flame analysis – student train how to use properly and safe flame burner.
   - The sample are ignited with the flame – the students observe their behaviour, smell carefully characteristic smell.
   - For PVC – the Balstein test with the copper wire is performed by placing the piece of sample on the wire and burning it with the flame.

- Finally, the teams are granted with commercial sample of unknown material and do the analysis of it.

5. Results analysis:
    - Each team will present the results of their research in the form of a short presentation.
    - Teams will draw the conclusion and discuss them regarding the identification of the samples.
    - Teams will define what is the main component of the unknown sample.
6. Summary:
    - Summary of the laboratory given by the teacher and a reminder of its goals.
    - Discussion of the results obtained and confirmation of the identity of all samples including commercial ones.
    - Summary of experience and determination of possible future actions, including any further research.
    - Critical evaluation of suitability and complexity of the method.
    - Enlisting content of the report.
    - Question and answer session regarding practical aspects of identification of polymeric materials.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:
- Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560
- Identifying the thermoplastics and thermosetting plastics by flame test (free online source: https://www.youtube.com/watch?v=asHNidtj6dc (access: May, 25th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point)

8. Optional information

Exercise manuals will be available prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topic: plastic, additives, flammability of polymeric materials, toxicity of polymeric materials, solubility of polymeric materials, density of polymeric materials.

Topics 2

1. The subject of the laboratory classes

Testing of polymers from natural products (thermoplastic starch material)

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Within the classes the material of natural origin will be modified and reprocessed. There are two types of polymers: synthetic and natural. Synthetic polymers are derived from petroleum oil, and made by scientists and engineers. Natural polymers occur in nature and can be extracted, they are often water-based. Examples of naturally occurring polymers are silk, wool, DNA, cellulose and proteins or rubber. Rubber can also be synthesized technologically by polymerization of a variety of monomers, like isoprene. The diversity in terms of provenance and composition provides the natural polymers with distinct physicochemical and biological properties that can be of interest in various application fields. In fact, natural polymers and their derivatives already find application in numerous sectors, e.g., in the manufacture of paper goods and textiles, as additives in food products, in the formulation of nutraceuticals and functional foods, and in the biomedical field (e.g., in cosmetic treatments and drug delivery). Owing to the natural abundance, renewability, and intrinsically negative carbon foot-print of polymers derived from renewable resources, their exploitation is favorable and can play a pivotal role in the development of advanced materials in the shape of films, membranes , coatings, hydrogels, and micro- and nanoparticle systems. Over the last two decades, the movement towards greener and more sustainable practices has gained momentum, and much interest has been devoted to the exploitation of naturally abundant feedstocks that can be accessed without competing with natural food supplies, as a path to reducing the massive consumption of fossil resources, associated with reserve depletion and environmental concerns.

The polysacharide namely starch will be utilized to form thermoplastic usable material. The students will use material of different origin (exemplary potato starch, corn starch) to check impact of this parameter on the final material's properties. The synthetic procedure involves several stages with heating, acidic hydrolysis and mixing with chosen plasticiser. The product is sticky, gel-like substance that can be spread into film forming layer. In terms of application such material is protective packaging material. This open the discussion about thin polymer packaging materials and their effectiveness and environmental impact.

3. Learning outcomes

The student knows the methodology of processing materials of natural origin and their transformation into film form. He / she is also able to describe physical and chemical phenomena accompanying such transformation. Additionally, he / she is aware of the importance of application of packaging materials but also their long-term impact in terms of the environmental issues.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with heating bath station with controlled temperature, a fume hood to remove fumes generated by the experiment. The pH meter is used during the classes to control the pH of the solution. Also weighting balance is used. The exercise takes place in laboratory equipped with a distilled water supply and personal protective equipment.

Materials for the classes involves:

- portion of polysacharide (starch of various origin),
- chemical compounds like distilled water, hydrochloric acid, NaOH, iodine,
- laboratory items e.g. beaker, wash bottle, pipette, pump, burette, steam heating, indicator paper, pliers, knife, tubes, tongs

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of natural products as a source of polymers for practical usage.
   - Discuss the principle of acidic hydrolysis and the stages of process performing. Instruction of the usage of pH meter.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives portion of starch of different origin and prepare the solution of starch gruel with dictated concentration needed for the following stages.
   - The starch gruel is gently heated for 15 minutes, than the portion of 1 mL of 1.0 M acidic acid is added to start the hydrolysis of the starch chains. The process can be controlled by the sample testing with iodine test.
   - The glycerol portion is added into the solution to plastify the material. Several different volume ratios of starch vs glycerol will be tested to trace their impact on the final material.
   - After cooling down the gel like product is spreaded on the flat (e.g. aluminum foil) surface and left to dry.

5. Results analysis:
   - Each team will present the results of their research in the form of a short presentation.
   - Teams will draw the conclusion regarding the process of material of natural origin usage and their processing (hydrolysis) for properties improvement.
   - Teams will draw the conclusion and discuss role of plasticiser and its content.
   - Teams will define basic properties of the final film.

6. Summary:
   - Summary of the laboratory given by the teacher and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the role of material of natural origin as the source of polymeric materials.
   - Summary of experience and determination of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of material of natural origin as the source of polymeric materials.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, “Polymer chemistry” Springer-Verlag (Berlin), 2017, ISBN: 9783662492772

- Development of edible film from different starch materials (free online source: https://www.youtube.com/watch?v=5TlOpUDrUN8, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

Co-funded by the European Union

8. Optional information

Exercise manuals will be available prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topic: natural polymers, starch, hydrolysis, sedimentation, decantation, molar concentration, dilution solution pH

Topics 3

1. The subject of the laboratory classes

Specific surface area determination for polymer by BET method

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the laboratory classes the student will perform physisorption studies of nitrogen molecules on the surface of chosen polymer materials. The surface area of a solid is defined as the external and the accessible internal pore surfaces. It is widely used to characterise materials for adsorption, catalysis and reactions on surfaces, as its value represents the number of potential active sites. The surface area is estimated using the Brunauer, Emmett & Teller (BET) equation, from a specific region of a gas adsorption isotherm where monolayers of adsorbate are considered to take place. The gas adsorption isotherm is obtained in the sequence: successive doses of an adsorptive gas probe, typically N_2 at 77 K, are sent to the solid material, preliminarily dried and evacuated. The amount of gas molecules that can adsorb onto the surface of the solid is derived from the evolution of the pressure in the system. The cumulative amount of adsorbate plotted with respect to the pressure is the adsorption isotherm. The samples can be either solid state cubes or powder materials. It is advisable to find the information of the range of expected surface area as the mass of the sample dependent on this parameter. The methodology of the Brunauer–Emmett–Teller theory is applied for the recorded isotherm within the linear part of the data to calculate the specific surface area (SSA) parameter. Prior to the measurement the materials will be degassed to remove adsorbed impurities. The temperature program is dependent on the type of the sample and is established for each sample separately. Collected data will serve as source data for the BET isotherm construction and subsequent specific surface area calculation. This parameter is useful for assessing the surface area available for heterogeneous processes or for functionalization.

3. Learning outcomes

The student has awareness of the importance of extension of surface area of the polymeric materials in particular for the one that work in the heterogenous reaction / phenomena. He / she has also knowledge about the process that are responsible for surface coverage or impurification.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with degassing station with controlled temperature and nitrogen supply, and precise weighting balance. The exercise takes place in laboratory supplied with a personal protective equipment.

Materials for the classes involves:
- polymer sample of either powder or bulk solid polymeric materials,

- highly advanced porosimeter for the proper measurements,
- small laboratory items like scissors, papers, washing solvents (isopropanol)
- glass tubes with rubber corks
- glass funnel with long leg (to pour the material correctly)

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of determination of specific surface area for polymer
   - Discuss the scope of operation and presentation of porosimeter operation, sample preparation instruction, weighting and degassing procedure.
   - Short introduction to BET methodology
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives 1 sample of known chemical composition. Based on the internet resource they determine the optimal degassing parameters and discuss them with the teacher.
   - Students prepare the sample in 3 stages: stage 1 – weighting with precision balance, stage 2 – degassing according to previously determined procedure, stage 3 – weighting after degassing with precision balance
   - Students prepare carefully the container with liquid nitrogen 30 min prior to the measurement. Afterwards, they install properly reference tube to measure p_0 parameter required for the measurement.
   - In the next step student perform tha sample analysis with parameter precisely discussed with the teacher.
   - On completing the measurement, the sample is gently remove, weighted and washed.
5. Results analysis:
   - Each team will present the results of their research in the form of a presentation.

- Teams will discuss their conclusions regarding the value of measured surface area for different samples. Also correlation factor and C valued are to be discussed.
- By knowing the materials character they classify them into low, average or high area type.

6. Summary:

- Summary of the laboratory given by the teacher and a reminder of its goals.
- Discussion of the results obtained and recall of the obtained values.
- Summary of experience and determination of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
- Enlisting content of the report.
- Question and answer session regarding practical aspects of specific surface area determination by BET method.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Charles E. Carraher, “Polymer chemistry”, CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388

- BET Adsorption Isotherm (free online source: https://www.youtube.com/watch?v=3j7qJCv6D_o (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:

the initial test prior to the exercise - 1 point,

team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:

- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topic: porosity determination, surface analysis, adsorption, desorption, specific surface area

Topics 4

1. The subject of the laboratory classes

Study on the swelling phenomenon of gelatine in water

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The objective of the exercise is to determine the isoelectric point of gelatine in aqueous solution based on the dependence of the degree of swelling (P) on the pH of the tested solutions. The gel swelling degree (P) relates to the mass of water absorbed by the gelatine over mass of dry gel. A minimum value of P indicates maximum spatial cross-linking of the structure of the gelatine.

The swelling process is related to an increase in the volume of a gel or solid connected with the uptake of a liquid. The absorption leads to changes in the mechanical properties of the swollen material and may create extra pressure when it occurs in confined spaces, which results in various deformations of the swollen material. The process may significantly alter adsorption - desorption properties of adsorbates. In terms of polymer dissolution, swelling is the first step of the interaction between liquid molecules and polymeric network, which is followed by solvation of polymer chains. The immersion of cross-linked polymers in solvents does not lead to their dissolution because of their chemically bonded hydrocarbon chains; nonetheless, these links do not prevent cross-linked polymers from swelling. Polymer swelling can be analysed by the Flory-Rehner equation which shows how the swelling is related to the molecular weight (MWt) of chains between crosslinks - with larger values allowing more swelling. In the experiment several buffer solutions will be prepared for sorption studies of protein namely gelatin at ambient temperature. In this experiment, the measure of swelling will be the amount of water absorbed by the gelatine in a given time. The results are to be discussed in relation to the swelling ability and solubility of polymeric materials.

3. Learning outcomes

The students has a knowledge of the sorption ability of polymeric material that influence on dimension and chemo – physical stability of the polymeric material. He / she is also aware of the phenomes that occur during dissolution of polymeric materials as well as within the washing in the environmental condition.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with a weighting balance. No special advanced device is used during the test. The classes takes place in laboratory equipped with a distilled water supply and personal protective equipment.

Materials for the classes involves:

- chemical substances for analysis and solution preparation e.g. CH_3COOH, CH_3COONa, food gelatine in flakes, distilled water

- small laboratory items like conical flasks, Petri dishes, funnel, dipstick, tweezers, filter paper, pipettes, weighting balance, stopwatch.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
    - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
    - Presentation of the purpose of the laboratory and discussion of the importance of swelling phenomenon of polymers in water.
    - Discuss the stages of experiment with description of required calculations and familiarization with the pH-meter.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team receives a set of samples and starts with preparing buffers solutions (6 pieces) in conical flasks (50 cm3). The components are acetic acid and sodium acetate.
    - The proper volume ratios (10:1 to 1:1) will be provided to obtain different buffer power.
    - Portion of gelatin will be weighted before and after the sorption step.
    - The weighted portion are immersed in sorption solutions for 5 minutes at ambient temperature. During the sorption all samples shall be immersed completely. The swelling time must be the same for all samples as the process is not brought to a steady state. Therefore in this experiment, the measure of swelling will be the amount of water absorbed by the gelatine in a given time
    - After 5 minutes, separate the solution from the swollen gelatine by transferring of the entire contents of the flask onto filter paper placed in a funnel and drain the solution. Using tweezers, place a sheet of swollen gelatine on dry filter paper in a petri dish and drain gently. Subsequently, weigh the dried gelatin flake in a tightly wrapped strip of foil. It is necessary to do it correctly as unbound water on the gelatine prevents accurate weighing.
    - The masses will be used to calculate the gel swelling degree (P) as the ratio of the mass of water absorbed by the gelatine over mass of dry gel.
5. Results analysis:

- Each team will present the results of their research in the form of a short presentation.
- Teams will discuss their conclusions regarding the swelling degree of the studied samples.
- The students will evaluate the cross linking degree of the samples based on the calculated gel swelling degree.

6. Summary:

- Summary of the laboratory and a reminder of its goals.
- Discussion of the results obtained and determination of the gel swelling degree and cross-linking degree.
- Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
- Enlisting content of the report.
- Question and answer session regarding practical aspects of swelling phenomenon of polymers in water.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560

- Lecture 82 - Swelling of polymers (free online source: https://www.youtube.com/watch?v=VWJiqzz2coU, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:

the initial test prior to the exercise - 1 point,

team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:

- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior tot he laboratory classes.
The scope of the issues for the colloquium involves the following topic: swelling phenomena, kinetic of swelling, linera vs branched polymer, plasticisation, viscosity, chain elasticity, chain streaching, swelling capacity, isoelectric point of peptide, solubility.

Topics 5

1. The subject of the laboratory classes

Analysis of optical properties of polymeric materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the study the optical properties will be traced by determination of the UV attenuation ability of transparent hydrogel and silicone hydrogel materials. As these are two main classes of modern contactological material with different oxygen transmittance both types will be tested by using commercial available materials. Also volunteer students can bring their own materials for testing. Prior to the measurement the lens will be conditioned in saline solution (preferably with concentration of 0.9%) and placed in an UVvis cuvette equipped with specially designed holder that allows to place center of the lens in the path of the radiation. The optical power of lenses is not uniform on their surface so to assure that each material is similarly tested in the same place the system is constructed. The holder can be printed with 3D printer to adjust its size to the dimensions of the cuvette. The spectrum shall be recorded shortly after rinsing the lens as the material starts to dehydrate immediately after taking it from the container. At least 3 spectra should be recorded to assure repeatability of the results. Quantitative information on the degree of protection for eye is to be provided by calculating the protective factor, a parameter established on the basis of the transmittance value recorded in the UV vis spectrophotometric analysis. The results are the starting point for the discussion concerning transparency and its lost for polymeric material influenced by the environmental factors.

3. Learning outcomes

The student knows the structure – related processes that induce changes in optical properties of polymeric material. He / she can provide information about techniques available for measuring optical properties

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with a distilled water supply and personal protective equipment.

Materials for the classes involves:

- polymer samples e.g. hydrogel (Hy) and silicone hydrogel (Sil - Hy) contact lenses, polycarbonate-based lenses materials, poly(methyl methacrylate)
- chemical substances for analysis and solution preparation e.g. distilled water, saline solution,
- small laboratory items quartz cuvette, beaker, forceps, lens mounting kit, pipette
- UV vis spectrophotometer for spectra collection

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of testing of optical properties of polymeric materials.
   - Discuss the stages of test procedure and familiarization with the UVvis spectrophotometer.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a set of 2 commercial samples and start with enlisting core properties delivered by manufacturer including name of material and water content. In the internet the students find the information about group of the material ensured by FDA.
   - The student start laboratory work with preparing saline solution and rinsing lenses with it to clean it.
   - Immediately after rinsing the lenses are transmitted into UVvis cuvette equipped with holder that allows to place center of the lense in the path of the radiation
   - The device record the spectrum within broad wavelength range (190 – 800 nm).
   - The activities are repeated for the second lens.
5. Results analysis:
   - Each team will present the results of their research in the form of a short presentation.
   - Teams will discuss their conclusions regarding the edges of absorption of radiation for studied material and for different lenses of the same type. They categorize the lenses into protective or non-protective group.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the results obtained and determination the factors influencing on optical properties of contactologic polymeric materials.

- Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
- Enlisting content of the report.
- Question and answer session regarding practical aspects of optical properties of polymeric materials.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, “Polymer chemistry” Springer-Verlag (Berlin), 2017, ISBN: 9783662492772

- Materials Science - Optical Properties (free online source: https://www.youtube.com/watch?v=B5LsyDxEnWQ&list=PLbbp5l0464cM40CulmE-l3dIV4ykTFn7g, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:

the initial test prior to the exercise - 1 point,

team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:

- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior tot he laboratory classes.

The scope of the issues for the colloquium involves the following topic: hydrogel / silicone-hydrogel contact materials, absorption of UV radiation, ranges of UV radiation, impact of UV radiation on the polymer material, polymer degradation, transmittance / absorbance, protection factor (PF)

Topics 6

1. The subject of the laboratory classes

Elastic recovery of the polymer sample

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the work the mechanical response of the material will be tested. Viscous properties of polymeric materials and their experimental determination have become an important area of research in the field of materials science. Elastic recovery in polymeric materials is a cooperative phenomenon where individual polymer molecules undergoing retraction must interact with one another in order to generate recovery. The extend of interest is brought by increasing use of polymers in products of wide range of industrial applications like e.g. gaskets. In the experiment the polymer samples of cylindrical shape will be squeezed with mechanical force to predefined value and then the load will be released. Such program is used to obtain the information about possibility of elastic recover of the samples. Within the loading – unloading cycles the stress – strain curve will be recorded that allow to determine the content of the energy saved and restored in the sample and the one dispersed within the cycle. The energy dispersion within the polymer matrix depends on the type of macromolecules, their flexibility, mutual entanglement or cross-linking density. More flexible and less stiffened system is more prone to disperse the impact of the energy then the brittle one. Additionally, introduction of additive into classic thermoplastic material change its behavior that will be traced in the experiment. The sample set should include materials that exhibit different behaviour to allow different responses to be observed. The information obtained will be discussed in terms of the flexibility of the polymer network and its ability to regenerate. The issues of degradation and ageing of materials will also be presented.

3. Learning outcomes

The students understand the idea of construction of internals structure of polymer matrix and the influence of the mechanical (un)loading on the chains mobility and stretching. He / she is aware of the events the cause energy storage and dissipation within the polymer sample and the elasticity.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory supported with personal protective equipment.
Materials for the classes involves:
- polymer samples e.g. thermoplasts with elastic additives
- device for mechanical test with software for data recording

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:
1. Knowledge test:

- A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.

2. Introduction:
    - Presentation of the purpose of the laboratory and discussion of the importance of testing of elastic recovery of the polymer sample.
    - Discuss the principle of operation and familiarization with the device for mechanical test with software for data recording.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team receives a set of samples and, after start with watching the surface, edges.
    - The samples will be prepared for the measurement by conditioned in a controlled humidity condition for 24 h before the measurement.
    - The sample will be squeezed with mechanical force to predefined value (determined by device operator / teacher) and then the load will be released.
    - The student will watch the sample again to compare the surface, edges
5. Results analysis:
    - Each team will present the results of their research in the form of a presentation.
    - Teams will discuss their conclusions regarding the effect of loading on studied material and will evaluate the content of the energy saved and restored in the sample.
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Discussion of the results obtained concerning elastic recovery of the polymer sample.
    - Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
    - Enlisting content of the report.
    - Question and answer session regarding practical aspects of elastic recovery of the polymer samples.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Charles E. Carraher, "Polymer chemistry", CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388

- Elastic recovery test of the polymer modified binder (free online source: https://www.youtube.com/watch?v=C7y9T9wTt0w (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior tot he laboratory classes.
The scope of the issues for the colloquium involves the following topic: streaching of the polymer chain, mechnical stability, elasticity, energy storage and dissipation

Topics 7

1. The subject of the laboratory classes

Abrasive wear of polymeric materials - toothbrush fiber

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of this study is to trace the abrasive wear process of technical polymer fibers. For many application of polymeric materials resistance to wear is important. One can mention use as a bearing material (for machinery parts or biomedical joint replacements) or utilization as glazing material where damage results in loss of optical properties. In the field of glazing materials, the low density and respectively high toughness along with high transparency are attractive. However, polymers subjected to abrasive wear may lose functionality and provide unwanted side products bringing harmful side effects. Such situation may be present in field of biomaterials or medical/hygienic related products like toothbrushes. The subject of the proposed analysis will be polyamide fibers from two sources: a virgin, unused toothbrush components and a used toothbrush one (possibly provided by students). After introductory purification of the material (preferably it should not be wet as PA tends to absorb humidity) several fibers will be sticked to the SEM microscope plate with conductive tape. After insertion into the microscope chamber their images will be recorded to reveal the morphology of the origin and used fibers. In the subsequent step the analysis of the morphology in terms of the degree of wear will be performed with the investigation of the roughness of the surface, diameters of the fibers. In the activity also fibers of natural origin can be imagined to trace the similarities and differences between petrol based products and natural ones. The obtained information will be discussed in terms of mechanical degradation the commonly used polymers. Additionally, the issue of microplastics formation may be raised.

3. Learning outcomes

The students is aware of the continuous changes of the materials properties being subjected to mechanical loading with abrasive strength. Moreover, he / she is able to predict the general degradation rate of the polymer in the environment and point potential risk of using this material.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with a fume hood to remove vapors of the solvents used in the experiment. The classes takes place in laboratory supplied with personal protective equipment.

Materials for the classes involves:

- polymer samples e.g. fibers of toothbrush from various sources,
- SEM microscope with the sample preparation position
- position to sample purification

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of testing of the abrasive wear of polymeric material.
   - Discuss the principle of operation, sample preparation and operation of SEM microscopy.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a sample – one is reference one, unused. They take the fibers and clean it in ethanolic solution (70%).
   - The fibres are mounted on the SEM stage.
   - The images are recorded for the respective samples.
5. Results analysis:
   - Each team will present the results of their research in the form of a presentation.
   - Teams will discuss their conclusions regarding the effect of usage on the shape, diameter, smoothness of the fiber.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the results obtained and determination of impact of mechanical abrasion of the worn PA fibers
   - Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of abrasive wear of polymeric materials.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560
- 09-3 Polymers: Mechanical Properties (free online source: https://www.youtube.com/watch?v=qUSCCGXXHpU&pp=ygUeYWJyYXNpdmUgcHJvcGVyaWV0IG9mIHBvbHltZXJz, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior to the laboratory classes.
The scope of the issues for the colloquium involves the following topic: mechanical properties of polymers, abrasion resistance, microplastic formation and ist environmental issues

Topics 8

1. The subject of the laboratory classes

Analysis of the permeability of polymer membrane

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the experiment, students will analyse the permeability of selected polymeric membrane materials (e.g. carboxymethyl cellulose (CMC), polyamide (PA), polytetrafluoroethylene (PTFE) of known pore size in terms of permeability to both hydronium (H_3O^+) and hydroxyl (OH^-) ions. Moreover, the membrane differs in terms of affinity for water being either hydrophilic or hydrophobic. This character influence markedly on the diffusion of the ions. Membrane materials have been used in biomedical engineering for a number of years. They have found wide application as separation baffles or filters to retain particles of a specific size or molar mass. Typical composite membranes are characterised by a specific structure, in which the active layer and the porous-bearing layer are made of separate materials. Such a membrane may consist of several layers, differing in both pore size (shape, pore size) and material. Such materials, due to their thickness (approx. 100-200 µm), are prone to rapid blockage, resulting from clogging of the pores and delamination or even mechanical failure. In the experiment a system with a suitable receiver will provide the ability to measure pH values, allowing tracking of ion movement throughout the chosen membrane. The experiment will be conducted to the point of time where the steady state will be reached. The student will prepare the graph of pH value versus time, which will allow to trace the changes occurring in the system including swelling phenomena and permeability. The obtained information will be discussed in terms of ion migration, osmotic phenomena, water purification systems, ophtamological implants.

3. Learning outcomes

The student knows the basic characteristic of polymer membrane and understands the process of ion transport through the porous layer. He/she can describe the factors that play crucial role in the effective transport process and the ones that handicap the process of diffusion.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with a fume hood to remove fumes and smoke generated by the experiment. No special advanced device is used during the test. The exercise takes place in laboratory equipped with a distilled water supply and personal protective equipment.

Materials for the classes involves:

- filtering membranes (hydrophilic e.g. MCE (mixed cellulose esters - cellulose acetate and nitrate), hydrophobic e.g. PTFE)
- chemical substances for solution preparation e.g. HCl solution, NaOH solution, distilled water,

- laboratory small items, e.g. beakers, volumetric cylinders, pipette, pH meter, stopper
- precise balance

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the importance of testing of permeability of polymer membrane.
   - Discuss the stages of experiment with description of required calculations and presentation of experimental setup. Familiarization with the pH meter operation.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a membrane of known porosity and chemical character (material, water affinity)
   - The experiment starts with calculation of the proper mass or volume of compounds to prepare working solutions of acid or base. The vails should be clearly marked with the content and concentrations. The mass of the dry membrane should be noted.
   - Next, the experimental setup is assembled with carful attachment of membrane no to destroy it. The area of the membrane in contact with the solution should be calculated. The measurement is taken in room temperature, in undisturbed condition.
   - The students start the analysis by measuring pH in time by 2 minutes periods. The position of the sensor of pH meter should bas a close to the membrane as possible, but shall not touch it. The analysis is performed till the steady state is achieved which is manifested by stable pH value in 5 subsequent time points.
   - After finishing experiment the students dismantle the setup, weight wet membrane, shake the receiver baker vitreously and measure the pH of the shaken solution. Afterwards, they clean working station reliably.
5. Results analysis:
   - Each team will present the results of their research in the form of a short presentation.

- Teams will discuss their conclusions regarding the permeability of the membrane in terms of migration possibility and its velocity.

6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the obtained results and indication of the effect of pore size and chemical character of the membrane on ion permeability.
   - Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of permeability of polymer membrane.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, "Polymer chemistry" Springer-Verlag (Berlin), 2017, ISBN: 9783662492772
- Topic 6 Polymer Permeability Part 1 (free online source: https://www.youtube.com/watch?v=yu0p1oYkvzg, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior to the laboratory classes.
The scope of the issues for the colloquium involves the following topic: polymer membrane, membrane porosity, ion permeation through membranes, diffusion rate.

Topics 9

1. The subject of the laboratory classes

Determination of crystallinity degree of the polymer

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The experiment aims to determine the degree of crystallinity of polymer samples. This is a parameter that significantly affects the mechanical and optical properties of material. The degree of crystallinity determines the content of the crystalline, ordered phase in the total volume of polymer. The parameter can be almost 0% for totally amorphic system, but also can reach up to 95% for highly crystalline ones. It is a result of mutual interaction present in the structure of the polymer matrix both inter- and intramolecular. Also molecular structure of the chain, its stereoregularity promotes formation of ordered phase. Moreover, as degree of crystallinity is not stable in the time and can be changed for some systems it can be an indicator of sample degradation and ageing. In the experiment the studied samples will be conditioned by gentle heating to remove traces of moisture from the surface. The temperature of the oven shall not be neither destructive nor influenced on the sample state. Its estimated range can be found form the literature sources. Afterwards, the FTIR spectra will be recorded for solid materials by use of ATR mode. In this case the surface layer of the sample is analysed with penetration depth dependent on the type of the crystal. The data will be used to identify the chemical characterisation in the first step. In the second stage, characteristic bands of crystalline and amorphous phases will be detected and used for quantitative analysis. The obtained information will be discussed in terms of materials chemical characterisation and degradation.

3. Learning outcomes

The student understand the idea of degree of crystallinity and process that enhance formation of the ordered areas within the polymer structure. She / he can point interactions that induce crystallinity formation and are aware of its impact on the mechanical properties of polymers.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped with sample annealing oven. The exercise takes place in laboratory supplied with personal protective equipment.

Materials for the classes involves:

- test samples, isopropanol
- FTIR spectrophotometer with ATR header

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:

- A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.

2. Introduction:
    - Presentation of the purpose of the laboratory and discussion of the importance of testing of the crystallinity degree of the polymer.
    - Discuss the principle of sample preparation and operation of spectrophotometer equipped with ATR head.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team receives samples and, after examining their basic properties (color, stiffness, texture, flexibility, smell, porosity) the samples are located in heating over to remove the humidity which is unwanted within the measurement. The temperature must be safe for the samples not to destroy or degrade them.
    - After 1 hour of heating the samples are taken out and cooled down to room temperature.
    - The previously instructed students mount ATR head to start the spectrophotometer. The background spectrum is recorded.
    - The spectra of the heated samples are recorded and stored. The students are provided with the data to restore the spectra in their reports.
5. Results analysis:
    - Each team will present the results of their research in the form of a short presentation.
    - Teams will discuss their conclusions regarding identification of polymeric material – the comparative analysis with the database is performed.
    - Teams will discuss their result of degree of crystallinity.
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Discussion of the results obtained including identification of the polymeric materials and their crystallinity degree.
    - Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
    - Enlisting content of the report.
    - Question and answer session regarding practical aspects of crystallinity degree of the polymer.

6.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Charles E. Carraher, “Polymer chemistry”, CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388
- MSE 201 S21 Lecture 31 - Module 2 - Measuring Polymer Crystallinity (free online source: https://www.youtube.com/watch?v=3Ny9yZUvemY, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7.	Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:

- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8.	Optional information

Exercise manuals will be available prior to the laboratory classes.
The scope of the issues for the colloquium involves the following topic: absorption, radiative emission, infrared spectroscopy, active transitions (allowed transitions), dipole moment of a molecule, spectrum, wave number, transmission and reflection techniques, degree of crystallinity of a polymer, crystalline phase, amorphous phase, ordering, crystallites, lamella, spherulite

Topics 10

1. The subject of the laboratory classes

Scanning Kelvin Probe (SKP) analysis of coating polymer layer

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the experiment scanning Kelvin Probe (SKP) will be used for imaging polymer topography and mapping its local reactivity by measuring contact potential difference value and subsequent calculation of work function. The method can be used to analyse local disruptive processes occurring on solid biomaterials and those covered by various types of coatings - both organic and inorganic. The value of the contact voltage can be determined with the use of measuring system based on a Kelvin probe, made of e.g. tungsten, positioned at the surface of the phase under test (sample) and an external voltage source Uapp. The probe and the sample surface aligned parallel to each other can be treated as a planar capacitor with capacitance C. The SKP method can be used to determine both the contact voltage Ucpd and to determine the topography of the sample surface. It is a non-destructive, non-contact method for testing the condition of the surface of material. Key applications of SKP relates to characterization of corrosion interface. The technique is unique as it allows a noncontact measurement of electrode potentials. In the experiment the polymeric material will be deposited electrochemically with either cyclic voltammetry or chronoamperometry technique on the surface of the polished electrode (e.g. stainless steel, ITO coated PET or glass). Depending on the applied technique different layers will be obtained in terms of the thickness, still both synthetic protocols should provide full surface coverage. During the measurement the sample is placed in air at stable, air conditioned room to achieve stable temperature. As the reference the pure, uncoated substrate will be tested as well. The obtained information will be discussed in terms of integrity of polymer coating, their homogeneity and protection ability.

3. Learning outcomes

The student understands the phenomena related to the SKP measuring technique and is aware of the applicability of this technique for characteristic of the polymer coatings in terms of local reactivity and stability.

4. Necessary equipment, materials, etc

The exercise takes place in laboratory equipped potentiostat to obtain the coatings. The classes takes place in laboratory supported with personal protective equipment.
Materials for the classes involves:
- test samples deposited on the substrate, pure substrate,
- water, monomer, supporting electrolyte
- scanning Kelvin Probe (SKP) system
- potentiostat

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
    - A test checking students' preparation for laboratory exercises based on information provided during the lecture and based on the literature resources.
2. Introduction:
    - Presentation of the purpose of the laboratory and discussion of the importance of testing the coating polymer layers.
    - Discuss the experiment stages including synthesis and characterisation by SKP, followed by principle of operation of the SKP system.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team deposits a sample along with instruction given by the teacher. After deposition the sample should be rinsed multiple time with distilled water.
    - After drying of the sample the student mount it in the holder of SKP system horizontally.
    - The students set working parameters for the measurement under the supervision of the device operator / teacher and start map recording.
5. Results analysis:
    - Each team will present the results of their research in the form of a presentation.
    - Teams will discuss their conclusions regarding the effect of different grinding and polishing parameters on surface roughness and will eventually suggest the appropriate procedure for each of the materials received.
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Discussion of the results obtained in terms of sample deposition and SKP map recording.
    - Summary of experience and identification of possible future actions, including any further research. Critical evaluation of suitability and complexity of the method.
    - Enlisting content of the report.
    - Question and answer session regarding practical aspects of coating polymer layer characterisation.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the laboratory classes:

- Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560

- How AFM Works 4-4 Scanning Kelvin Probe Microscopy (SKPM) (free online source: https://www.youtube.com/watch?v=PTrIiKE8peI, (access: May, 27th, 2023)

Students are obliged to prepare a theoretical background as the introduction part to the laboratory report.

7. Additional notes

The following rules and points are granted as assessment of one laboratory activity:
the initial test prior to the exercise - 1 point,
team work on performing the exercise and developing a report - 10 points in total gathered from the following elements:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point).

8. Optional information

Exercise manuals will be available prior to the laboratory classes.
The scope of the issues for the colloquium involves the following topic: scanning Kelvin Probe (SKP) background, imaging polymer topography, work function, polymeric material deposition with electrochemical techniques

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

GREEN TRIBOLOGY

Code: GT

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

History of Tribology and Green Tribology, challenges, and Perspectives. Global warming processes and prevention options

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, the concept of tribology was defined and explained, and its history from ancient and medieval times was presented through the Peter Jost Report, published in 1966, until 2010, when the scientific volume on green tribology in one of the most prestigious and oldest (published since 1666) research journals - Philosophical Transaction of the Royal Society A. In addition, the lecture presented twelve principles of green tribology, such as minimizing friction and wear, reducing, and eliminating lubrication, introducing natural and biodegradable lubrication, applying the principles of sustainable chemistry and green engineering, biomimetic approach, surface texturing, determining the impact of coatings on the environment, designing the surface degradation process of tribological elements, real-time monitoring and analysis of tribological systems and sustainable energy application. In the part of the lecture devoted to global warming, topics such as the structure of the earth's atmosphere, the impact of greenhouse gases, and their potential for creating the greenhouse effect were discussed, followed by forecasts of the greenhouse effect and the impact on the earth's climate. The next part presents the challenges facing green tribology, especially regarding global warming progressing with increasing speed and strength, and presents future research directions. During the lecture, students will also learn that green technology, in general, and green tribology plus surface engineering, in particular, hold the key to the twin objectives of enhancing the conservation of natural resources and improving energy efficiency, with the ultimate goal of finding a technologically viable solution to the current critical problem of global warming.

3. Learning outcomes

- Learn the history and evolution of tribology from its origins to the emergence of green tribology.
- Understand the 12 main principles of green tribology.
- Learn about the structure of the Earth's atmosphere.
- Explore the impact of greenhouse gases on global warming and the Earth's climate.
- Understand the need for change and the challenges facing green tribology.
- Identify the most important events that influenced the development of 3D printing technology.

- List the advantages of green tribology and sustainable surface engineering and evaluate their impact on protecting natural resources and improving energy efficiency.
- Discuss the potential benefits of using green technologies.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the impact of greenhouse gases on the effect of global warming, examples of the use of green tribology and technology in various fields, such as space, aviation, automotive, biomedical applications

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - conducting a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M. Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 2

1. The subject of the lecture

Wear of materials for Green Tribology. Basic equations and types of wear

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the beginning, the lecture discusses issues related to economic and energy losses generated by wear and friction. Literature data indicate that annual losses in the United States due to wear and corrosion amount to USD 500 billion. Tribological improvements in the automotive industry could save 18.6% of the total annual energy consumed by cars in the United States, equivalent to approximately US$14.3 billion per year. The total cost per flight hour of one US Navy aircraft is estimated at US$243. In the next part of the lecture, the concept of tribological wear was defined, and the structure of a typical tribological system was shown. Another aspect discussed in the lecture is the classification of types of wear based on environmental interactions. Students will also learn about such concepts as the wear equation, hardness of the material, wear volume, wear life, energy loss in wear, and wear coefficient of different materials and wear types. The next part of the lecture was devoted to discussing the most commonly used standard wear tests and relevant standards. The last part broadly discusses the main mechanisms of wear processes, in particular: Abrasion, Adhesion and Friction, Erosion, Corrosion, Surface Fatigue Wear, Thermal Wear, and issues of the possibility of reducing wear in accordance with the assumptions of green tribology.

3. Learning outcomes

- Understanding the causes of enormous energy costs and losses generated by wear and friction.
- Getting acquainted with the possibilities of reducing these costs by implementing the principles of green tribology and sustainable material engineering
- Consolidation and extension of knowledge on the basics of tribology and basic concepts such as wear equation, hardness of the material, wear volume, wear life, energy loss in wear, wear coefficient of different materials, and wear types
- Knowledge of the most commonly used standards in tribological tests such as ASTM G99, G105, G75, G98, G73, G76, G102, and G59.
- Extended knowledge of the identification of wear processes such as Abrasion, Adhesion and Friction, Erosion, Corrosion, Surface Fatigue Wear, and Thermal Wear.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the impact of enormous energy costs and losses generated by wear and friction

Discussion - encouraging participants to actively participate in the discussion on the discussed issues about the possibility of reducing wear in accordance with the assumptions of green tribology

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 3

1. The subject of the lecture

Wear of Ceramic Materials, Wear of Polymers, and a summary of lectures on friction, wear and wear mechanisms

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, students in the first part will learn about the basic properties of ceramic materials and their impact on green tribology. They will learn the method of determining the fracture toughness (KIc coefficient) using the modern method of microindentation. They will also learn the fracture mechanics-based ceramic wear equation proposed by Evans and Marshall and learn that the hardness of ceramic materials is a key element in controlling wear rates. In the next part, wear tests of ceramic materials and possible applications for ceramic materials in terms of sustainable and green tribology will be discussed. The next part of the lecture will be devoted to the consumption of polymers. Students will learn about the structure and the most common types of polymers. They will learn the basic concepts such as the glass transition temperature Tg and degradation temperature Td and try to think about what applications of green tribology this type of material can be used for, taking into account the low thermal conductivity and low melting point but also a very high strength-to-weight ratio. Students will then learn about friction, wear, and erosive wear of thermoplastic materials. At the end of the lecture, the most important information about green tribology, basic concepts, formulas, types, and mechanisms of wear will be summarized in a compact form.

3. Learning outcomes

- Knowledge of the properties of ceramic materials
- Understanding of basic calculations and methods of fracture toughness measurement
- Familiarity with tribological testing of ceramic materials and the key effect of hardness in controlling the amount of wear
- Repeating the information on the molecular structure of the most common types of polymers and extending knowledge about polymeric materials with aspects related to green tribology
- Understanding the specificity of both types of materials in terms of the possibility of sustainable and green tribology applications
- Repetition and consolidation of knowledge in the field of green tribology, basic concepts, formulas, types, and mechanisms of wear

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the possibilities of using ceramic and polymer materials for green tribology

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 4

1. The subject of the lecture

Effect of lubricants. Water lubricated bearings. Green and natural oil lubricants

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the first part of the lecture, students will learn about the main role of the lubricant. They will learn such concepts as a fluid film between two surfaces and boundary lubricants. They learn that the load, sliding velocity, temperature, time, and film thickness are the variables affecting lubricant performance in reducing the wear rate. The normally accepted practice to prevent metal contact is to maintain a minimum film thickness of the lubricant layer three times the composite surface roughness value for the sliding or rolling surfaces. Then, students will learn about examples of solid, liquid, and semisolid lubricants, classifying them according to the assumptions of green tribology. The second lecture discusses water-lubricated bearings. The assumptions of green tribology and sustainable technology, the growing environmental awareness of engineers, and stricter requirements for environmental protection led to the development of water-lubricated bearings in many applications where oil was used as a lubricant. Students will learn the theoretical background, types of bearings, and applications such as (hydropower, marine, offshore, pump, large diameter deep wells and petrochemical (where spark-free operation is imperative), water purification, and sanitation. During the last part of the lecture, students will learn about green and natural oil lubricants. Green lubricants can significantly outperform conventional lubricants with respect to frictional and wear performance. Exerted by hydraulic and gear oils. Students learn the advantages and limitations of vegetable oils over mineral oils, the possible application of vegetable oil in the field of Green Tribology, the composition, and structure of vegetable oils, and the use of different vegetable oils as bioderived lubricants with their properties and functions.

3. Learning outcomes

- Understanding the role of lubricant as an effective wear reduction method in green tribology
- Knowing and understanding the effects of load, sliding speed, temperature, time, and sliding film thickness as variables affecting grease performance
- Understanding the environmental impact of lubrication and the applicability of water-lubricated bearings
- Understanding the advantages and disadvantages of green lubricants compared to conventional lubricants
- Getting to know the theoretical background and examples of applications in green tribology for bearings lubricated with green lubricants and water-lubricated bearings.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the possibilities of using water or green natural lubricants for green tribology

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 5

1. The subject of the lecture

Solid surfaces and properties, engineering processes of surfaces for Green Tribology

2. Thematic scope of the lecture (abstract, maximum 500 words)

In previous lectures, students learned that wear and friction are intrinsic properties of materials. During this lecture, they will learn that the properties of bounding faces on surfaces control the extent of wear and friction in solid materials. It is therefore possible to control wear and friction by engineering the properties of the surface phase of the working face(s) of the solid. The properties of the surface phase, such as energy, microstructure, composition, roughness, and hardness, dictate the extent of wear and frictional loss in a material. The hardness, a derived property, depends on the composition, microstructure, and surface energy. The roughness of the surface, or surface texture, is dependent on the forming and finishing processes. The modification of one or more of the following surface properties minimizes wear and friction. In the next part of the lecture, students will learn about the theoretical foundations and expand their knowledge about the influence of individual elements such as morphology, surface roughness, microstructure and its modification, and hardness. Then they will learn about the most common green surface engineering processes: mechanical, chemical, electrochemical, and thermal. They understand that the topography is made up of surface roughness, waviness, errors of form, and flaws. Surface topography directly affects wear, friction, and fatigue properties. The surface layer characteristics that change through processing include plastic deformation, residual stresses, cracks, hardness, overaging, phase changes, recrystallization, intergranular attack, and hydrogen embrittlement. The finishing treatment negates the surface finishes and thus improves surface integrity. They will learn and expand information on such processes as Strain-Hardening Processes, Electrochemical Processes, Chemical, Thermally Assisted Processes, Vapor-Phase Deposition, Thick-Film Overlays.

3. Learning outcomes

- Learning the basic properties of solid surfaces and understanding that the properties of the surface phase, such as energy, microstructure, composition, roughness, and hardness, dictate the extent of wear and frictional loss in a material.
- Discussion and extension of knowledge related to morphology, surface roughness, microstructure, modification, and hardness.
- Discuss, list, and explain the most commonly used methods of green surface engineering
- How to relate the properties of solid surfaces with surface engineering and improve the service life of friction pairs for green tribology.
- What will be the impact on the environment and natural resources?

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the possibilities of different enginerring processes for Green Tribology to extended service life of friction pairs.

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 6

1. The subject of the lecture

Green and Sustainable Nanotribology in the frame of the global challenges for humankind

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, students will learn about the challenges, development, and opportunities of these new, emerging fields of science and embed them in the major frame of the most serious problems we currently face on our planet. Green Nanotribology is of specific relevance when addressing Global Challenge 13 (Energy) and Global Challenge 14 (Science and Technology) – these two aspects are discussed in more detail in the next part of the lecture. Students will learn about the fifteen challenges of the Millennium Project initiated in 1996 and an action plan for the world. Until now, it has comprised the work of 2,500 futurists, scholars, decision-makers, and business planners from over 50 countries. The Millennium Project publishes the annual State of the Future Report (SOF). Then, listeners will learn that the term green nanotribology was first introduced in 2009 by Si-wei Zhang, past chairman of the Chinese Tribology Institution. In turn, Peter Jost 2009 defined green tribology as the science and technology of the tribological aspects of ecological balance and environmental and biological impacts. Its main objectives are the saving of energy and materials and the enhancement of the environment and the quality of life. In the next part of the lecture, students learn that economic benefits derived from the application of green tribology for the UK include £8-10 billion, out of which 60-70% would be energy-related, all this largely from existing and applied research (innovation). Students learn about the relationship between green nanotribology and nanosurfaces, nanoagents, and nanoprocesses. For green nanosurfaces, points such as nanostructured surfaces, hierarchical surfaces, material selection, coated materials, and monomolecular lubricant layers must be addressed. They will learn the main goals of effective nanotribology located in three main areas: production (agents), reaction (agents; object to nanoproduct; waste agents direct effects), and nanoproduct life cycle (effects on the environment during the service period and during degradation). At the end of the lecture, they will learn some examples of applications for green sustainable nanotribology.

3. Learning outcomes

- Discussing and expanding knowledge on challenges, development, and opportunities of these new, emerging fields of science (green tribology)
- Getting to know the challenges of the Millennium program.
- Getting to know the term nanotribology and understanding the impact of nanotribology on ecological and economic aspects
- Understanding the links between nanotribology and nanosurfaces, nanoagents and nanoprocesses
- Understanding the goals, main areas, and specific applications for green nanotribology

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation on the impact of using green nanotribology on the natural environment, reducing the consumption of natural resources and large economic benefits

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Topics 7

1. The subject of the lecture

Life-Cycle Assessment and applications in Green Tribology

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the first part of the lecture, students will learn about Life-Cycle Assessments. In the context of global warming, the life-cycle assessment of a product refers to the evaluation of the environmental performance, particularly with respect to energy, of the product during its tenure from “cradle to grave.” However, in the present context, the term life cycle is the working life span of a product in a particular application. Students also learn that the progressive degradation of material in use limits its life span. The time-dependent progressive degradation processes include wear, friction, fatigue, creep, and fracture toughness. For a given material, the severity of the environment controls the rate and, thus, the life span. Surface engineering can improve the response to the severity of the wear environment, leading to an extension of the working life. Another aspect discussed in the lecture is predictable life-cycle estimation. Learn in detail the life cycles of materials in green tribological processes, including Abrasion-based life, Adhesion-based life, Erosion-based life, Fatigue-based life, Creep-based life, Fracture-mechanics-based life, and Corrosion-based life. The second part of the lecture discusses tribological applications. Green tribology plus surface engineering enhances the capabilities of wear-resistant surfaces to cope with more hostile environments, leading to increases in overall energy efficiency in advanced engineering applications. Students will get acquainted with specific examples of applications from power-generation industries, transportation industries, machine tool industries, mineral-processing industries, cement industries, steel industries, and paper and pulp industries, and at the end, they will try to propose further possible applications for green tribology

3. Learning outcomes

- What are the differences between the concept of the product life cycle in the context of global warming and the context of product use in specific applications?
- Identify product degradation processes.
- Recognize the benefits of estimating the life cycle of a product and the possibilities of using appropriate treatments to extend it.
- Identify types of the life cycles of materials in green tribological processes
- Familiarize with specific examples of applications for green tribology and propose new solutions.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, and SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the possibilities of propose further possible applications for green tribology

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Quiz - Conduct a short quiz after the lecture to check how well the participants have absorbed the knowledge discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

6. Additional notes

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Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

Technology of surface preparation for green tribology

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Laboratory exercises aim to acquaint students with the surface preparation of samples for tribological tests. During the laboratory, students will have the opportunity to work independently by selecting the appropriate course of the grinding and/or polishing process to obtain a surface per the recommendations of the ASTM G99 standard. For this purpose, they will use papers with appropriately selected grain. During the laboratory, students will gain practical knowledge about the operation of the contact profilographometer. Students will familiarize themselves with the device's software, make independent measurements of the surface roughness profile and calculate the parameters by the assumptions of the EN ISO 21920 standard (formerly ISO 4288) both before and after the grinding process to obtain a suitable surface for tribological tests. The exercises will use all types of materials that will be tested in the next classes.

3. Learning outcomes

Working on this lab project, students will:

- will gain experience in preparing surfaces for green tribology tests - will be able to select a grinding procedure depending on the test material and will be able to operate a grinding/polishing machine.
- will develop the skills of handling measurements and profilographometric calculations
- they will learn how to interpret and analyze the research results and effectively use the results of measurements.

4. Necessary equipment, materials, etc

The exercise takes place in two laboratories.

- Metallography Laboratory equipped with automatic and manual grinders and polishers.
- Surface Layer Research Laboratory equipped with a Surftest SJ-500 contact surface tester (Mitutoyo, Tokyo, Japan)

Necessary materials

- diamond pads/ polishing cloths
- various materials for tribological tests

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
    - A quiz checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
    - Presentation of the purpose of the laboratory and Discussion of the importance of testing the impact of surface roughness parameters as one of many important parameters for reducing wear by the principles of green tribology.
    - Discuss the principle of operation and operation of grinding/polishing devices and familiarization with the contact profilographometer.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team receives a set of samples and, after examining the initial surface and developing a plan, grinding and polishing using appropriately selected sandpapers and polishing wheels (if necessary).
    - Students control the positioning of the samples and the appropriate pressure to obtain a flat surface.
    - After the grinding and polishing process is completed, each team proceeds to carry out profilographometric tests and calculate surface roughness parameters.
5. Results analysis:
    - Each team will present the results of their research in the form of a presentation.
    - Teams will discuss their conclusions regarding the effect of different grinding and polishing parameters on surface roughness and will eventually suggest the appropriate procedure for each of the materials received
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Discussion of the results obtained and determination of the best surface preparation methods.
    - Summary of experience and identification of possible future actions, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-disk Apparatus, ASTM International, West Conshohocken, PA, 2017.
- ASTM Standard G133-05, Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA, 2016.
- ISO 21920-1:2021, Geometrical product specifications (GPS) — Surface texture: Profile — Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium, 2021.
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996
- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.

7. Additional notes

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8. Optional information

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Topics 2

1. The subject of the laboratory classes

Tribological tests of light alloys - influence of surface roughness on tribological wear in friction pair ball-on-disc

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Laboratory exercises are aimed at familiarizing students with the procedure of tribological research - learning the device software, preparing the stand, cleaning, weighing, measuring and correctly placing samples and counter-samples. They selected appropriate test conditions and conducted tests that will allow drawing reasonable conclusions on the impact of surface roughness on the coefficient of friction and tribological wear of samples made of light alloys such as magnesium alloys and/or aluminum alloys and titanium alloys. After the measurements, students will learn how to measure the resulting wear tracks using the previously known contact profilographometer, how to take photos of wear tracks and identify the wear mechanism, how to read and calculate the coefficient of friction and draw conclusions based on the results and better understand how to optimize the preparation process surface of the material to achieve the lowest possible wear in accordance with the assumptions of green tribology.

3. Learning outcomes

By working on this lab project, the student will:

- Gain experience conducting tribological tests by standards and norms and learn how to optimize the surface preparation process to obtain the lowest material wear.
- Develops the ability to use measurements and calculations of tribological and profilographometric tests and the morphology of wear tracks.
- They will learn to interpret and analyze research results and communicate them effectively.

4. Necessary equipment, materials, etc

The exercise takes place in two laboratories.

- Metallography Laboratory equipped with automatic and manual grinders and polishers.
- Surface Layer Research Laboratory equipped with a Surftest SJ-500 contact surface tester (Mitutoyo, Tokyo, Japan), TRN tribometer device with the InstrumX software, OLYMPUS GX-51 light microscope equipped with a camera SC30 and Stream Essentials software

Necessary materials

- light alloys: magnesium, aluminium, titanium
- counterspecimens: ball

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
    - A quiz to check students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
    - Discussion of the principle of operation and operation of tribometers and a light microscope, a reminder of the principle of operation of a contact profilographometer, and learning how to use such devices as a laboratory balance and an ultrasonic cleaner.
    - Presentation of the purpose of the laboratory and paying attention to surface roughness as one of the important factors affecting the wear value of the tested material.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team receives a different set of samples (light metals) and counter samples (balls) and proceeds to tribological tests after cleaning, weighing, and examining the surface in its initial state.
    - Students monitor the tribological test, report any irregularities, and note their observations.
    - After the test, they clean the sample again, weigh it and proceed to profilographometric examination of wear tracks, then take pictures of the surface of wear tracks using a microscope and analyze the wear mechanisms occurring on light metal alloys.
5. Results analysis:
    - Each team will present the results of their research in the form of a presentation.
    - Teams will discuss their findings on the effect of different grinding and polishing parameters on surface roughness, wear, and coefficient of friction.
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Discussion of the results obtained and determination of the best surface preparation methods.
    - Summary of experience and identification of possible future actions, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.
- ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-disk Apparatus, ASTM International, West Conshohocken, PA, 2017.
- ASTM Standard G133-05, Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA, 2016.
- ISO 21920-1:2021, Geometrical product specifications (GPS) — Surface texture: Profile — Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium, 2021.
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996

7. Additional notes

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8. Optional information

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Topics 3

1. The subject of the laboratory classes

Tribological studies of polymers - polymer wear micromechanism

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory aims to study the tribological properties of various polymeric materials in pin-on-disk and ball-on-disk systems. Students will receive sets of samples and counter-samples where in one system, the polymer material is a pin and in the other, a disk. Using the knowledge gained during the previous exercises, students will prepare appropriate test material, workstation, and environmental conditions and conduct tribological tests. Then, they will wear track measurements and learn to determine the wear micromechanism β and the index of polymer resistance to abrasive wear Wβ. They will also take photos of wear tracks and try to recognize the wear mechanisms occurring on the surface of polymers and cooperating elements of friction pairs. They will consider possible applications of polymers for green tribology.

3. Learning outcomes

Working on this lab project:

- Students will learn the standards/norms for tribological testing of polymers and prepare and run pin-on-disk and ball-on-disk tests.
- Students will learn to perform wear track measurements of polymeric materials and, on their basis, determine the micromechanism of wear and the index of resistance to abrasive wear.
- Therefore, Students will expand their ability to use measurements and calculations in tribological and profilographometric tests and the morphology of wear marks for another group of materials.
- Students will interpret, analyze and show the research results, allowing them to learn how to communicate relevant information.

4. Necessary equipment, materials, etc

The exercise takes place in two laboratories.

- Metallography Laboratory equipped with automatic and manual grinders and polishers.
- Surface Layer Research Laboratory equipped with a Surftest SJ-500 contact surface tester (Mitutoyo, Tokyo, Japan), TRN tribometer device with the InstrumX software, OLYMPUS GX-51 light microscope equipped with a camera SC30 and Stream Essentials software

Necessary materials

- polymers
- counterspecimens: ball and disk

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A quiz checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the most important information related to tribological tests of polymeric materials - discussion of the differences between pin-on-disk and ball-on-disk tests.
   - Repetition of the principle of operation and operation of devices in the laboratory of the surface layer, such as: tribometer, profilographometer, microscope, laboratory balance, ultrasonic cleaner.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities leading to the achievement of appropriate work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - After developing and approving the plan, each team proceeds to prepare and conduct tribological tests, receives a set of samples, and proceeds to test after examining the surface in the initial state.
   - Students observe the tribology test, report any abnormalities and record their observations.
   - After the tests are completed, they clean the sample, weigh it and proceed to profilographometric examination of wear marks, then take pictures of the surface of wear marks under a microscope and analyze the wear mechanisms of polymer materials and cooperating elements - answering the question of what new mechanisms were observed during the tests.
5. Results analysis:
   - Each team will present the results of their research in the form of a presentation.
   - The teams will discuss their conclusions regarding different polymeric materials and choose the most advantageous one that meets the assumptions of green tribology.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the obtained results
   - Summary of experience and identification of possible future actions, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.
- ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-disk Apparatus, ASTM International, West Conshohocken, PA, 2017.
- ASTM Standard G133-05, Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA, 2016.
- ISO 21920-1:2021, Geometrical product specifications (GPS) — Surface texture: Profile — Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium, 2021.
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996

7. Additional notes

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8. Optional information

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Topics 4

1. The subject of the laboratory classes

Tribological tests of friction pairs lubricated with green lubricants

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory aims to practically investigate the role of green lubricants as an effective method of reducing friction and wear. During the exercises, students will also get acquainted with a new type of motion. Using various green lubricants, They will perform linear reciprocating motion tests in a ball-on-flat system. Students will compare test results for friction pairs without and using green lubricants. They will perform measurements and learn to interpret test results for reciprocating motion. They will become familiar with new concepts such as static and dynamic coefficient of friction. They will consider the advantages and limitations of green lubricants compared to conventional lubricants.

3. Learning outcomes

Working on this lab project:

- Based on the tests performed, Students will understand the influence of factors such as load, sliding speed, type of lubricant, time, etc., as factors affecting the performance of green lubricants.
- They will learn to perform tribological measurements in linear reciprocating motion in the ball-on-flat system.
- Therefore, Students will expand their ability to use measurements and calculations for this type of movement - they will learn new concepts such as static and dynamic coefficient of friction and learn to determine it from the obtained research results.
- They will understand the environmental impact of lubricants and will be able to list the advantages and disadvantages compared to conventional lubricants.
- Students interpret, analyze and show the results of the research, which will allow them to learn how to communicate relevant information.

4. Necessary equipment, materials, etc

The exercise takes place in two laboratories.

- Metallography Laboratory equipped with automatic and manual grinders and polishers.
- Surface Layer Research Laboratory equipped with a Surftest SJ-500 contact surface tester (Mitutoyo, Tokyo, Japan), TRN tribometer device with the InstrumX software, OLYMPUS GX-51 light microscope equipped with a camera SC30 and Stream Essentials software

Necessary materials

- light alloys: magnesium, aluminium, titanium
- counterspecimens: ball, flat

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A quiz to check students' preparation for laboratory exercises based on information provided during the lecture
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the most important information related to the impact of the use of green lubricants on tribological wear.
   - Learning to operate a tribometer adapted to linear reciprocating motion where the friction pair works in a ball-on-flat system, operating additional accessories for conducting tests using green lubricants.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities leading to the achievement of appropriate results of work. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan
4. Research:
   - After developing and approving the plan, each team proceeds to prepare and conduct tribological tests, receives a set of samples, and, after examining the surface in the initial state, proceeds to test.
   - Students observe the tribology test, report any abnormalities and record their observations.
   - After the tests are completed, they clean the sample, weigh it and proceed to profilographometric examination of wear marks, then take pictures of the surface of wear marks under a microscope and analyze the wear mechanisms of polymer materials and cooperating elements - answering the question of what new wear mechanisms were observed during the tests.
5. Results analysis:
   - Each team will present the results of their research in the form of a presentation.
   - The teams will discuss their conclusions regarding different polymeric materials and choose the most advantageous one that meets the assumptions of green tribology.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the obtained results
   - Summary of experience and identification of possible future actions, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.
- ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-disk Apparatus, ASTM International, West Conshohocken, PA, 2017.
- ASTM Standard G133-05, Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA, 2016.
- ISO 21920-1:2021, Geometrical product specifications (GPS) — Surface texture: Profile — Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium, 2021.
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996

7. Additional notes

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8. Optional information

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Topics 5

1. The subject of the laboratory classes

The properties of the surface phase and their influence on friction and wear

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory is to familiarize students with the procedure of micromechanical tests of the surface phase on one of the most modern devices of this type - the micro-combi-tester (MCT3). Using microindentation, students will examine such properties as instrumental hardness HIT, Young's modulus instrumental EIT, total indentation work Wtot (and its components Wplast, Welast), material stiffness S, percentage of elastic strain work ηIT, etc. Measurements will be carried out for light alloys metals, polymers and all other materials used later during tribological tests. Students will try to draw conclusions on how surface roughness and texture together with micromechanical properties influenced the results of tribological tests performed in previous exercises.

3. Learning outcomes

Working on this lab project:

- Students will consolidate the knowledge provided during the lecture on the basic properties of the surface of solids, such as energy, microstructure, composition, roughness, and hardness, as factors determining wear and friction in the material.
- Students will learn how to operate a device for micromechanical testing - Micro-Combi-Tester (MCT3) and perform measurements using the microindentation method.
- After the measurements, they will learn how to analyze the results and generate a test report.
- Ready research results will be presented during the discussion, allowing you to learn how to provide relevant information, listen and answer questions.

4. Necessary equipment, materials, etc

The exercise takes place in two laboratories.

- Metallography Laboratory equipped with automatic and manual grinders and polishers.
- Surface Layer Research Laboratory equipped with a Surftest SJ-500 contact surface tester (Mitutoyo, Tokyo, Japan), Anton Paar Micro-Combi-Tester (MCT^3)

Necessary materials

- light alloys, polymers

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - A quiz to check students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
   - Presentation of the purpose of the laboratory and discussion of the impact of solid surfaces properties on tribological wear.
   - Learn how to use the Anton Paar Micro-Combi-Tester (MCT3), for performing microindentation tests. Discussion of the measurement method and the importance of the most important quantities obtained during the tests.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities leading to the appropriate work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in the development of the research plan on an ongoing basis, pointing out any shortcomings and finally approving the correct research plan.
4. Research:
   - After developing and approving the plan, each team receives a set of samples and proceeds to prepare and conduct microindentation tests.
   - Students observe the research, report any irregularities and record their observations.
   - After the tests are finished, they take sample print photos, perform calculations and generate final reports.
5. Results analysis:
   - Each team will present the results of their research in the form of a presentation.
   - Teams will discuss their conclusions regarding the impact of properties on tribological wear and select the most advantageous material that meets the assumptions of green tribology.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the obtained results.
   - Summary of experience and identification of possible future actions, including any further research.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chattopadhyay, R. Green Tribology, Surface Engineering and Global Warming, ASM International, 2014.
- Nosonovsky, M.; Bhushan, B. Green Tribology Biomimetics, Energy Conservation and Sustainability, Springer Berlin, 2012.
- ISO 21920-1:2021, Geometrical product specifications (GPS) — Surface texture: Profile — Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium, 2021.
- Oliver, W.C.; Pharr, G.M. An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments, J. of Mater. Res. 7 (1992) 1564-1583. https://doi.org/10.1557/JMR.1992.1564
- ISO 14577-4, Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 4: Test method for metallic and non-metallic coatings (2016).
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987
- Bhushan, B. Principles and Applications of Tribology, Wiley, New York, 1999
- Bhushan, B. Introduction to Tribology, Wiley, New York, 2002
- Ludema, K.C. Friction, Wear, Lubrication: A Text Book in Tribology, CRC Press, New York, 1996

7. Additional notes

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8. Optional information

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Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

Design For Sustainability Using CAD/CAM Software

Code: DFSUCCS

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

Physical and environmental properties of materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

As an introduction to the topic of design for sustainability using CAD/CAM software, the lecture will present the main characteristics of sustainable design, indicating that it is the design of the future. The reasons why it is of great interest in different fields of technology will be presented. Students will organize their knowledge of the physical and environmental properties of materials.

During the lecture, students will learn that to choose greener materials, they need to consider the environmental cost and performance of the material in the design.

They will also learn that the performance of a material depends on its physical properties and that optimizing these is the essential way to reduce the environmental impact of a product.

3. Learning outcomes

Learn about tools for determining the physical properties of materials.

Explore life cycle assessment for materials analysis.

Discuss metrics and the fundamentals of mechanics.

Understand that deformation and failure modes are significant objectives of simulation.

Discuss and answer questions such as:

- Will the design withstand the stresses it will experience in everyday use?
- Could the weight and amount of material in the design be reduced?

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - use a multimedia presentation to visualize the issues discussed.

Case study - to present the impact of sustainable design on the environment.

Discussion - to encourage students to actively participate in discussing the issues discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Ismail A.E., Yunos M.Z., Haq R., Haq A., Ahmad S.: *Synergizing Sustainable Design and Engineering Materials*. Trans Tech Publications Ltd. Zurich, Switzerland 2018
- Proctor R.: *The Sustainable Design Book*. Laurence King Publishing. London 2015

6. Additional notes

Topics 2

1. The subject of the lecture

Introduction to sustainable design – methods to reduce product weight and maximize product lifetime

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the lecture, students learn that following lines of force can help visualize where the material is needed in the design and where the material can be removed. They will also discover they can reduce material usage and create lighter designs by intelligently reinforcing designs. Some reinforcement strategies for lightweighting are discussed, such as hollow parts and thin walls, spot reinforcement, columns, ribs, and trusses.

Designing for disassembly has several advantages. It can make a product easier to repair or upgrade, extending its useful life. Also, a product must be physically and stylistically durable to last. Not only does it need to withstand damage and wear, but it must also remain relevant and desirable to users. Students will learn that repairing and upgrading can address the problem of waste by extending the product’s useful life and slowing down the disposal rate.

3. Learning outcomes

Learn how to create designs that carry loads most efficiently.
Learn how to use Finite Element Analysis (FEA) software to test designs for strength and stiffness requirements while reducing material usage.
Learn how to design for disassembly.
Learn how to design for physical durability.
Discover that the key to designing for repair and upgrade is clear design intent and understanding user behavior.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - use a multimedia presentation to visualize the issues discussed.
Case study - to present product weight reduction and product life maximization methods.
Discussion - to encourage students to actively participate in discussing the issues discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Ismail A.E., Yunos M.Z., Haq R., Haq A., Ahmad S.: *Synergizing Sustainable Design and Engineering Materials*. Trans Tech Publications Ltd. Zurich, Switzerland 2018
- Proctor R.: *The Sustainable Design Book*. Laurence King Publishing. London 2015

6. Additional notes

Topics 3

1. The subject of the lecture

Generative design – high-performance 3D models with optimized geometry

2. Thematic scope of the lecture (abstract, maximum 500 words)

The manufacturing industry is changing rapidly by developing new manufacturing processes and computer algorithms to drive innovation. This digital transformation allows companies to customize production through advances in machine learning and generative design, with integrated design and manufacturing processes. The benefits of generative design are also not limited to the world of additive manufacturing. However, they can also be used with subtractive manufacturing and even as design inspiration for traditional techniques.

Students will learn about trends in generative design, machine learning, and additive manufacturing. This lecture will introduce CAD and digital manufacturing innovations and address the rapid changes in the industry.

3. Learning outcomes

Understand the benefits and workflow of generative design.
Summarise digital manufacturing and the key stages within the process.
Explain and discuss the trends influencing the future of manufacturing.
Summarise and compare subtractive and additive manufacturing processes.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - use a multimedia presentation to visualize the issues discussed.
Case study - to present a modern approach to design.
Discussion - to encourage students to actively participate in discussing the issues discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Agkathidis A.: *Generative Design*. Laurence King Publishing. London 2015
- Izdebska-Podsiadły J.: *Polymers for 3D Printing: Methods, Properties, and Characteristics*. William Andrew 2022
- Kamalpreet S., et al.: *Sustainability for 3D printing*. Springer. Berlin 2022

6. Additional notes

Co-funded by the European Union

Topics 4

1. The subject of the lecture

Virtual prototyping

2. Thematic scope of the lecture (abstract, maximum 500 words)

A modern product design concept is first realized by design engineers using CAD tools as a solid model. The initial product is often based on the designer's experience and legacy data from previous product lines. With the solid product model represented in CAD, product performance, reliability, and manufacturing simulations can be performed.

Virtual prototyping consists of building a parametric product model in CAD, performing product performance simulations and reliability assessments using CAE software, and performing manufacturing simulations and cost estimates using CAM software. Product modeling and simulation using integrated CAD/CAE/CAM software are the fundamental and common activities involved in virtual prototyping. A parametric product model in CAD is essential to the modern approach to modeling. The product model evolves to a higher level of detail from concept to detailed design.

Students will learn how to create a parameterized product model defined in CAD that allows designers to conveniently explore alternatives to support product design. The CAD product model is parameterized by defining dimensions that control the geometry of parts through geometric features and by establishing relationships between dimensions within and between parts.

3. Learning outcomes

Learn how to consider product performance, quality, and manufacturing costs early in the design process.

Understand how to support design decisions with quantitative product performance data.

Explore integrating physical prototyping techniques to support design verification and functional prototyping.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - use a multimedia presentation to visualize the issues discussed.

Case study - to present an example of virtual prototyping.

Discussion - to encourage students to actively participate in discussing the issues discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014

- Kakaraparthi S., Chen N.: *A multi-material additive manufacturing virtual prototyping method for design to improve part strength*. International Journal of Advanced Manufacturing Technology. Springer 2023

6. Additional notes

Topics 5

1. The subject of the lecture

Finite element simulation to support sustainable design and production

2. Thematic scope of the lecture (abstract, maximum 500 words)

Although the terms stress analysis and finite element analysis (FEA) are often used interchangeably, it may be helpful to understand them as they relate to the tools available in the CAD/CAM environment. FEA is an analysis of a complex object that is solved by dividing the object into a mesh of smaller elements on which manageable calculations can be performed. Stress analysis uses this method to analyze the design under a given set of conditions specified by the designer to determine fundamental trends concerning the specifics of the design.

This lecture will cover the CAD software's stress analysis tools and dynamic simulation environments. Students will learn to set up and run stress analysis and dynamic simulations and export results from the dynamic simulation environment to the stress analysis environment.

3. Learning outcomes

Learn how to set up and run stress analysis simulations.

Learn how to set up and run dynamic simulations.

Understand how to export results from the dynamic simulation environment to the stress analysis environment.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - use a multimedia presentation to visualize the issues discussed.

Case study - to demonstrate how to carry out stress analysis simulations.

Discussion - to encourage students to actively participate in discussing the issues discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

6. Additional notes

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

Sketch and basic modeling techniques - an overview

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory aims to learn the principles of parametric sketching used in CAD part modeling. All skills discussed in the lab will be based primarily on creating a single part, both in a single-part file and in the context of an assembly file. In general, CAD programs use two types of sketches: a 2D sketch and a 3D sketch. A 2D sketch is created on any geometry plane and is the more common of the two types. A 3D sketch is not limited to the sketch plane and can include geometry at any point in space. Students will learn how to create parametric 3D parts using CAD software. The class will begin with an overview of standard options and settings associated with CAD and part files before moving on to an essential exercise on the fundamentals of creating parametric models.

During the initial part of the course, students will become familiar with the interface and basics of the CAD program used and learn how to work in it quickly and efficiently. The ability to navigate the program's various features and take full advantage of its capabilities can make the difference between a smooth workflow and a messy one. Students will become familiar with dialog boxes, the ribbon, tabs, and tools that make viewing and analyzing a project easier. They will also learn how to customize the interface to make working in the program even more convenient. They will also learn about the functions for visualizing the project and find out that just changing the color scheme of the preview or using a background can give very interesting effects. After completing all the tasks in the first lab lesson, the students will be aware that to use the CAD program effectively, it is necessary to become familiar with the function of the design file. They will know that it is a configuration file that contains information about where to look and where to store project data and is used, among other things, to create shortcuts that refer to other files, to change the default location of templates, and to modify predefined standards.

In the next phase of the lab, students will learn how to properly create 2D and 3D sketches using parametric dimensions that define their size. During this part of the lab, students will become familiar with most of the basic tools for creating 2D sketches required when designing CAD programs. They will also learn about methods for manipulating the geometry of a design and fundamental aspects of 3D sketching as an extension of the capabilities of flat sketching. They will also be introduced to the key properties of 2D sketches, what sketch disambiguation means, and how to use dimensional constraints. They will also learn good practices for creating and deploying sketches.

In the final part of the class, students will learn the principles and techniques of creating parametric solid models. This is one of the basic skills needed to work freely with CAD. Students will also become familiar with tools for modeling simple parts during this part of the course. Modeling parts is usually the main task faced by new CAD users. In this part of the class, students will become familiar with the most commonly used tools for modeling 3D solids.

Topics covered include parametric solid modeling, base object modeling, designing revolving solids, and solids with complex shapes. Students will also learn techniques for modeling additional elements and holes.

3. Learning outcomes

During laboratory classes, students will learn to:

- set up options and settings for the sketch environment and part modeling;
- create a sketch;
- use sketch constraints to control sketch geometry;
- use 3D sketch tools;
- create basic part features;
- use the extrude and revolve tools;
- create smart hole features.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss the interface and basics of the CAD system.
   b. Discuss basic sketching techniques.
   c. Discuss principles and techniques for creating parametric solid models.
2. Perform the exercise:
   a. Create sketches and simple solids based on instructions provided by the instructor.
   b. Model basic mechanical components such as bolts, nuts, gears, etc.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

The laboratory exercises will be divided into three parts. The first part will include learning the interface and basics of the CAD program used. In the second part of the lab, students will learn how to properly create 2D and 3D sketches using parametric dimensions that determine their size. In the third part of the lab, students will learn the principles and techniques of creating parametric solid models. During this part of the lab, students will also become familiar with tools for modeling simple parts.
The lab will finish with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:
- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 2 – Lab 2

1. The subject of the laboratory classes

Advanced modeling techniques

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Modern parametric modeling uses many tools to create stable, editable parts. The basic workflow for creating a part is to create a base feature and then build on that base. The tools used to create the additional features can vary depending on project needs and range from simple extruded features to complex combinations of different feature types.

During this lesson, students will explore some more complex and curved modeling techniques used to create models using CAD programs. Some of these features include the creation of a basic profile sketch and support sketches used to define paths and shape contours. Other advanced features covered during the lesson move from these concepts to more advanced design features.

These laboratory classes are a continuation and extension of the previous laboratory exercises. Students who already have the knowledge and skills to create simple solid objects will learn techniques to create objects of a more complex nature.

In the first part of these lab exercises, students are introduced to using sweeps and lofts. Both sweeps and lofts require one or more profiles to create a streamlined shape. Students will learn the differences between these operations and understand that sweeps require a sketch profile and a second sketched sweep path to create 3D geometry. In contrast, lofts typically require two or more sketch profiles and optional paths and/or points to control the final geometry.

Further in this lab, students will learn that creating a multi-body part file with separate solids representing each part of an assembly is possible. Such a file allows it to save the solids as individual parts and automatically place them in an assembly.

In this part of the class, students will find that creating multiple solids in a single-part file offers some unique advantages over traditional methods of creating parts in the context of an assembly file. First, there is a single file location where all the design data resides. Second, it is often easier to match parts using this method by simply sketching one part on top of another.

Next, students will be introduced to the Derive tool and learn how to create parts based on other components. They will learn typical applications of the Derive tool, such as creating scaled and mirrored versions of existing parts, creating component arrays, cutting one part from another, and merging an assembly into a single-part file.

Another issue discussed in the class will be analyzing parts to ensure proper fit and function over extreme dimensional values.

Students will learn that when inserting parts into an assembly file, they can verify that the parts can be assembled without collisions by setting each part to be evaluated at the upper or lower tolerance values. In addition, they will see that by specifying dimensional tolerances in parts, they gather valuable design data that will help manufacturing and assembly. They will also learn that in addition to creating parts separately and assembling them, multi-body parts can be used to create combined parts in a single file, making it easier to design tolerances for multiple parts.

During this lab, students will also realize that even the most skilled design engineer will occasionally experience a modeling or design failure. It may also happen that a part was supplied by a customer or colleague who did not use good modeling techniques. Alternatively, radically modifying a fundamental function in a designed part may be necessary. In these situations, editing the drawing changes the base function to a point where the dependent functions cannot be resolved, and a cascade of errors can then occur. Knowing how to fix these errors can save the designer many hours of work.

3. Learning outcomes

During laboratory classes, students will learn to:

- create complex sweeps and lofts;
- work with multibodies and derived parts;
- utilise part tolerances;
- understand and use parameters;
- troubleshoot modeling errors.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the lab's aim and the “sweep” and “loft” modeling methods.
   b. Discuss techniques for creating a multi-body part file.
   c. Discuss techniques for creating parts based on other components, such as scaling, mirroring, component array, etc.
   d. Discuss dimensional tolerance issues.
2. Execution of the exercise:
   a. Create solid and multi-body parts based on instructions provided by the instructor.
   b. Model a complex part (such as a gearbox) using various CAD features such as Boolean operations, surface modeling, etc.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:
- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 3 – Lab 3

1. The subject of the laboratory classes

Reusing parts and features

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The ability to reuse parts and features in other designs is an essential step in increasing productivity. Modern CAD software provides this capability through various workflows.
This lesson introduces students to several methods to help them achieve this goal. Developing the correct workflow depends on several criteria. Students will learn how to reuse parts and features from one design in other designs during this lab.
Students will learn about parametric parts and how they differ from standard parts in these lab exercises. They are essentially table-driven part factories that allow multiple variations to be generated from the same base design.
They will also learn how to configure object dimensions in the parametric part generator, specifying different values for the same parametric dimension, and see that you can include or exclude entire objects and configure parametric part properties. Students will also learn that thread features and workspace features such as workplanes, axes, and points can be configured in addition to general configuration settings.
Later in the lab, students will learn about an efficient CAD modeling technique called geometry reuse. They will learn to reuse existing elements and sketch geometry to create additional elements in the same or other open parts. During the exercises, students will see that it is not necessary to create new sketches to use this technique and that it is possible to copy sketches and elements and create dependent and independent relationships between elements and features.
Students will also learn how to define a relationship between two parts, between two assemblies, or between a part and an assembly by combining file parameters. This method lets you keep all design information in one file and link other files to it to maintain design consistency.

3. Learning outcomes

During laboratory classes, students will learn to:

- create and modify table-driven parts;
- copy and clone features;
- link parameters between two files.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss the parametric part generator.
   b. Discuss the configuration of parametric part features.
   c. Discuss how to combine parametric files.
2. Execution of the exercise:
   a. Make a solid model using the part generator following the instructions given by the class instructor.
   b. Model an assembly with the relationship between parts and the assembly.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:
- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 4 – Lab 4

1. The subject of the laboratory classes

Assembly design workflows

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

A typical assembly file comprises links to its components and assembly relationships. The components are parts or sub-assemblies that exist as separate files. When components are placed in an assembly file, links to those separate files are created in the assembly file. A good assembly design workflow is essential to achieving performance, flexibility, and stability.

In this lesson, students will explore different types of workflows to achieve this goal. This lesson includes discussing how to use subassemblies to improve performance while using subassemblies within a design can significantly improve performance.

In this exercise, the student will learn that when creating an assembly, the initially inserted component is free-floating and can be moved and rotated in any direction unless it is fixed in place or connected to other components. First, the student will create a simple assembly consisting of a drilled base plate and a screw to be inserted into the hole. The student will also notice that if the hole in the base plate part is enlarged, the assembly is automatically updated to reflect this change since it is linked to the part file. To assemble a plate and a bolt, at least one assembly relation must be created by selecting the bolt pin and the hole in the plate. Assembly relationships can be created using the Constraint tool or the Joint tool.

The student will learn that relationships in an assembly have two functions: they define how two or more components are related and limit the degrees of freedom of each component in the assembly. Initially, each component in the assembly file has six degrees of freedom. The degrees of freedom (DOF) are bi-directional and consist of three axial degrees of freedom along the initial x, y, and z axes and total rotational freedom about the same axes.

A component can be fixed so it cannot move or rotate unintentionally. Such a restrained component is fully constrained and has 0 degrees of freedom. Every assembly should have at least one constrained component to remain stable. Assembly constraints connect parts or subassemblies by creating assembly relationships between components to define how they fit together based on a selection of surfaces, edges, vertices, and user-defined parameters. In practice, the constraint function follows assembly techniques where fasteners, adhesives, and welds connect one component to another. Joint allows you to define a relationship between components using a single joint relationship. You can use the constraint tool to create multiple constraints to remove degrees of freedom. In contrast, the same results can be achieved with a single joint that defines the remaining degrees of freedom. Although the Constraint tool can achieve the same result as the Joint tool, the Joint tool results in fewer assembly relationships, which can be much easier for later design modifications.

After completing all of the exercises in this lesson, the student will have mastered using the Constraint and Joint tools to create functional relationships in assemblies, an essential part of learning how to create assemblies in CAD. Assembly relationships are the glue and nails of construction when creating assemblies. Proper assembly relationships will allow you to create stable assemblies and control parts to show an animation of the process.

3. Learning outcomes

During laboratory classes, students will learn to:

- create assembly relationships using the constraint and joint tools;
- organize designs using structured subassemblies;
- work with adaptive components;
- use positional reps and flexible assemblies together;
- copy assembly designs for reuse and configuration;
- substitute a single part for entire subassemblies;
- work with assembly design accelerators and generators;
- use design calculators.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss assemblies and assembly techniques.
   b. Discuss concepts such as degrees of freedom, restraint, etc.
   c. Discuss constraints and joints in assemblies.
2. Execution of the exercise:
   a. Create a simple assembly consisting of a drilled base plate and a bolt to be placed in the hole using the instructions provided by the instructor.
   b. Model the assembly using the learned constraints and joints.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:

- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 5 – Lab 5

1. The subject of the laboratory classes

Project documentation

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

One can start documenting the design using the CAD program at any point in the design process. Although the creation of drawings has traditionally been something that had to wait until the design was fully completed, there are no such limitations with CAD programs. One can start developing an annotated 2D drawing file at any point. However, it is generally recommended to start documenting as late in the design process as possible.

The ultimate goal of this laboratory class is to illustrate how one can use drawing features in CAD programs to create traditional 2D annotated drawings. One can then output the documentation in various file formats, including DWF and PDF.

In the previous laboratory classes, students were introduced to methods for creating simple and slightly more advanced drawings of parts. Creating technical assemblies drawings is not fundamentally different from creating drawings of individual parts.

In this lab class, students will develop and enhance existing skills and learn new advanced drafting techniques and drawing editing tools. They will also learn new dimensioning and annotation tools.

Students will learn how to draw sections and projections based on the parent view and discover that sketches are not only helpful in modeling parts but that one or more sketches can be used to create custom, advanced views on a sheet.

Students will also learn that sketching directly on a drawing sheet can come in handy in many situations; during the lesson, they will create a sketch that will be used to modify a view. They will also see that the sketch they create can be used to delineate the boundary of a section of an assembly to be removed so that the inside of the assembly can be made visible.

A given view can be an intermediate step to another, more important view. Students will learn that in such situations, it is helpful to be able to hide the parent view to avoid clutter on the sheet. You can also hide specific lines and other elements in a selected drawing. On the other hand, if a subassembly is long or most of it has a fixed, unchanging design, you can use an interrupted view, which allows you to hide a uniform section of the subassembly to make the design of the other parts more visible. Automatic text annotation tools are also discussed, allowing you to gather information from various model properties and insert it into drawing sheets and annotations.

3. Learning outcomes

During laboratory classes, students will learn to:

- create and maintain drawing templates, standards, and styles;
- generate 2D drawing views of parts and assemblies;
- annotate drawing views of a model.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
    a. Introduce the purpose of the lab and discuss methods for creating simple and more advanced drawings of parts and assemblies.
    b. Discuss dimensioning and annotation tools.
    c. Discuss techniques for creating a sketch on a drawing sheet and creating breakouts.
    d. Discuss disabling views and disabling element visualization.
    e. Discuss the use of breakout views and automatic insertion of text descriptions.
2. Execution of the exercise:
    a. Create sectional drawings and plan views based on the parent view as instructed by the instructor.
    b. Create a sketch to modify the view.
    c. Prepare technical specifications based on the CAD design, including dimensions, materials, tolerances, etc.
3. Summary:
    a. Summarize the lab and review its objectives.
    b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:

- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 6 – Lab 6

1. The subject of the laboratory classes

Advanced assembly and engineering tools

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Previous laboratory classes have covered most of the tools needed to build functional assemblies routinely. In this lesson, students will learn some new features.

Navigating within an assembly while maintaining acceptable system performance is very important. This is because complex assemblies have high memory requirements, and insufficient memory can lead to data loss.

This problem can be solved by using visual representations. During the class, students will learn how to use them to manage the assembly's visualization. A unique feature of these tools is that special engineering calculators can be used. Students will learn how to design typical device components and how to ensure that they fulfill their purpose.

One often underestimated aspect of working with assemblies is managing the design and presentation of the finished project. Another, even more important, is the system requirements of working with extended assemblies. In this class, students will learn about examples of visual representations that can be used to address these issues.

They will see that visual representations can control the visibility and appearance of components in an assembly and that creating multiple representations allows a user (or multiple users) to view an assembly differently. Not only can you hide selected components, but you can also remove the data for those components from memory by changing the level of detail in the representation. When working with complex assemblies on a system with relatively limited capabilities, changing the level of detail can be extremely useful.

In the next step, students are introduced to unique tools that facilitate the design of typical machine components. They are known collectively as Design Accelerators and are divided into two basic types: calculators, which calculate the necessary parameters (such as fastener sizes), and creators, which are used to automatically create components or use built-in calculation functions to facilitate the selection of components with the correct parameters, such as screw size or shaft diameter.

Students will learn how the bearing wizard works and how to use it. They will also learn how to use the shaft wizard and calculate and visualize shaft properties. They will then learn how to use the helical gear wizard and the slot wizard and how to use other utilities for editing assemblies.

3. Learning outcomes

During laboratory classes, students will learn to:

- manage the environment of the assemblies;
- use tools from the Design Accelerator group;
- employ support tools for editing assemblies.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss advanced assembly and engineering tools.
   b. Discuss the management of the assembly environment.
   c. Discuss methods for creating visual representations with varying levels of detail.
   d. Discuss the use of tools from the Design Accelerator group.
2. Execution of the exercise:
   a. Create visual representations of objects provided by the instructor.
   b. Create a shaft using the shaft wizard based on instructions provided by the instructor.
   c. Introduction to the design of a hand-powered metal grinder.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:

- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 7 – Lab 7

1. The subject of the laboratory classes

Generative design – use of the shape generator for conceptual analysis

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Generative design is an exploratory design process. Professionals such as designers or engineers feed design objectives into generative design software, supplemented by parameters such as performance or spatial requirements, materials, production techniques, and financial limitations. This software sifts through all possible solution combinations, rapidly generating alternative designs. It tests and learns from each iteration, understanding what succeeds and falls short. Generative design is a form of artificial intelligence that harnesses the potential of cloud computing and machine learning to accelerate the entire journey from design to manufacturing.

Students will learn to quickly identify solutions that reduce mass and material consumption while meeting performance standards, design objectives, and engineering constraints. They will also understand how to achieve sustainability goals by using generative design to simplify product design, reduce manufacturing waste and assist in selecting more sustainable materials.

Generative design creates high-performance 3D models with optimized geometry to solve complex engineering problems. It enables the consolidation of multiple parts into a single component by reducing the total number of components and reducing the weight of parts and components by using the least amount of material to make the part as efficient as possible. It also enables increased efficiency by designing stronger parts and components. Generative design provides designers with a choice of design options, editable CAD geometry, and the ability to influence the design based on manufacturing technology. There is no single solution with generative design, but many reasonable solutions exist. It is up to the designer to choose the model that best suits his/her needs.

CAD modeling using generative design is one of the most fascinating aspects of modern design. This class teaches students to use CAD software and generative design to create optimized 3D models. To begin, students will be introduced to the basics of working with CAD software and generative design. They will learn how generative design can help create optimized models that meet specific functional and structural requirements. They will learn how to define specific requirements for a design, such as strength, weight, or material cost requirements, and then have the software generate alternative solutions that meet those criteria. Students will then create their models using the generative design technique. Using the knowledge gained in the class, they will define their requirements and then use generative design to create optimized solutions.

This class will provide an understanding of the philosophy behind CAD and generative design and practical skills in these areas.

3. Learning outcomes

During laboratory classes, students will learn to:

- improve design cycle productivity;
- improve product performance;
- optimize production costs;
- explore a broader range of design options;
- optimize for materials and manufacturing processes.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss the principle of generative design and the process of defining requirements for a project in the context of generative design.
   b. Discuss examples of the use of generative design in various engineering fields.
2. Execution of the exercise:
   a. Discuss and define requirements for a sample project and generate different solutions.
   b. Analyze the results and compare the different solutions generated.
   c. Perform an individual project using a generative design based on the instructions given by the instructor.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:

- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 8 – Lab 8

1. The subject of the laboratory classes

Plastics design features

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

When designing thin-walled plastic parts, one can choose between two common approaches. One approach is to start with a solid and shell it out; the other is to start with a surface and thicken it. Although these methods approach thin-walled features from different starting points, the result can be the same. One can also mix and match the two methods required for a design. Typically, other features are added to the plastic part once the base feature is created. More CAD software has several specialized tools for creating plastic part features in the part modeling environment.

In this lesson, students will learn how to create parts designed to be made of plastic, taking into account the specific components and characteristics of such parts.

In this class, students will become familiar with the CAD tools typically found in the Plastic Part panel. Students will understand that learning about these tools is very important because they can be used for many more applications than the panel name suggests, such as designing sheet metal structures to intelligently creating fillets in traditional solid models.

They will also find that the tools enable non-standard modeling techniques, such as creating solids from surfaces or constructing multi-body models, and that, in many cases, these techniques can replace simple extractions or methods for building an assembly from separate components.

In these lab exercises, students will learn the methodology for creating components specific to plastic products and the methodology for creating an assembly based on a multi-body model to maintain a uniform shape. Students will also learn that while it is possible to use simple methods to create models similar to those created using specialized plastic part design tools, the traditional approach to modeling some standard features often found in plastic assemblies would require many different tools and features.

During the labs, students will learn methods for creating a solid based on a surface, joining surfaces, separating solids, adding bosses, and creating connecting elements. They will learn the tools for creating pairs of matching join elements and discover that the two elements included in such a join have a rather complex structure that would require the creation of multiple objects to model with standard tools.

Students will then learn about the tools included in CAD software that allow them to perform various analyses of the shape and topology of the model.

They will learn to analyze part curvature, cross-sections, and surface continuity.

They will perform tilt analysis, which allows them to make a preliminary estimate of the ease with which the finished part will separate from the mold. This knowledge makes it possible to modify the part's design early in the design process.

3. Learning outcomes

During laboratory classes, students will learn to:

- create thicken/offset features;
- create shell features;
- create split features;
- create lip and groove features;
- create snap-fit features;
- create rib and web features;
- create an injection mold.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and review the CAD tools typically found in the Plastic Parts panel.
   b. Discuss the methodology for creating parts specific to plastic products.
   c. Discuss the methodology for creating an assembly based on a multi-body model to maintain a consistent shape.
   d. Discuss tools for performing various analyses on the shape and topology of the model.
2. Perform the exercise:
   a. Create a surface that encloses the structure, which is then converted to a solid model and enhanced with the necessary details.
   b. Create connection elements to assemble the two parts of the plastic housing using screws.
   c. Perform a tilt analysis to estimate the ease of separation of the finished part from the mold.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:
- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

Topics 9 – Lab 9

1. The subject of the laboratory classes

Stress analysis and dynamic simulation

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

This laboratory lesson introduces students to stress analysis tools and dynamic simulation environments found in CAD software. The stress analysis environment allows to perform static and modal analysis on parts and assemblies by defining component materials, loads, constraints, and contact conditions. A second type of stress analysis uses beam elements represented by a line segment centered on a frame generator member and interpolates the effects of loads on the frame geometry. This greatly improves the speed of the analysis.

The dynamic simulation environment allows an assembly-in-motion analysis by specifying loads, constraints, joints, velocities, accelerations, and environmental factors such as gravity and friction. These environments can be used together to determine the motion loads imposed on a component by another component at a given time.

In this lesson, students will learn how to perform stress analysis and dynamic simulation using CAD software.

Students will learn that FEA is the analysis of a complex object solved by dividing the object into a mesh of more minor elements on which controllable calculations can be performed. Stress analysis in CAD software uses this method to analyze the design under a given set of user-specified conditions to determine fundamental trends related to the specifics of the design. Simulation tools available in CAD programs typically allow fundamental analysis to validate the design. This can be useful to establish the basics of a design before going down the wrong path. These tools can also determine if a component or assembly is over- or under-designed for a given set of loads.

Stress analysis tools are also helpful in determining how component size and position affect part integrity. For example, how close can a hole be moved to the edge of a bracket? Students will find that these tools are ideal for these questions and can significantly reduce the number of physical prototypes needed to prove the final design.

Dynamic simulation allows you to make model elements move to see how the elements interact and determine the force exerted on one element (or group of elements) by another element (or group of elements).

In this course, students will learn about the dynamic test environment. They will learn how it allows them to define how parts interact with each other and how the forces present create motion in the context of the timeline. They will learn how simulations can be used to determine how and when parts interact and the value of the force present at any given time. For example, they will use these tools to simulate the force applied to a shaft to rotate a lever that contacts a stop to determine the maximum force present throughout the sequence. Once this maximum force is determined, they will apply it as a load to the shaft in a static stress analysis.

3. Learning outcomes

During laboratory classes, students will learn to:

- set up and run stress analysis simulations;
- set up and run dynamic simulations;
- export results from the dynamic simulation environment to the stress analysis environment.

4. Necessary equipment, materials, etc

Computer with CAD/CAM software installed and internet access.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory classes are conducted using specialized software.

Laboratory class outline:

1. Introduction:
   a. Introduce the purpose of the lab and discuss the stress analysis tools and dynamic simulation environment available in CAD software.
   b. Discuss the methodology for performing static stress and strain analysis.
   c. Discuss the methodology for performing dynamic analysis.
2. Perform the exercise:
   a. Perform a simulation of the force applied to the shaft used to rotate the lever, which in turn contacts the stop to determine the maximum force that occurs throughout the sequence.
   b. Perform a static stress analysis using a predetermined force value as the load on the shaft.
   c. Perform an analysis of the results obtained.
3. Summary:
   a. Summarize the lab and review its objectives.
   b. Students will submit their independent projects as lab reports.

Laboratory exercises will consist of independent student modeling of objects assigned by the instructor. The instructor will present the modeling techniques discussed in the first part of the class by presenting his CAD workspace using a multimedia projector. At the same time, students will perform the presented exercises on assigned computers in the lab. In a subsequent stage, students will independently model objects assigned by the instructor. This part will end with the preparation and submission of a report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kuang-Hua Chang: *Product Design Modeling using CAD/CAE. The Computer Aided Engineering Design Series*. Academic Press 2014
- Munford P., Normand P.: *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016*: Autodesk Official Press. John Wiley & Sons, Inc. 2015

Additional, optional literature:

- any textbooks on CAD modeling

7. Additional notes

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8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MAUFACTURING AND CHARACTERIZATION OF SINGLE CRYSTALLINE MATERIALS

Code: MCSCM

UNIVERSITY OF SILESIA IN KATOWICE
UNIVERSITY OF ŽILINA

Course content – lecture

Topic 1

1. The subject of the lecture

Thermodynamic, kinetic, and structural aspects of the single-crystallization process

2. Thematic scope of the lecture

Crystallization is one of the most ubiquitous physical phenomena in nature. It is generally accepted that it begins with nucleation, i.e., the formation of a nanometer-sized nucleus (an ensemble of atoms), followed by growth of the nucleus. Nucleation is the first random formation of a distinct thermodynamic new phase (daughter phase or nucleus) that can irreversibly grow into a larger-sized nucleus within the body of a metastable parent phase. The classical nucleation theory assumes that nucleation occurs in a spherical crystallite with a stable network structure in the bulk. The above-mentioned and other nucleation theories will be presented during the lecture. Most crystal growth processes are performed close to thermodynamic equilibrium and can hence be characterized by equilibrium thermodynamics. Knowledge of the thermodynamic foundations of crystallization processes is essential for the design of new materials, including single-crystalline materials. Several useful terms and tools for understanding crystal growth from a thermodynamic point of view will be presented during the lecture. The introduced knowledge will focus mainly on systems with two components in coordinates temperature versus composition. Phenomena such as solid solutions, eutectics, and peritectics will be discussed. Additionally, this lecture aims to better understand the complex phase behavior of single-crystalline materials, the related crystallization kinetics, and its consequences on microstructure formation. Crystallization kinetics are characterized by two dominant processes, nucleation and growth kinetics, occurring during crystallization from solution. These two types of kinetics will be described during the lecture. Nucleation kinetics is related to the formation rate of stable nuclei, and growth kinetics is related to the rate at which stable nuclei grow to a macroscopic crystal. The knowledge will be supported by a discussion of phenomena related to the thermodynamics and kinetics of phase transition during the crystallization process of single-crystalline materials. Basic definitions and issues related to solidification will be presented: nucleation, thermodynamic conditions of nucleus formation, Gibbs free energy, etc. The presented information regarding the phase diagrams will be described and characterized in relation to the single-crystallization process. Knowledge about the growth mechanisms and the characteristics of the crystallization front will be presented.

3. Learning outcomes

- Has extended and in-depth knowledge in the field of thermodynamic and kinetic crystallization
- Has extended and in-depth knowledge of the theory of crystal growth

- Can analyze phase diagrams in terms of solidification and crystal growth

4. Didactic methods used

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.
Case study - presentation of specific examples of the mechanism of single-crystal formation
Discussion - participants will be encouraged to actively participate in the discussion on the presented issues
Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.
In the first week, issues related to general knowledge about thermodynamics and the kinetics of crystallization will be discussed. In the second week, Students will learn about phase diagram analysis and single-crystal growth.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- T. Nishinaga, "Handbook of Crystal Growth – Fundamentals" Elsevier 2014

6. Additional notes

- The topic will be covered in the next two lectures.

Topic 2

1. The subject of the lecture

Methods of single-crystalline materials manufacturing

2. Thematic scope of the lecture

The lecture aims to familiarize students with the classification of solid materials, especially single-crystalline materials, and the classification of various techniques for producing single-crystals depending on the type of obtained product and its application. The classification of solids will be presented based on atomic arrangement, binding energy, physical and chemical properties, and the geometrical aspects of the crystalline structure. In one class, the atoms in a crystalline solid are set irregularly, without any short- or long-range order in their atomic arrangement. This class of solids is commonly known as amorphous materials. In another class, the atoms or groups of atoms of the solid are arranged in a regular order. These solids are usually called crystalline solids. The division of crystalline solids into two categories will be presented: into the single-crystalline and the polycrystalline solids. Single-crystalline solids will be described as materials in which the entire sample has a continuous and unbroken crystal lattice to the edges of the sample with no grain boundaries. A low density of defects in single-crystalline materials is related to the manufacturing method. The manufacturing of single-crystalline methods is mainly based on the crystallization process. The classification of crystallization methods from liquid, from vapor, and from others will be discussed. The types of crucibles used in each method, the materials from which they are made, and their properties will be discussed. During the lecture, specific techniques for producing large single-crystalline materials will be presented. Groups of methods used to manufacture materials for the electronic industry and engineering materials for the aviation industry will be described. Differences in the product manufacturing technology from single-crystalline materials on an industrial and laboratory scale will be explained. The main parameters that allow manufacturing process control will be defined. Several of the most important and frequently used methods of manufacturing single-crystalline materials will be described in detail, along with an analysis of technological parameters and methods of their modification. For such techniques, the grain selection methods for choosing the needed crystal orientation during directional crystallization will be described in detail.

3. Learning outcomes

- Has wide, general, theoretically based, and structured knowledge of techniques used in single-crystalline manufacturing
- Has in-depth, theoretically based knowledge of the most significant techniques used in single-crystalline manufacturing

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.

Case study - presentation of specific examples of the technological parameters applied during the manufacturing process

Discussion - participants will be encouraged to actively participate in the discussion on the presented issues

Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.

In the first week, issues related to the general division and classification of techniques for manufacturing various classes of single-crystalline materials will be discussed. In the second week, Students will learn in-depth about the most significant techniques.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- T. Duffar, "Crystal Growth Processes Based on Capillarity" Willey 2010

6. Additional notes

- The topic will be covered in the next two lectures.

Topic 3

1. The subject of the lecture

Directional crystallization

2. Thematic scope of the lecture

The crystallization process involves permanently joining the crystal surface atoms moving from the liquid phase. During the lecture, various processes of joining atoms on the crystal surface and the physical phenomena occurring during these processes will be described. They will be described based on the change in the Gibbs free energy of the phase system during the phase transformation. The surface of the solid phase having direct contact with the liquid phase is called the crystallization front. The crystallization front will be described in the context of the border between the liquid and solid phases. The progress of the crystallization front increases the solid phase at the expense of a decrease in the liquid phase, so the parameters related to the front progress will be explained. The main parameter is the rate of progress. It determines the rate of crystallization, which in turn significantly influences the structure of the obtained material. The issues of equilibrium crystallization temperature and true crystallization temperature and their influence on the growth process of single-crystalline material will be discussed. The difference between the equilibrium crystallization temperature and the true temperature of the crystallization front, called undercooling, will be discussed. Undercooling as the driving force of the crystallization process will be explained in detail. Directional crystallization methods using the Bridgman, Czochralski, and floating zone (Pfann) techniques will be described in detail. The phenomena occurring during crystallization using each of the methods will be presented. The topography of the crystallization front and its dependence on the crystallization method and crystallization process conditions will be presented. Special attention will be paid to directional crystallization using the Bridgman method. Various techniques in the Bridgman method will be described: crystallization with a vertical temperature gradient and crystallization with a horizontal temperature gradient. The differences between the techniques mentioned above and their advantages and disadvantages regarding various single-crystalline materials will be noted. The components of devices for producing single-crystalline materials using directional crystallization methods and the role of each element of the equipment in the production process will be described. Equipment for the production of single-crystalline materials and their types will be presented. The division and comparison of equipment according to its use will be presented, e.g., for the production of single-crystalline materials on a laboratory scale and industrial scale. Differences in processes on a laboratory and industrial scale will be defined. The influence of directional crystallization parameters on the morphology and selected properties of the single-crystalline material will be presented.

3. Learning outcomes

- Has in-depth knowledge of the process of directional crystallization from a liquid
- Can describe in detail the crystallization process using the Bridgman and Czochralski methods

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.
Case study - presentation of specific examples of the directional solidified materials
Discussion - participants will be encouraged to actively participate in the discussion on the presented issues
Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.
In the first week, issues related to general knowledge about directional crystallization and effects exist during crystallization. In the second week, students will learn about specific methods and equipment used.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- T. Duffar, "Crystal Growth Processes Based on Capillarity" Willey 2010
- G. Dhanaraj, K. Byrappa, M. Dudley, V. Prasad, „Springer Handbook of Crystal Growth" Springer 2010

6. Additional notes

- The topic will be covered in the next two lectures.

Topic 4

1. The subject of the lecture

Comparative analysis of structural perfection and technological parameters of single-crystalline materials manufacturing

2. Thematic scope of the lecture

During the production of products from single-crystalline materials, various types of defects may form, which affect the quality of the single-crystalline material. The lecture will present general information on the types and classification of defects occurring in single-crystalline materials depending on the scale of size and way of creation, as well as the main types of defects that may occur in single-crystalline materials and products, as well as their division according to geometry and impact on the quality of the material. A low concentration of defects, e.g., due to a lack of grain boundaries, can give single-crystalline materials unique properties thanks to the structural perfection of the product. The Czochralski and the Bridgman techniques are most commonly used to manufacture single-crystalline materials. Because of the good physical properties, particularly mechanical, optical, and electrical properties, single-crystalline materials produced by the Czochralski process are widely used in the semiconductor and solar photovoltaic industries. The other application of single-crystalline materials is manufacturing the turbine blades using the Bridgman technique using nickel-based alloy. The above applications require high durability of components made of single-crystalline materials, which is related to the need to achieve high structural perfection. Structural perfection and the factors influencing it will be defined during the lecture. Factors influencing structural perfection related to the technological parameters of the single-crystalline materials production process will be discussed in detail. The technological parameters of the single-crystal manufacturing process will be presented, and their influence on selected properties of single-crystalline materials will be discussed. For example, differences in the dendritic structure of single-crystalline nickel-based superalloys will be revealed, resulting from different pull-out rates from the high-temperature zone. The morphology and arrangement of the created dendrites will be analyzed, and the influence of visible differences on structural perfection will be discussed. The influence of heat treatment on defects created during manufacturing will be presented; in particular, the degree of reduction of growth defects after the heat treatment and the type of defects that remain in the single-crystalline material will be analyzed. The main parameters of the heat treatment process and their influence on the elimination of defects will be specified. The effects of modifying technological parameters will be described. Possibilities and methods of reducing or eliminating defects that occur in single-crystalline materials to improve the structural perfection of products will also be presented.

3. Learning outcomes

- Has in-depth knowledge of types and classification of defects occurring in single-crystalline materials
- Can determine the influence of the technological parameters of single-crystalline materials manufacturing on their structural perfection

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.

Case study - presentation of specific examples of the technological parameters

Discussion - participants will be encouraged to actively participate in the discussion on the presented issues

Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.

In the first week, issues related to general knowledge about types and classification of defects *will be discussed. In the second week, Students will learn how to improve the structural perfection of single-crystalline materials by modification of technological parameters.*

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- K. Byrappa, “Crystal Growth Technology” Springer 2003

6. Additional notes

- The topic will be covered in the next two lectures.

Topic 5

1. The subject of the lecture

Manufacturing and characterization of modern single-crystalline materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will familiarize students with modern single-crystalline materials, manufacturing technology, and characterization methods. Students will learn what types of single-crystalline materials are considered modern and what their applications are. They will also learn the difference between a single-crystalline material and a strictly single crystal and how to distinguish them practically. The essential groups of these single-crystalline modern materials and their manufacturing methods, structure, and properties will be presented.

In-depth information related to the manufacturing process will be provided on specific groups of single-crystalline materials, such as superalloys and composite electronic materials. Nickel or cobalt-based superalloys are modern high-temperature engineering materials used mainly in constructing turbine engines, most often for turbine blades in the hot section. Types of superalloys, their genesis and development, structure, and properties will be presented. The major methods of manufacturing turbine blades made of superalloys and their intermediate and finishing processing methods will be presented. The process of preparing ceramic casting molds will be presented, including the creation of dies and wax models and then the spraying of subsequent layers of ceramic coating until the final casting mold is obtained. Later in the lecture, the manufacturing technology of composite electronic materials will be described. Modern single-crystalline semiconductor materials are used, among others, to produce various types of sensors and detectors. The division and characterization of crucibles used to produce single-crystalline electronic materials will be presented depending on the preparation method. Students will learn about finalizing the manufacturing process through removing molds or crucibles, sanding and cleaning surfaces, product finishing machining, treatment, applying protective coatings, etc. For example, the solution heat treatment will be described in-depth to eliminate the microsegregation of the microstructure of γ and γ' precipitates. The microsegregation negatively affects the mechanical properties of single-crystalline materials. During the lecture, among others, heat treatment being carried out in a hardening furnace will be described as ensuring a fast hardening rate. In this way, it is possible to standardize chemical heterogeneities, close porosity, and establish a fine and uniform microstructure through rapid quenching and subsequent aging in one processing step. Microstructure defects created during manufacturing can be eliminated depending on treatment parameters such as temperature, pressure, and hardening.

General information on the characterization procedures will be provided on different modern single-crystalline materials, such as superalloys and composite electronic materials. A division of characterization methods will be presented depending on the type of single-crystalline material and the size and shape of the manufactured product. The most important research methods from the point of view of quality control of the manufactured single-crystalline element will be noticed. The lecture will present general information on optical and electron microscopy methods and methods based on X-ray diffraction and their application in the study of modern single-crystalline materials.

3. Learning outcomes

- Has in-depth knowledge of classification, obtaining methods, structure and properties of superalloys
- Has in-depth knowledge of classification, obtaining methods, structure and properties of selected single-crystalline composite semiconductor materials

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation - lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.
Case study - presentation of specific examples of superalloys
Discussion - participants will be encouraged to actively participate in the discussion on the presented issues
Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.
In the first week, issues related to superalloys will be discussed. In the second week, issues related to single-crystalline electronic materials will be discussed.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- M.J. Donachie, S.J. Donachie, „Superalloys: A Technical Guide” ASM 2002
- R. C. Reed, „The Superalloys, Fundamentals and Applications” Cambridge Univ. Press 2008
- R. Fornari, “Single Crystals of Electronic Materials, Growth and Properties” Elsevier 2018

6. Additional notes

- The topic will be covered in the next two lectures.

Topics 6

1. The subject of the lecture

Testing methods of single-crystalline materials

2. Thematic scope of the lecture

Many research methods based on various physical phenomena are used to test engineering materials. The methods include those that can be used for all materials and those intended only for specific groups. During the lecture, the classification of research methods will be presented depending on the physical phenomenon used, the properties and parameters tested, and the covering area of the material. The latter is particularly important because certain properties of a single-crystalline material can only be analyzed on entire large products, not fragments like samples. Research methods used to study single-crystalline materials will be described in detail. The research methods to confirm the single-crystalline nature of the material, based mainly on X-ray radiation, will be presented. Methods to obtain data on crystallographic properties and parameters, such as the crystal lattice parameter, crystal lattice symmetry types, crystal orientation determination methods, angular relations between selected crystal planes, etc., will be presented. In particular, microstructure analysis methods using light and electron microscopy, such as scanning electron microscopy and transmission electron microscopy, will be described. Research methods to determine the mechanical properties of single-crystalline materials will also be described in detail. These are, for example, strength, creep resistance, thermal resistance, and corrosion resistance. The structural perfection of single-crystalline materials is important for the applicability of products made of the materials. Therefore, the lecture will present research methods for analyzing various types of structural defects that may be created in single-crystalline materials. The methods mentioned above will be classified by the type of defects identified and their size scale. Defect analysis methods using X-ray diffraction methods and nuclear methods will be presented. Various X-ray methods will be described in-depth, such as X-ray diffraction topography, Ω-scan diffraction method, etc. The possibility of using positron annihilation lifetime spectroscopy to study defect structure at the atomic level will also be presented. An important element of the lecture will be the presentation of the reasons, methods, and effects of combining the results of various research methods. Often, research methods that allow for examining important properties at the atomic scale in a small sample area will not detect defects imaged by methods that collect data from a large product area at the micro and macroscopic scale. Only the combination of these methods' results allows for a detailed analysis of the revealed properties.

3. Learning outcomes

- Has in-depth knowledge of the classification and methods applied in single-crystalline materials testing
- Can choose the appropriate method for testing the structure of single-crystalline materials in terms of their quality

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.
Case study - presentation of specific examples of single-crystal testing
Discussion - participants will be encouraged to actively participate in the discussion on the presented issues
Quiz - a short quiz provided after finishing the last lecture on the topic to help participants remember the most important knowledge from the lecture

- The main topic will be continued for two more classes.
In the first week, issues related to general knowledge about classification and testing methods of single-crystalline materials will be discussed. In the second week, Students will learn about selected structure analysis methods.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- P. Luger, "Modern X-Ray Analysis on Single Crystals" DeGruyter 2014
- G. Cailletaud, G. Eggeler, J. Cormier, L. Nazé, V. Maurel, "Nickel Base Single Crystals Across Length Scales" Elsevier 2021

6. Additional notes

- The topic will be covered in the next two lectures.

Topic 7

1. The subject of the lecture

X-ray diffraction in the study of single-crystalline materials

2. Thematic scope of the lecture

Among many methods for testing single-crystalline materials, methods based on X-ray radiation's effect on matter are among the most important. This is because methods based on X-ray diffraction are non-destructive methods that can provide a lot of important data about the structure of single-crystalline materials. X-ray diffraction is based on constructive interference of monochromatic X-rays and a single-crystalline sample. First, details about X-ray radiation and how to generate it will be discussed. X-ray tube types will be presented, and the differences in construction, principle of operation, and intensity of the primary radiation beam will be discussed. The formation and characteristics of X-rays used for single-crystalline materials testing will be presented. The required conditions to produce constructive interference (and a diffracted beam) during the interaction of the incident beam with the single-crystalline sample will be presented. The primary beam-forming systems and types of X-ray detectors will be discussed, along with a comparison of their parameters and applicability. The interaction of X-ray radiation with single-crystalline material will be presented. The lecture will provide a detailed presentation of X-ray methods used to study single-crystalline materials. The described methods will be classified in terms of purpose, the scale of the examined properties, radiation source, and ways of forming the X-ray beam. The strengths and limitations of X-ray diffraction on single-crystalline materials will be discussed. For example, the advantages will be presented, such as no separate standards required, non-destructive, and detailed crystal structure, including unit cell dimensions, bond lengths, bond angles, and site-ordering information, which can be analyzed. Research methods based on X-ray diffraction also have disadvantages, which will be described during the lecture, e.g., the sample must be robust (stable) and optically clear, and twinned samples can be handled with difficulty; data collection generally requires a relatively long time. The methods and means of recording the obtained results will be described in detail. Typical single-crystalline material structures contain several thousand unique reflections, whose spatial arrangement is called a diffraction pattern. Indices of crystal planes may be assigned to each reflection, indicating its position within the diffraction pattern. The procedures for interpreting the obtained X-ray diffraction patterns will be described in detail, depending on the method used in the research. The methods of X-ray diffraction topography, the omega-scan diffraction method, and the Laue method will be described in detail. Procedures for interpreting and relating the results with those obtained using other research methods will be presented.

3. Learning outcomes

- has in-depth knowledge of the use of X-rays in the study of single-crystalline materials
- has in-depth knowledge of the phenomena on which the most important X-ray methods for testing single-crystalline materials are based

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Multimedia presentation – the lecture realized with a multimedia visual presentation to provide knowledge on the discussed issues.
Case study - presentation of specific examples of the X-ray topography studies
Discussion - participants will be encouraged to actively participate in the discussion on the presented issues
Quiz - a short quiz provided after finishing the last lecture on the topic to help teach participants the main information on the topic.

- The main topic will be continued for two more classes.
In the first week, issues related to general knowledge about X-ray diffraction, X-ray apparatus, and equipment will be discussed. In the second week, Students will learn about the most important X-ray methods for testing single-crystalline materials.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- P. Luger, "Modern X-Ray Analysis on Single Crystals" DeGruyter 2014

6. Additional notes

- The topic will be covered in the next two lectures.

Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

Thermal analysis of solidification process – phase diagrams

2. Thematic scope of the laboratory classes

The exercise aims to familiarize students with the solidification process of two-component alloys and the phenomenon occurring during the process. Students learn the principles of measurement and analysis of parameters of the solidification process of metal alloys and the effects of modifying these parameters. The methods and purpose of constructing heating and cooling curves will be presented. Students will independently construct heating and cooling curves for a simple two-component alloy. For this purpose, they will prepare a heating stand with thermal shields to stabilize temperature changes and a crucible with the material for melting. They will also prepare a temperature measurement system by calibrating a thermocouple. The subject of the exercise is also related to the creation of simple two-component phase diagrams based on the obtained heating and cooling curves. Students will construct simple phase diagrams based on the data (heating and cooling curves) obtained in the first part of the exercise for an alloy with different stoichiometric ratios of components. Using the constructed phase diagrams, students will determine the percentage of each component phase at different stages of solidification of alloys with different stoichiometric ratios and chemical compositions. They will also perform comparative analyses of calculated values.

3. Learning outcomes

- can measure temperature using different methods, e.g., using a thermocouple
- can construct cooling and heating curves based on temperature measurements during solidification and melting
- can construct simple phase diagrams based on cooling and heating curves
- can analyze simple phase diagrams regarding chemical composition and the percentage of individual phases

4. Necessary equipment, materials, etc.

- heat resistant cups
- heater/burner
- low-temperature two-component alloys with various amounts of elements, e.g. Sn-Pb
- temperature sensor, e.g., thermocouple with equipment or pyrometer
- stopwatch

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Presentation of the lab's objective and discussion of the importance of a solidification process.
   - Discussion on the experiment stages and a description of the required parameters measurement procedure.
3. The division of labor:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team will receive a set of low-temperature two-component alloys with different chemical compositions.
   - The alloys should be melted by heating them uniformly while measuring the temperature at regular intervals, e.g., every 3 s.
   - A similar procedure should be performed during solidification when cooling the alloys.
   - Based on the obtained data, graphs should be prepared to show the temperature-time relationship, i.e., cooling and heating curves.
   - Students will identify the melting point by determining the temperature at which the cooling (and heating) curves are plateau or clearly changes.
   - By taking a series of cooling and heating curves for the same alloy system over a range of compositions, students will determine the liquidus and solidus temperatures for each composition.
   - Then, students, by superimposing cooling curves of different chemical compositions on one graph, removing the time axis, and replacing it with the composition, will indicate the solidus and liquidus temperatures for a given composition and construct a phase diagram.
   - Finally, students will determine the fraction of each phase for the selected alloy composition.
5. Results analysis:
   - Each team will present the results of their research in the form of a short presentation.

- Teams will discuss the conclusions regarding differences in the shape of heating and cooling curves for alloys with the same chemical compositions and differences in melting point temperatures for different chemical compositions.

6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Summary of experience and critical evaluation of suitability and complexity of the method for constructing phase diagrams.
   - Discussion of the obtained results and formulated conclusions.
   - Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below text related to the topic:

- H. Saka, "Introduction To Phase Diagrams In Materials Science And Engineering" WSPC 2020 ISBN:9789811203725, 9811203725

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topics: cooling and heating curves, phase diagrams, solidification process, the level rule, phase transformations.

Topic 2

1. The subject of the laboratory classes

Raw materials preparation for single-crystallization

2. Thematic scope of the laboratory classes

The subject of the exercise is related to the process of preparing raw materials for the crystallization process of single-crystalline material. At the beginning of the exercise, several phase diagrams will be provided for students to analyze. Based on the phase diagrams provided and information from the teacher, students will select several chemical compositions of alloys, for which they will then prepare weighed portions. The raw elements preparation process will begin with analyzing and selecting data available for each chemical element in the selected phase of the alloy. Then, each component element's percentage composition will be calculated based on the prepared chemical data. The next step will be to calculate the weight of each raw chemical element, which will also be related to the expected total weight of the product. After completing the calculation part of the exercise, students will start preparing raw materials. The raw chemical elements will be crushed or cut at this stage depending on the initial form the manufacturer supplied. The calculations made earlier will be used to weigh each chemical element that has been previously crushed. Raw chemical elements with the required mass will be placed together in the crucible, ensuring that the method of loading the crucible is consistent with the technological principles of melting. Attention should be paid to, among other things, the melting points of individual chemical elements and the possibility of evaporation of the raw materials out of the crucible. If the volume of the batch material after weighing is too large concerning the size of the crucible, the load will be compressed into a form that allows it to be placed entirely in the crucible.

3. Learning outcomes

- can calculate the weight content of the raw elements based on the stoichiometric formula of the alloy
- can prepare the raw materials for the manufacturing process

4. Necessary equipment, materials, etc.

- pure elements, e.g., Al, Cu, Fe, in various forms (rods, bullets, powder, sheets, etc.)
- laboratory scales
- tweezers, laboratory gloves, cutters
- laboratory press with steel form
- ceramic crucibles

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
    - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
    - Presentation of the lab's objective and discussion of the importance of preparing raw materials for the crystallization process in single-crystalline materials technology.
    - Discussion of the stages of the experiment, along with a description of the individual procedures required.
3. The division of labor:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
    - Each team will receive data on the chemical composition that must be prepared to manufacture a single-crystalline material.
    - In the first step, students must find each element's atomic mass in the composition using the periodic table.
    - Students then determine the total mass fraction of each element in an alloy with a specific chemical composition and total molecular mass.
    - In the next step, students calculate the percentage mass composition of each element contained in the alloy.
    - At the end of the calculation part, students determine the weight of the individual chemical components of the alloy to manufacture the single-crystalline element with the given total weight.
    - Later, during the class, students prepare raw elements for weighing and melting, forming a shape suitable for placing in the casting mold.
    - Students weigh each of the prepared raw elements according to previous calculations.
    - Students place the weighed raw elements in a casting mold, preparing them for melting. If there will be problems with placing raw materials in the casting mold, students must compress them using the laboratory press.
5. Results analysis:
    - Each team will present the results of their research in the form of a short presentation.

- The teams will discuss conclusions regarding the results of calculations of the mass fraction of individual elements in the alloy and problems with placing the raw materials in the mold.
- Students will evaluate the influence of the compressing process on the parameters of raw materials.

6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Summary of experience and critical evaluation of suitability and complexity of the method for preparing raw materials for manufacturing.
   - Discussion of the obtained results and formulated conclusions.
   - Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below text related to the topic:

- G. Dhanaraj, K. Byrappa, M. Dudley, V. Prasad, „Springer Handbook of Crystal Growth" Springer 2010 I SBN:9783540747611, 3540747613

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topics: attributes of chemical elements, analysis of the periodic table of elements, atomic and weight percentage of elements in a chemical compound.

Topic 3

1. The subject of the laboratory classes

Single-crystallization process

2. Thematic scope of the laboratory classes

The subject of the exercise is related to the crystallization process of single-crystalline materials. The stages of preparation for melting and solidifying will be presented, i.e., placing the crucible in the growth chamber, installing the furnace components depending on the single-crystallization technique used, preparing the growth chamber protective atmosphere, and setting the furnace parameters. Students will take part in the single-crystallization process, observing the phenomena taking place, controlling the temperature of the melt and other technological parameters, e.g., the speed of moving the crucible out of the high-temperature zone. The crystallization process will begin with selecting the method that will be used to obtain a single crystal. Depending on the chosen method, the crystallization furnace will be equipped with appropriate components for holding the crucible and extracting the single-crystalline material. Then, the crucible with the charge will be placed in a graphite heating element, and the whole set will be mounted in the growth chamber. The growth chamber will be closed, and the air will be pumped out. Inert gas will be pumped into the growth chamber, the initial flow value of which will be higher than previously determined for the single-crystal growth process. In the preparatory stage, a device should also be set up to measure the melt temperature: a pyrometer with a prism or a set of thermocouples with a measuring system. Further, the cooling of the growth chamber and generator will be started. At this stage, the melting of the charge begins by starting the generator and gradually increasing its power, increasing the temperature in the growth chamber. The temperature is raised to that previously determined melting point of all the alloying elements. The melt is then kept at this temperature to homogenize the ingredients. After the homogenization stage, the single-crystallization process begins, depending on the selected method. The parameters for pulling out the crystal from the high-temperature zone will be set - mainly the pulling-out rate. At this stage, only the process and its parameters are checked. The process ends when all the melt crystallizes.

3. Learning outcomes

- can indicate and describe the components of a directional crystallization furnace
- can set the necessary parameters of the furnace and prepare it for the directional crystallization process
- can load the growth chamber with the raw materials

4. Necessary equipment, materials, etc.

- raw materials with crucible and graphite holder
- Bridgman / Czochralski crystal growth furnace

- pyrometer

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Discussion on methods of obtaining single-crystalline materials and presentation of the lab's objective.
   - Discussion on the stages of demonstration with a description of each stage.
3. The division of labor:
   - The classes will be held together for all students.
   - Students develop a research plan and define all the necessary activities to achieve relevant work results.
   - The instructor controls and supports students in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - For all students, a single-crystallization process will be demonstrated using a laboratory furnace for Bridgman and Czochralski methods.
   - Students will actively participate in the presentation by mounting the mold in the growth chamber, preparing the chamber for the process, setting the measurement parameters, and observing the progress of the process.
5. Results analysis:
   - Each student will prepare a presentation on the demonstration presented during classes. The presentation will be a report for the classes.
   - Students will discuss conclusions regarding the single-crystalline material production processes in which they participated.
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Summary of experience and critical evaluation of suitability and complexity of the methods for the single-crystallization process.
   - Discussion of the obtained results and formulated conclusions.
   - Enlisting content of the presentation (report).

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the topic:

- T. Duffar, "Crystal Growth Processes Based on Capillarity" Willey 2010 ISBN:9781444320213, 1444320211

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report; (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topics: Bridgman technique, Czochralski technique, single-crystal characteristics.

Topic 4

1. The subject of the laboratory classes

Microstructure analysis of single-crystalline materials

2. Thematic scope of the laboratory classes

The topic of the exercise concerns determining the share of individual phases of the composite single-crystalline materials by performing a stereological analysis of previously obtained microphotographs. As part of the exercises, students will prepare metallographic sections of the provided samples of single-crystalline materials by grinding and then polishing the surfaces of the samples using polishing suspensions with various abrasive gradations. The prepared metallographic specimens will be subjected to microscopic observations, and the obtained images of the microstructure of composite single-crystalline materials will be saved for further stereological analysis. Stereological analysis of metallographic images of various single-crystalline materials will include selected characteristic areas of the samples. Several measurement methods used in stereology will be used. Measurements will be carried out both traditionally, using procedures based on nodal and planimetric methods, and by digital analysis of microstructure images using dedicated computer software. Samples of composite single-crystalline materials obtained with various technological parameters will be analyzed. Then, a comparative analysis of the results obtained using different methods will be carried out. The results obtained for samples produced with different technological parameters will also be compared.

3. Learning outcomes

- can analyze the microstructure of single-crystalline material in terms of the quantitative share of component phases using light and electron microscopy
- can identify component phases based on chemical microanalysis

4. Necessary equipment, materials, etc.

- optical or scanning electron microscope
- ruler
- planimeter
- a computer with ImageJ (or equivalent) software installed
- images of the microstructures of a composite single-crystalline material – in digital and printed form

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Presentation of the lab's objective and discussion of the importance of phase composition and properties of the phases in single-crystalline materials.
   - Discussion on the stages of the experiment with a description of stereological analysis methods.
3. The division of labor:
   - Students will perform the activities individually.
   - Each student develops a research plan and defines all the necessary activities to achieve relevant work results.
   - The instructor controls and supports students in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each student will receive a set of samples to prepare cross-sections and, after preparation, obtain micrographs showing the microstructure for further analysis using an optical or electron microscope.
   - Saved micrographs will be analyzed in digital and printed form.
   - Students need to analyze the microstructures and indicate the individual phases or subgrains observed in the image.
   - Using three different methods, students need to determine the percentage of individual component phases in the composite single-crystalline material or the percentage of subgrains.
   - For the grid method, students must draw an orthogonal grid with a nodal distance of 0.5 cm on printed micrographs and then count all nodes (points where the lines intersect) located in the measurement area (whole image of the microstructure or its representative fragment - at least 70%), count the nodes located on the surface of the individual phases or subgrains that are visible in the image of the microstructure and determine the percentage amount of the observed phases using the appropriate mathematical equations.
   - For the planimeter method, students must measure the surface area occupied by each identified phase or visible subgrains and determine the percentage of the observed phases using the appropriate mathematical equations.
   - For the computer method, students must measure the surface area occupied by each identified phase or visible subgrains using the tools available in the software (e.g.,

ImageJ) and determine the percentage amount of the observed phases using the appropriate mathematical equations.
- Students must compare the results obtained with all three methods.

5. Results analysis:
    - Each student will present the results of their research in the form of a short presentation.
    - Students will discuss their conclusions regarding the share of individual phases and differences in determining them for various single-crystalline materials.
6. Summary:
    - Summary of the laboratory and a reminder of its goals.
    - Summary of experience and critical evaluation of suitability and complexity of the methods for determining the percentage of phases in a composite single-crystalline material.
    - Discussion of the obtained results and formulated conclusions.
    - Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the topic:

- J. C. Russ, R. T. Dehoff, "Practical Stereology" Springer 2012 ISBN:9781461512332, 1461512336

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
    - the opening test before the exercise (0-100%)
    - report (0-100%) - the following elements will be taken into account:
        - completeness of the report (10%)
        - content included in the theoretical introduction (10%)
        - the quality (in terms of correctness) of the obtained results; (30%)
        - the correctness of interpretations, discussions, and conclusions (40%)
        - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the test involves the following topics: chemical microanalysis, stereology in materials engineering.

Topic 5

1. The subject of the laboratory classes

Determination of crystal orientation and symmetry

2. Thematic scope of the laboratory classes

During the classes, students will learn how to perform X-ray measurements of single-crystalline materials and how to identify single-crystalline materials using the Laue diffraction method. Participants will become familiar with the measurement procedure and learn to operate an X-ray apparatus for Laue diffraction testing. They will also be able to learn how to adjust exposure parameters to the type of material being tested. The exercise will begin with preparing a measurement bench and an X-ray apparatus for testing. The provided samples will be mounted on a goniometric measuring head and positioned according to the method requirements. Then, the detector cassette will be prepared and set up (in the case of X-ray film, the cassette is loaded in a photographic darkroom). In the next stage, the X-ray generator will be started, and the geometry of the primary X-ray beam falling on the selected area of the sample will be set by adjustment with a Laue camera and a goniometer. The results will be obtained and analyzed after exposing the sample for a specified time. If X-ray film was used, it must be developed and, if necessary, digitized. The analysis of the results of the Laue method allows the determination of the crystallographic parameters of single-crystalline materials, in particular, the orientation of the crystal lattice and the type of crystal symmetry, as well as, initially, the quality of the single-crystalline material. For the recorded Laue patterns, students will index the visible Laue spots and determine the angles of deviation of selected crystal atomic planes from the plane of the examined sample cross-section - they will orient the samples. The Laue patterns obtained as a result of sample exposure by X-rays for different times and different single-crystalline materials will be compared. Students will also analyze the distribution of diffraction spots on the Laue patterns, indicate the planes of a crystal zone, and determine the types of symmetry occurring in individual samples. Based on the shape of the Laue spots, participants will estimate the quality of the single-crystalline material.

3. Learning outcomes

- can indicate and describe the components of an X-ray diffractometer used in the study of crystal orientation and symmetry
- can prepare an X-ray apparatus and samples for testing crystal orientation and symmetry
- can analyze the results of crystal orientation and symmetry studies obtained by the Laue method

4. Necessary equipment, materials, etc.

- properly prepared single-crystalline sample
- X-ray apparatus equipped with the Laue camera
- X-ray film

- developer and fixer for X-ray films
- photography darkroom
- or automatic Laue measurement X-ray system
- Greninger net
- Laue patterns
- a computer with Qlaue (or equivalent) software

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Presentation of the lab's objective and discussion on the importance of determining crystal orientation and symmetry using the Laue method.
   - Discussion on the stages of experiment with description of each stage.
3. The division of labor:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a sample and starts preparing metallographic sections.
   - Next activities include preparing the X-ray apparatus by mounting the sample in the goniometer holder and preparing the detector. The detector in the form of an X-ray film should be prepared in the darkroom by placing the film in a light-protective cassette.
   - Then, students will set diffractometer parameters, perform measurements, and obtain Laue patterns. Students will develop the exposed films for Laue patterns obtained on X-ray film.
   - Students analyze the obtained Laue patterns in terms of the arrangement and shape of the Laue spots and measure the angles between the most intense spots using the Greninger net.
   - Laue patterns in the digital form are analyzed by students using the Qlaue software, indexing selected Laue spots and identifying symmetry. If Laue patterns had been recorded on X-ray film, they should have been digitized previously.

5. Results analysis:
- Each team will present the results of their research in the form of a short presentation.
- Teams will discuss their conclusions on recording Laue patterns, the quality and shape of Laue spots, and the analysis of their distribution.
- Students will evaluate the degree of single-crystallinity of the tested samples based on the obtained Laue patterns.

6. Summary:
- Summary of the laboratory and a reminder of its goals.
- Summary of experience and critical evaluation of suitability and complexity of the Laue method for analysis of single-crystalline materials' quality, crystal orientation, and symmetry.
- Discussion of the obtained results and formulated conclusions.
- Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below text related to the topic:
- J.L. Amoros, “The Laue method” Elsevier, 2012 ISBN:9780323140768, 0323140769

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.
The scope of the issues for the colloquium involves the following topics: X-ray radiation, diffraction, the Laue method, crystal symmetry.

Topic 6

1. The subject of the laboratory classes

Defect analysis in single-crystalline materials – X-ray diffraction topography

2. Thematic scope of the laboratory classes

Laboratory classes will enable students to learn in detail about the defects that form in single-crystalline materials, both in the as-cast manufacturing process and during further processing. Students will independently examine selected types of defects and analyze how and why they are created. During the classes, students will learn one of the most important X-ray methods for examining defects in single-crystalline materials: X-ray diffraction topography and its types. Low-angle boundaries and subgrains in single-crystalline materials will be analyzed. Based on the previous Laue patterns prepared, students will learn to calculate the angles necessary to position the sample in the goniometric holder before measurement. Then, the sample will be set up for measurement, the X-ray apparatus will be started, and the X-ray parameters will be adjusted to the sample specifications. Then, the detector will be prepared and set up - if it is a detector with the X-ray film, it will be placed in the cassette in the photographic darkroom. The exposure will proceed with the sample oscillation or the sample and detector oscillation coupled. The results will be carefully analyzed, including determining the shift of the bands of an orientation contrast recorded on the topograms. The misorientation angles of crystal subgrains in various single-crystalline materials will be calculated based on the shift values. The occurrence of extinction contrast will also be analyzed, the occurrence of which may indicate the appearance of internal stresses in the material.

3. Learning outcomes

- can indicate and describe the elements of an X-ray diffractometer used in X-ray diffraction topography examination
- can prepare an X-ray machine and arrange samples for X-ray diffraction topography examination
- can analyze test results - indicate recorded defects, and determine the misorientation of neighboring subgrains

4. Necessary equipment, materials, etc.

- properly prepared single-crystalline sample
- previously obtained Laue pattern from the currently tested sample
- X-ray apparatus equipped with the Auleytner topography camera
- X-ray film
- developer and fixer for X-ray films
- photography darkroom
- or automatic topography measurement X-ray system

- ruler (or a computer with ImageJ software for digital topograms)

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Presentation of the lab's objective and discussion of the importance of defects analysis in single-crystalline materials.
   - Discussion on the stages of the experiment with a description of each stage.
3. The division of labor:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Based on the Laue patterns recorded in the previous exercises, each team must calculate the sample's inclination angles to the primary X-ray beam to obtain a diffraction for the selected type of reflection (e.g., 113 reflection for single-crystalline nickel-based superalloy).
   - Students mount the sample in the goniometer holder of the Auleytner camera and position it according to the previously calculated angles.
   - The next activities include preparing the X-ray apparatus and the detector. The detector in the form of an X-ray film should be prepared in the darkroom by placing the film in a light-protective cassette.
   - Then, students will set diffractometer parameters, perform measurements, and obtain topograms. Students will develop the exposed films for topograms obtained on X-ray film.
   - Students analyze the obtained topograms regarding the arrangement and shape of the subgrains and the existence of low-angle boundaries, and they measure the misorientation angles between neighboring subgrains.
   - Using ImageJ software, students can analyze digital topograms by measuring the shifts between neighboring grains. If topograms were recorded on X-ray film, they must be digitized first. Topograms can also be analyzed in printed form using a ruler. The instructor will provide formulas for calculating the misorientation angle of subgrains.

5. Results analysis:
- Each team will present the results of their research in the form of a short presentation.
- Teams will discuss their conclusions regarding the creation and presence of low-angle boundaries of the studied single-crystalline samples.
- Students will evaluate the quality and crystal perfection of the tested single-crystalline samples based on the obtained topograms.

6. Summary:
- Summary of the laboratory and a reminder of its goals.
- Summary of experience and critical evaluation of suitability and complexity of the X-ray diffraction topography method for analysis of single-crystalline materials' quality and crystal perfection.
- Discussion of the obtained results and formulated conclusions.
- Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the topic:

- G. Dhanaraj, K. Byrappa, M. Dudley, V. Prasad, „Springer Handbook of Crystal Growth" Springer 2010 I SBN:9783540747611, 3540747613
- J. Auleytner "X-ray Methods in the Study of Defects in Single Crystals" Pergamon Press 2007

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topics: X-ray radiation, diffraction, X-ray topography methods, crystal defects.

Topic 7

1. The subject of the laboratory classes

Relation between manufacturing conditions and microstructure

2. Thematic scope of the laboratory classes

The exercise aims to acquire the skills to characterize the structure of a single-crystalline composite material and its suitability for use, determine its chemical composition, the phase composition of the composite material, and the ratio of the mass of the constituent phases. Students will be familiarized with the more advanced methods for preparing metallographic sections of composite single-crystalline materials so that it is possible to distinguish individual component phases during microscopic observations. After selecting the appropriate chemical reagents for a given composite single-crystalline material, students will etch the selected component phases. Students will learn to determine some technological parameters of the manufacturing process based on the characteristics of the microstructure, observing the changing morphology of individual phases. One of the methods used will be the method to determine the interdendritic distances and linear interdendritic distances in single-crystalline nickel superalloys. The mean distance between the centers of the primary dendrite arms (dendrite cores) will be measured using macro SEM images of the dendritic structure. Based on the value of this parameter, students will estimate the rate of pulling the melted mold out of the high-temperature zone in the furnace to obtain single-crystalline materials. Based on microscopic observations, using the stereological method, students will determine the phase composition of the composite and the share (percentage and weight) of individual phases. Students will use the phase diagram to determine the mechanism of the crystallization process and its parameters.

3. Learning outcomes

- can perform the necessary preparation of sample surfaces to make visible the characteristic morphological features of the microstructure related to technological parameters
- can analyze the morphology and quantitative share of the component phases of a single-crystalline composite material manufactured under various technological conditions and indicate the changed parameters

4. Necessary equipment, materials, etc.

- set of Sn-Sb single-crystalline composite samples with metallographic sections prepared (samples manufactured with different technological parameters)
- optical microscope
- Sn-Sb phase equilibrium diagram
- ruler
- a computer with ImageJ software for digital images of the microstructure

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Test:
   - A brief test checking students' preparation for laboratory exercises based on information provided in the recommended literature.
2. Introduction:
   - Presentation of the lab's objective and discussion of the importance of the relation between manufacturing conditions and microstructure.
   - Discuss the stages of the experiment with a description of the required microstructure analysis.
3. The division of labor:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The groups represent the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research:
   - Each team receives a set of two-phase Sn-Sb composite alloy samples manufactured with different crystallization rates and starts with preparing the metallographic section by polishing and etching. Each sample should be etched using different etchant concentrations: HF - 50 vol.%, HF - 40 vol.%, HF - 10 vol.%.
   - Students will observe the metallographic sections of the prepared samples using a light optical microscope.
   - Students must save the images of the microstructure of the samples digitally or sketched on paper.
   - Based on microscopic observations, using the stereological method, students must determine the phase composition of the composite and the share (percentage and weight) of individual phases.
   - The obtained results and analysis of the Sn-Sb phase diagram will be used to calculate the initial chemical composition of the sample by applying the lever rule.
5. Results analysis:
   - Each team will present the results of their research in the form of a short presentation.
   - Teams will discuss their conclusions regarding the differences in microstructure related to manufacturing conditions (crystallization rate).
6. Summary:
   - Summary of the laboratory and a reminder of its goals.
   - Discussion of the obtained results and formulated conclusions.

- Enlisting content of the report.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below text related to the lecture:

- K. Byrappa, "Crystal Growth Technology" Springer 2003 ISBN:9783540003670, 3540003673

Students should prepare a theoretical introduction to the laboratories. The introduction will be next used during report preparation.

7. Additional notes

- The topics will be covered in the next two classes.
- Assessment of the laboratory activity:
  - the opening test before the exercise (0-100%)
  - report (0-100%) - the following elements will be taken into account:
    - completeness of the report (10%)
    - content included in the theoretical introduction (10%)
    - the quality (in terms of correctness) of the obtained results; (30%)
    - the correctness of interpretations, discussions, and conclusions (40%)
    - the aesthetics of the report (10%).

8. Optional information

Exercise manuals will be provided prior to the laboratory classes.

The scope of the issues for the colloquium involves the following topics: composite single-crystalline materials, microstructure, optical and electron microscopy, manufacturing technological parameters

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

ADVANCEMENTS AND APPLICATIONS OF NANOMATERIALS IN ENVIRONMENTAL SCIENCES

Code: AANES

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

A short overview of Nanotechnology

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic will take a comprehensive journey through the issue of "Nanotechnology," commencing with a detailed understanding of its definition and historical roots. We'll trace the discourse back to the visionary insights of Feynman, who envisioned a future where scientists would wield control over matter at the atomic level. This historical background sets the stage for a discussion on nanotechnology's revolutionary (or evolutionary) impact, not only within scientific and technical realms but significantly within the public domain, including its incorporation into the terminology of commercially available products.

Students will discover that nanotechnology represents a revolutionary technology that introduces specific risks requiring careful consideration. The initial topic will underscore the crucial need to comprehend the problem complexities inherent in defining nanotechnology, spanning natural and materials sciences, engineering, and medicine. It will be added that the term "nano" should not be considered only as a prefix denoting a length scale but must be tied to the emergence of novel physical or chemical properties.

Throughout this exploration, we'll shed light on the absence of a universally accepted definition in nanotechnology. It will underline that the imprecision surrounding "nano" is often exploited in product marketing, potentially leading to products lacking a proper "nano-effect." Hence, a crucial aspect will emphasize how this gap can lead to numerous misunderstandings, including ethical, social, legal, and environmental implications.

Understanding the evolution and intricacies associated with nanotechnology will lay the foundation for a more in-depth thematic exploration and understanding of why today's solutions are less material and energy requirement, more durable, functional and ease of use, longer-lasting, cheaper, lighter and smaller, etc. Consequently, collaboratively with students, we'll examine a series of examples that bridge the definition of nanotechnology across various fields of daily life, including diagnosing and treating diseases, generating and storing energy, building complex structures, improving crop production and food quality, monitoring and protecting the environment, etc.

3. Learning outcomes

Students will acquire fundamental knowledge about nanotechnology from the beginning to the future, enabling them to discern this discipline from others. Additionally, they will develop the proficiency to apply the term "nano appropriately" and understand the concept of the "nano-effect."

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 4 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues concerning the "nano-effect."

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Feynman, R. P., (1960) "There's Plenty of Room at the Bottom," Annual Meeting at American Physical Society at the California Institute of Technology, December 29, 1959. First published by Caltech Engineering and Science 23, 5, pp. 22–36
2. Ratner, M. and Ratner, D. (2003). Nanotechnology: A gentle introduction to the next big idea. Upper Saddle River, NJ: Prentice Hall, pp. 1–18
3. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
4. Size of the Nanoscale (n.d.). Retrieved December 15, 2014, from www.nano.gov/nanotech-101/what/nano-size
5. Koo, J. (2016). Introduction to Nanotechnology. In Fundamentals, Properties, and Applications of Polymer Nanocomposites, pp. 3-21. Cambridge: Cambridge University Press
6. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
7. Balasubramanian, G., (2018). Advances in Nanomaterials Fundamentals, Properties and Applications, Springer International Publishing Rafique, M., Bilal Tahir, M., Shahid Rafique, M., Hamza, M. (2020). Chapter 1 - History and fundamentals of nanoscience and nanotechnology, Nanotechnology and Photocatalysis for Environmental Applications, pp.1-25
8. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25

6. Additional notes

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Topics 2

1. The subject of the lecture

Top-Down Versus Bottom-Up

2. Thematic scope of the lecture (abstract, maximum 500 words)

Topic 2 will look at practical techniques for fabricating nano-systems with their advantages and disadvantages, including two main approaches: "Top-down" and "Bottom-up."

Students will find out for what purpose the Top-down physical approach is used and what positive and negative aspects are associated with using this technique (e.g., controlling the shape and size of nanostructured bulk materials). This fragment will summarize techniques like grinding, dissolution, or ball milling with the impact of applied parameters to reduce large bulk materials to the desired size. Interestingly, aspects related to Top-down techniques will look at lithography, where large structures are gradually reduced in size through precise removal or alteration of bulk material.

On the other hand, students will learn how limitations of the top-down approach to artificial nanostructures can be overcome by mimicking nature's bottom-up processes related to building nanostructures from the ground up, utilizing smaller building blocks, namely atoms, molecules, and clusters. Then, they will correlate their knowledge from many disciplines (physics, chemistry, material science) and find out that familiarity with fundamentals (e.g., short-range forces like van der Waals, electrostatic, and different interatomic or intermolecular) is a critical factor for the understanding of the formation process of nanometer-sized particles with well-defined geometries and specific functions. Students will look at more in specificity of this approach. They will understand that the intricate dynamics at the atomic and molecular levels will enable the design of a wide range of structures with unprecedented control, efficiency, a homogenous particle size distribution, and controllability in the size and properties of materials via proper control of the reaction conditions. This fragment will summarize standard bottom-up techniques, including chemical vapor deposition, chemical precipitations, self-assembly, molecular beam epitaxy, or homogenous and heterogeneous nucleation.

In an interactive collaboration with students, we will comprehensively examine a series of illustrative examples of nanotechnology's Top-Down and Bottom-Up approaches. This exploration will encompass a diverse array of applications, including but not limited to thin films, nanotweezers for precise manipulation at the nanoscale, nanomotors for controlled movement, and advanced patterning techniques. Throughout this exploration, we will delve into the perspectives and limitations associated with each approach, fostering a nuanced understanding of their practical implications.

3. Learning outcomes

After this topic, students will master practical techniques for nano-system fabrication, distinguishing between "Top-down" and "Bottom-up" approaches. They'll learn the Top-down method for precise control over nanostructured bulk materials, while the Bottom-up approach enables the design of the nanostructures from atoms, molecules, and clusters. Through illustrative examples, such as thin films and nanomotors, students will gain practical insights into these approaches, understanding their applications and limitations.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 5 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues concerning the Top-down and Bottom-up approaches

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Feynman, R. P., (1960) "There's Plenty of Room at the Bottom," Annual Meeting at American Physical Society at the California Institute of Technology, December 29, 1959. First published by Caltech Engineering and Science 23, 5, pp. 22–36
2. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
3. Ratner, M. and Ratner, D. (2003). Nanotechnology: A gentle introduction to the next big idea. Upper Saddle River, NJ: Prentice Hall, pp. 1–18
4. Size of the Nanoscale (n.d.). Retrieved December 15, 2014, from www.nano.gov/nanotech-101/what/nano-size
5. Koo, J. (2016). Introduction to Nanotechnology. In Fundamentals, Properties, and Applications of Polymer Nanocomposites, pp. 3-21. Cambridge: Cambridge University Press
6. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
7. Rafique, M., Bilal Tahir, M., Shahid Rafique, M., Hamza, M. (2020). Chapter 1 - History and fundamentals of nanoscience and nanotechnology, Nanotechnology and Photocatalysis for Environmental Applications, pp.1-25
8. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25

6. Additional notes

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Topics 3

1. The subject of the lecture

Modern directions of bottom-up approach to nanotechnology

2. Thematic scope of the lecture (abstract, maximum 500 words)

This segment will comprehensively present a broad spectrum of nanostructures, systematically categorizing them into independent groups: inorganic, organic, composite, carbon-based, and others. The advantages and disadvantages accompanying each group of materials will be presented, allowing for a comprehensive understanding of the fascinating world of nanostructures and the challenges facing contemporary nanotechnology, with particular emphasis on the bottom-up approach to nanostructure creation.

While exploring organic nanomaterials, their crucial role in biomedical applications will be highlighted, particularly their contribution to developing many biocompatible materials. Discussed topics will show how nanomaterials affect the solubility or release of active substances. They will present chelation, sorption, and desorption methods, enabling an understanding of their potential transformative impact on healthcare and related fields.

The presentation of inorganic and complex nanostructures will help to understand how different materials' synergistic properties contribute to increasing the functionality of nanostructures and commercially available counterparts. The discussion will also cover the role of nanostructures in various aspects of daily life, such as catalysis, electronics, photonics, (bio)medicine, and environmental issues, including removing toxic substances from groundwater and soil.

Theme 3 will focus on the practical applications of nanostructures, encompassing the biomedical sector, including biosensing, drug delivery, cancer therapies, tissue engineering, biomolecular imaging, bacteriostatic action, etc. The role of materials in agriculture will also be discussed in the context of innovative solutions. Promising and susceptible solutions as detectors will also be presented, which may contribute to removing potential pollutants from air and water.

3. Learning outcomes

Students will leave this topic with a comprehensive grasp of diverse nanostructures categorized by material types. They'll understand the applications of organic nanomaterials in medicine, tissue engineering, and drug delivery, appreciating their role in enhancing solubility and targeted drug release. They should know the applications of inorganic, composite, and carbon-based nanostructures, spanning fields like catalysis, electronics, photonics, biomedical applications, and environmental contexts for pollutant removal.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 7 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues concerning the variable kind of nanostructures with their specific applicational character

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
2. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
3. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25
4. Ersöz, M., Işitan, A., Balaban, M., (2018). NANOTECHNOLOGY 1 (1st ed.). BilalOfset
5. Nasrollahzadeh, M., Issaabadi, Z., Sajjadi, M., Mohammad Sajadi, S., Atarod, M., (2019), Chapter 2 - Types of Nanostructures, Interface Science and Technology 28, pp. 29-80
6. Jeelani, P.G., Mulay, P., Venkat, R. et al. (2020). Multifaceted Application of Silica Nanoparticles. A Review. Silicon 12, 1337–1354
7. Baig, N., Kammakakam, I., Falathabe, W. (2021). Nanomaterials: a review of synthesis methods, properties, recent progress, and challenges Mater. Adv., 2, pp. 1821-1871
8. Farmand, M., Jahanpeyma, F., Gholaminejad, A. et al. (2022). Carbon nanostructures: a comprehensive review of potential applications and toxic effects. 3 Biotech 12, 159
9. Joudeh, N., Linke, D., (2022). Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists, Journal of Nanobiotechnology 20, 262

6. Additional notes

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Topics 4

1. The subject of the lecture

Methods for Structural and Chemical Characterization of Nanomaterials

2. Thematic scope of the lecture (abstract, maximum 500 words)

In this segment, our focus pivots towards the fascinating realm of nanoparticle characterization. Students will embark on a journey through an extensive array of methods, each tailored to reveal specific features of nanostructures. When combined, the spotlight will be on understanding individual techniques and appreciating their collective strength.

A meticulous comparative analysis will consider availability, cost, selectivity, precision, non-destructive nature, simplicity, and affinity to specific compositions or materials. We will delve into the fundamentals of each approach, ensuring a profound grasp of their applications in the analysis of nanomaterials.

The initial focus will be on microscopy-based techniques, including SEM (Scanning Electron Microscopy), TEM (Transmission Electron Microscopy), and AFM (Atomic Force Microscopy), unraveling insights into the size and morphology of nanomaterials. Progressing further, we'll explore specialized methods tailored for specific material groups, such as spectroscopic measurements (UV-VIS, FTIR, Raman, XPS) and diffraction methods (XRD, GIDX, SAXS), providing a holistic understanding of the physical attributes of nanostructures. Sophisticated techniques like SQUID (Superconducting Quantum Interference Device), VSM (Vibrating Sample Magnetometer), FMR (Ferromagnetic Resonance), and XMCD (X-ray Magnetic Circular Dichroism) will also be elucidated.

This topic doesn't end with the technicalities but also extends to unraveling the real-world applicability of each method. We will navigate the intricacies of these techniques, exploring their nuances and deciphering the information they unveil. Hence, considering the individual techniques, we will transition to a profound understanding of the physicochemical interactions governing nanostructures. From van der Waals forces to electrostatic attractions, we'll decipher how nanostructures engage with their environment and each other. The topic will focus on unraveling the factors influencing aggregation and the intricate dynamics of surface chemistry, impacting the reactivity, stability, and functionality of nanostructures.

These issues are a dynamic exploration, equipping students to comprehend and apply these principles in the ever-evolving landscape of nanotechnology.

3. Learning outcomes

Students should gain comprehensive knowledge about the spectrum of various methods for characterizing nanomaterials, ranging from microscopy-based techniques, methods tailored to specific material groups, to sophisticated techniques. They will not only understand the technical details behind each technique but also grasp the physicochemical fundamentals stemming from the nature of nanostructures. This knowledge prepares students to apply these principles in the evolving field of nanotechnology.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 4 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues allowing gathering the knowledge about the method of material characterization

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
2. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
3. Ersöz, M., Işitan, A., Balaban, M., (2018). NANOTECHNOLOGY 1 (1st ed.). BilalOfset
4. Mourdikoudis, S., Pallares, R.M., Nguyen T. K. (2018). Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties, Nanoscale, 10, pp. 12871-12934
5. Nasrollahzadeh, M., Issaabadi, Z., Sajjadi, M., Mohammad Sajadi, S., Atarod, M., (2019), Chapter 2 - Types of Nanostructures, Interface Science and Technology 28, pp. 29-80
6. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25

6. Additional notes

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Topics 5

1. The subject of the lecture

Environmental Applications of Nanomaterials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The ceaseless march of industrialization and urbanization, encompassing transportation, manufacturing, construction, petroleum refining, mining, and beyond, depletes natural resources and unleashes substantial hazardous wastes. These pollutants pose a grave threat to air, water, and soil, imperiling human health and environmental security. The intricate web of environmental degradation weaves together atmospheric pollutants, including toxic gases and suspended particles, with soil and water contaminants like pesticides, heavy metals, and microbial pathogens.

In this segment, Students will delve into issues related to the use of nanotechnology in the environmental aspect, focusing on methods of detecting and removing harmful environmental pollutants. They need to understand that these pollutants not only pose immediate risks but can also accumulate in food chains, increasing threats to human health and ecosystems. Therefore, searching for new solutions becomes a key challenge, requiring sustainable, efficient, and cost-effective monitoring and removal technologies for environmental toxic pollutants.

Students will become acquainted with the differences between traditional pollution detection methods and two modern approaches: i) "ex-situ" nanotechnology, which involves creating self-assembling monolayers on mesoporous carriers, and the more cost-effective ii) "in situ" approach, which involves creating reactive zones in situ with immobilized nanostructures or using reactive mobile nanomaterials that can be transported to contaminated areas. Both approaches will delve into the critical role of nanotechnology in environmental protection, including producing environmentally friendly products, improving the quality of environments contaminated with toxic substances, and developing environmental pollution detectors.

Concepts of "green chemistry" or "nanoformulation" will also be introduced, emphasizing the importance of nanotechnology as an approach that offers new production opportunities with minimal risk. Through this exploration, students will understand how nanotechnology can contribute to creating a cleaner and more sustainable future.

3. Learning outcomes

After this topic, students will comprehensively understand environmental nanotechnology, distinguishing it from traditional methods and appreciating its role in detecting and remediating pollutants. They will grasp the urgency of sustainable technologies to monitor and remove toxic pollutants, exploring modern nanotechnological approaches like "*Ex-situ*" and "*In situ*." Additionally, students will be introduced to the concepts of "green chemistry" and "nanomanufacturing," realizing the potential of nanotechnology in creating a cleaner and more sustainable future.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 4 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues allowing gathering the knowledge about the method belongs to environmental nanotechnology.

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
2. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
3. Ersöz, M., Işitan, A., Balaban, M., (2018). NANOTECHNOLOGY 1 (1st ed.). BilalOfset Nasrollahzadeh, M., Issaabadi, Z., Sajjadi, M., Mohammad Sajadi, S., Atarod, M., (2019), Chapter 2 - Types of Nanostructures, Interface Science and Technology 28, pp. 29-80
4. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25

6. Additional notes

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Topics 6

1. The subject of the lecture

Pollution control, remediation versus environmental implications

2. Thematic scope of the lecture (abstract, maximum 500 words)

This segment will highlight how nanotechnology is a powerful tool to combat air, water, and soil pollution resulting from the intensified production and consumption of resources during societal development. It intricately explores critical parameters such as the reactivity, delivery mechanisms, transport dynamics, and targeting precision of nanomaterials across diverse applications. It will present solutions for mitigating air pollution involving leveraging nano-catalysts (specifically carbon-based nanoparticles) and nano-fiber catalysts (metal oxide), addressing water pollution through innovative nano-sized fibers, and assessing soil pollution by examining the integrity and stability of nanoparticles in the soil matrix.

In a nuanced discussion on the effectiveness of remediation, the focus will extend to intricate processes like adsorption, absorption, chemical reactions, photocatalysis, and filtration. Simultaneously, it will delve into the inherent physical properties of nanomaterials, encompassing aspects such as size, morphology, porosity, surface modification, and chemical composition.

The module will conclude with a thorough exploration of the toxicological impacts of nanomaterials, scrutinizing potential health ramifications associated with prolonged accumulation in organisms. It involves using models for forecasting environmental risks and considering the life cycle of nanomaterials. The final segment will critically evaluate the landscape of nanotechnology governance for sustainable science and policy, providing an insightful analysis of the existing regulatory frameworks overseeing nanomaterials.

3. Learning outcomes

This course equips students with a holistic grasp of how nanotechnology addresses air, water, and soil pollution amid societal development. Students explore critical parameters like nanomaterial reactivity, delivery mechanisms, and toxicological impacts, concluding with evaluating regulatory frameworks for sustainable nanotechnology governance.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 4 h of classes.

<u>Multimedia presentation</u> - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

<u>Case study</u> - presentation of the issues to gather knowledge about the processes and remediation methods.

<u>Discussion</u> - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Hassellov, M; Readman, JW; Ranville, JF; et al. (2008). Nanoparticle analysis and characterization methodologies in environmental risk assessment of engineered nanoparticles, Ecotoxicology. 17, 5, pp. 344-6.
2. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
3. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
4. Ersöz, M., Işitan, A., Balaban, M., (2018). NANOTECHNOLOGY 1 (1st ed.). BilalOfset
5. Nasrollahzadeh, M., Issaabadi, Z., Sajjadi, M., Mohammad Sajadi, S., Atarod, M., (2019), Chapter 2 - Types of Nanostructures, Interface Science and Technology 28, pp. 29-80
6. Rafique, Muhammad (2020). Nanotechnology and Photocatalysis for Environmental Applications, History and fundamentals of nanoscience and nanotechnology, pp. 1–25
7. Bansal, A., Sachan, R.S.K., Devgon J., Devgon, I., Karnwal, A., (2023). Nanotechnology in Environmental Clean-up, Materials Research Foundations 145, pp. 281-310

6. Additional notes

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Topics 7

1. The subject of the lecture

Ethics of Nanotechnology. State of the Art and Challenges Ahead

2. Thematic scope of the lecture (abstract, maximum 500 words)

Topic 7 addresses the most current issues related to nanotechnology, focusing on the ethical aspects of developing guidelines and cooperation strategies in their societal implementation. Ethical aspects of nanotechnology development in various fields and sectors of the economy will be discussed to demonstrate how to maximize the benefits of nanotechnology while minimizing potential social side effects.

From ethics to regulations, we will thoroughly discuss regulations concerning the safe use of nanomaterials. The discussion will cover potential risks associated with nanomaterials, with particular emphasis on the role of regulatory frameworks in ensuring proper integration across different sectors. The regulatory review will consider both national and international contexts. We will carefully evaluate risk assessment methodologies and protocols, emphasizing safety standards, including storage and protecting workers', consumers', and society's health.

Together with students, we will consider how advancements in nanotechnology can be linked to ethical issues related to defense or health. Aspects such as informed consent to use products containing nanomaterials, medical data privacy, active pharmaceuticals in nanoformulations, and the ethical boundaries of nanotechnology in human enhancement will be highlighted. We will also address issues related to the impact of nanomaterials on the natural environment, focusing on responsible use of nanomaterials and considering potential ecological consequences and sustainable practices in nanotechnology development. In this regard, safety regulations will be discussed, considering various exposure pathways, toxicity profiles, and potential environmental impacts, focusing on studying sustainable ecological development, waste management, and preventing undesirable impacts on ecosystems.

The final stage will include a summary of labeling and reporting requirements imposed by regulatory bodies, ensuring transparency in using nanomaterials, and facilitating informed decisions for stakeholders

3. Learning outcomes

Students will gain comprehensive insights into current and future nanotechnology advancements, emphasizing ethical considerations across diverse sectors. The course covers regulatory frameworks, safety protocols, and environmental impact assessments, ensuring a holistic understanding of responsible nanomaterial application. The final focus is labeling and reporting requirements, promoting transparency and informed decision-making.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture will be realized with a traditional interactive board along with the use of multimedia. The topic will be realized within 4 h of classes.

Multimedia presentation - a multimedia presentation, such as Microsoft PowerPoint, WPS Office, Google Slides, or Prezi, will present the discussed issues (online or stationary).

Case study - presentation of the issues to gather knowledge about the ethical problems related to nanotechnology.

Discussion - encouraging participants to participate in the discussion

Q and A session – series of questions asked by the teacher or student, answers given by the students or teacher.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

1. Wiesner, Mark R., and Jean-Yves Bottero, eds. (2017). Environmental Nanotechnology: Applications and Impacts of Nanomaterials. 2nd ed. New York: McGraw-Hill Education
2. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press
3. Kumar Mishra, A., Das, R., Sahoo, S., Biswal, B., (2022). Chapter Ten - Global Regulations and Legislations on Nanoparticles Usage and Application in Diverse Horizons, Comprehensive Analytical Chemistry 99, pp. 261-290
4. Abdus Subhan, M., Subhan, T., (2022). Chapter 5 - Safety and global regulations for the application of nanomaterials, Nanomaterials Recycling Micro and Nano Technologies, pp. 83-107
5. Lu, L.Y.Y., Lin, B.J.Y., Liu, J.S. et al. (2012). Ethics in Nanotechnology: What's Being Done? What's Missing?. J Bus Ethics 109, pp. 583–598

6. Additional notes

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Course content – <u>laboratory classes</u>

Topics 1

1. The subject of the laboratory classes

Materials features versus (de)sorption

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Throughout this course, students will engage deeply with the nuanced landscape of (de)sorption processes, taking into account diverse porous environmentally-friendly materials like titanium dioxide and silica with variable porosity (ranging from 200 to 800 m^2/g), pore size (from a few nanometers to micrometers), and functionalization levels, achieved through tailored polymeric groups like oleic, PVP, 3-aminopropyltriethoxysilane (APTES), or dimethyl [3-(triethoxysilyl)propyl]phosphonate (PPTES).

In tandem with students, the classes will commence with a comprehensive theoretical exploration of (de)sorption processes, covering mechanisms and models such as first-order, second-order, pseudo-second-order, Langmuir, Freundlich, and Temkin models, as well as pseudo-second-order kinetics and intraparticle diffusion. The impact of environmental conditions such as pH, humidity, temperature, and the nature of pollutants (organic or inorganic) will be meticulously discussed.

Students will be introduced to state-of-the-art techniques such as Mass Spectrometry coupled with Inductively Coupled Plasma (ICP-MS), Atomic Absorption Spectroscopy (AAS), and UV-vis spectroscopy. In the practical segment, students actively participate in planning experiments using available materials (porous inorganic carriers and organic/inorganic pollutants). Based on the relevant literature, they will estimate the (de)sorption duration and expected concentration and conduct experiments individually or in groups using the devices discussed in the theoretical part.

Results obtained from the experiments will be correlated with theoretical models, providing students with a nuanced understanding of the quantitative aspects of (de)sorption depending on porosity, environmental conditions, and extent of functionalization. This multifaceted approach will fortify theoretical foundations and equip students with practical skills crucial for advanced materials science and environmental remediation research.

In summary, integrating theoretical principles with hands-on experimentation, advanced analytical techniques, and profound knowledge ensures that students develop a comprehensive understanding of sorption within porous materials from this module. This knowledge contributes to academic excellence and prepares students for real-world challenges, cultivating a versatile skill set crucial in the dynamic landscape of materials science.

3. Learning outcomes

After this segment, students will know (de)sorption processes concerning porous materials. Theoretical discussions will help discover various models and environmental factors, while practical experience will allow advanced techniques in specific applications.

4. Necessary equipment, materials, etc

The exercise will be performed in laboratories equipped with specialized spectrometers, including an atomic absorption device (AAS) with atomization in flame and graphitic furnace to analyze liquids and solid samples and a UV-VIS spectrometer to analyze liquids. The exercise takes place in a laboratory equipped with personal protective equipment.

Necessary materials

Materials for the classes involve:

- porous materials (titanium dioxide, silica),
- organic pollutants (pesticides, fungicides),
- inorganic pollutant precursors (lead chloride, nickel chloride, iron chloride, copper sulfate, silver acetate, etc.)
- chemical compounds like sodium/potassium hydroxide, hydrochloric acid, distilled water as a solvent,
- laboratory glass items, e.g., beakers, spatulas, glass rods, test tubes, and test tube holders.
- magnetic stirrers

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge test:
   - An assessment will be realized to evaluate students' readiness for laboratory exercises, drawing from relevant literature resources.
2. Introduction:
   - A presentation will focus on the nature of (de)sorption, porous materials, and fundamentals related to specific techniques used during the classes.
   - A discussion will refer to the experiment stages by describing the principle and a reminder of safety rules.
3. The course of the exercise:
   - Students will be divided into working teams.
   - The teams will develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor will control and support the teams in developing the research plan on an ongoing basis, pointing out any shortcomings and approving the correct research plan.

4. Research:

UV-Vis vs. AAS approaches to data analysis

- Each team receives a set of samples, reagents/pollutants, and chemicals.
- To obtain reliable results, students prepare standard solutions in water using individual reagents in at least 5 concentrations.
- Students begin the experiment by combining reference porous materials with dissolved reagents/pollutants in water at various concentrations, each in an individual flask.
- (only for UV-Vis) UV-VIS measurements will be performed on the samples to image the electronic spectra of the solutions prepared in this way. On this basis, systems with too high absorbance will not be considered in further research.
- After selecting the appropriate concentrations, suspensions will be prepared at a given concentration in at least 5 separate flasks to perform valuable kinetic studies.
- Each flask will remain protected with parafilm and await measurement or be subjected to ultrasonic radiation throughout the experiment.
- After an appropriate period, the specific content of the solution will be collected to examine the electronic structure (UV-Vis analysis) or atomization (AAS) level. The collected data will be appropriately described and saved for further processing.
- Similar procedures will be adopted for solutions with various pH (3 to 10) or temperatures (from 0oC to 40oC) to reproduce the environmental condition precisely.

5. Results analysis:

- Each team will present the results of their research in the form of a short presentation.
- Teams will conclude and discuss outcomes on the base of the samples and reagents.
- Teams will define what is the main component of the unknown sample.

6. Summary:

- Discussion of the obtained results.
- Summary of experience and determination of possible future research.
- Critical evaluation of suitability and complexity of the method.
- Question and answers.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Parida, S.K., Dash, S., Patel, S. Mishra, B.K., (2006). Adsorption of organic molecules on silica surface Advances in Colloid and Interface Science, 121, 1–3, pp. 77-110
- Karnib, M., Kabbani, A., Holail, H., Olama, Z., (2014). Heavy Metals Removal Using Activated Carbon, Silica and Silica Activated Carbon Composite, Energy Procedia 50, pp. 113-120

- Di Natale, F., Gargiulo, V., Alfè, M., (2020). Adsorption of heavy metals on silica-supported hydrophilic carbonaceous nanoparticles (SHNPs), Journal of Hazardous Materials 393, 122374
- Da'na, E., (2017). Adsorption of heavy metals on functionalized-mesoporous silica: A review
- Author links open overlay panel, Microporous and Mesoporous Materials, 247, pp. 145-157

7. Additional notes

The following rules and points (=notes) are granted as an assessment of one laboratory activity:

1) The initial test - 1 point,
2) A report - 4 points in total gathered from the following elements:

- completeness of the report (1 point)
- the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results (1 point)
- the correctness of interpretations, discussions, and conclusions (1 point)

8. Optional information

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Topics 2

1. The subject of the laboratory classes

Determination of the porous nature of the materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students will comprehend porous materials' intricacies of scientific and economically viable perspectives in these classes. For this purpose, more in detail will be presented the theoretical background of an advanced porosimeter / the BET (Brunauer, Emmett, and Teller) sorptometer, with emphasizing their capability to assess specific surface areas and pore sizes intricately—parameters of utmost importance in characterizing the properties of porous materials. More closely, the classes will present the fundamentals related to the adsorption of a gas on the material's surface. Here, it will be discussed a phenomenon related to van der Waals forces that are created by a film of the adsorbate, which consists of atoms, ions, or molecules on the surface of a substance. More detail will summarize how physical adsorption correlates with van der Waals forces.

In contrast, chemical adsorption refers to the reaction between the solid and the adsorbate (gas), and the amount of the adsorbed gas on the adsorbent material correlates with its surface area. Students will know more about several parameters influencing gas adsorption, including temperature, pressure, and material characteristics. This comprehensive exploration will equip students with essential knowledge and practical skills for analyzing and interpreting porous materials in diverse scientific and industrial contexts.

Hands-on sessions with the porosimeter / BET sorptometer will allow students to grasp the intricacies of its operation. They will actively engage in experiments to analyze how gases interact with the surface of porous materials at varying temperatures and pressures. This practical exposure will deepen their understanding of the dynamic sorption processes and how they relate to the specific surface area calculations.

Moreover, students will explore the limitations and advantages of BET analysis, critically evaluating its application to different types of porous materials. Understanding these nuances will be essential for accurate and meaningful interpretation of experimental results. Through this, students will gain proficiency in operating the porosimeter / BET sorptometer and making informed decisions about its use in diverse research and industrial contexts.

3. Learning outcomes

Students will understand the theory's fundamental principles upon completing this topic. They know how to use individual terms like porosity-specific surface area and how to estimate the porosity based on the experimental data.

4. Necessary equipment, materials, etc

The exercise will be performed in a laboratory equipped with a porosimeter / BET sorptometer, degassing station, controlled temperature, nitrogen supply, and precise weighing balance. The laboratory is supplied with a piece of personal protective equipment.

Materials for the classes involve:
- porous samples in the form of powders,
- highly advanced porosimeter for the proper measurements,
- small laboratory items like scissors, papers, washing solvents (isopropanol),
- glass tubes with rubber corks,
- glass funnel with a long leg (to pour the material correctly),

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge Test:
    - A comprehensive test assessed students' readiness for laboratory exercises based on lecture information and literature resources.
2. Introduction:
    - Presentation of the laboratory's purpose, emphasizing the importance of determining specific surface areas and pore size.
    - Introduction to the methodology.
    - Discuss about the porosimeter, sample preparation, weighing, and degassing procedures.
3. Course of the Exercise:
    - Students will be divided into working teams.
    - The teams will develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor will control and support the teams in developing the research plan on an ongoing basis, pointing out any shortcomings and approving the correct research plan.
4. Research:
    - Each team receives porous samples used before the (de)sorption experiment of known chemical composition and determines optimal degassing parameters based on this knowledge.
    - Sample preparation involves three stages: precise weighing, degassing according to the predetermined procedure, and post-degassing weighing.
    - The experiment will start by carefully preparing the liquid nitrogen container 30 minutes before measurement, including correctly installing the reference tube for measuring the p_0 parameter.
    - After that, a precise sample analysis following predetermined parameters will be performed with subsequent removal, weighing, and sample washing.
5. Results Analysis:
    - Each team will present the results of their research in the form of a short presentation.
    - Teams will conclude and discuss outcomes on the base of the samples and reagents.

- Teams will define what is the main component of the unknown sample.

6. Summary:
   - Discussion of the obtained results.
   - Summary of experience and determination of possible future research.
   - Critical evaluation of suitability and complexity of the method.
   - Question and answers.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Brunauer, S., Emmett, P. H., Teller, E. (1938). "Adsorption of Gases in Multimolecular Layers". Journal of the American Chemical Society 60 (2): 309–319.
- Ambroz, F., Macdonald, T. J., Martis, V., Parkin I. P., (2018) Evaluation of the BET Theory for the Characterization of Meso and Microporous MOFs, Small Methods 2, 11 1800173
- BET Adsorption Isotherm (free online source: https://www.youtube.com/watch?v=3j7qJCv6D_o (access: May, 27th, 2023)
- ISO, ISO/TR 13014:2012: Nanotechnologies -- Guidance on physico-chemical characterization of engineered nanoscale materials for toxicologic assessment, 2012.
- ISO 9277:2010 determination of the specific surface area of solids by gas adsorption -- BET method
- DIN ISO 9277:2013 Bestimmung der spezifischen Oberfläche von Feststoffen durch Gasadsorption nach dem BET-Verfahren

7. Additional notes

The following rules and points (=notes) are granted as an assessment of one laboratory activity:

1) The initial test - 1 point,
2) A report - 4 points in total gathered from the following elements:

- completeness of the report (1 point)
- the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results (1 point)
- the correctness of interpretations, discussions, and conclusions (1 point)

8. Optional information

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Topics 3

1. The subject of the laboratory classes

Mechanical tests

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students will prepare more applicative powder forms within this laboratory class, i.e., transform powder using pressure to pellets. Hence, additional information will be discussed more precisely, comparing the advantages and disadvantages of porous materials in the form of powder and pellets. The impact of pressure will be considered, especially in understanding how improving the pellet's mechanical strength lowers the specific surface area, pore size, and the same lower sorption potential of the material. Students will also delve into the nuanced realm of nanomaterial mechanical properties, comprehending fundamentals and mechanical behaviors at the nano(micro)scale using AFM/tribometer and more macroscopic using a load machine. For this purpose, the response of the sample's surface or the whole pellet will be compared, considering various forces given to the sample. The difference between the features and their impact on the (de)sorption potential will be discussed.

Through collaborative teamwork, students formulate research plans and execute mechanical tests on nanomaterial samples, employing pellets as a common applicational form. Students will take a share in the process of pellets' preparing involves applying specific pressures critical for compaction of porous powder material. As students engage in the practical application of mechanical testing, they confront the complexities of nanomaterial behavior, mainly focusing on fundamental aspects like determining Young's modulus, stiffness, and hardness, total indentation work, or percentage of elastic strain work on nano(micro)scale and macro scale.

The course will assume that a multifaceted approach to preparing applicative forms of porous materials will give students a grasp of theory and theoretical concepts for assessing nanomaterials' mechanical characteristics. Ultimately, the course aims to foster a comprehensive understanding of how nanomaterials behave mechanically, laying a robust foundation for future research and applications in the dynamic field of nanotechnology.

3. Learning outcomes

Students will learn more about the strengths and weaknesses of porous materials in different forms. The impact of pressure on pellet properties, connecting mechanical strength, surface area, and pore size to (de)sorption potential will be discussed. Examining nanomaterial behavior at both micro and macro scales will foster a comprehensive understanding of their mechanical characteristics for future applications in nanotechnology.

4. Necessary equipment, materials, etc

The exercise will be performed in a laboratory equipped with different machines to study mechanical properties at variable levels of force, such as Atomic Force Microscopy (AFM), Tribometer, and Load Machine. The laboratory is supplied with a piece of personal protective equipment.

Materials for the classes involve:

- porous samples,
- hydraulic press,
- small laboratory items like scissors, papers, washing solvents (isopropanol),
- holders, glass tubes with rubber corks,
- tips for the measurements,

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge Test:
    - A comprehensive test assessed students' readiness for laboratory exercises based on lecture information and literature resources.
2. Introduction:
    - Presentation of the laboratory's purpose, emphasizing the importance of determining the mechanical properties of the materials.
    - Introduction to the methodology.
    - Discuss the effect of compression, various devices used to study mechanical parameters and forces related to them in the context of sample features.
3. Course of the Exercise:
    - Students will be divided into working teams.
    - The teams will develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor will control and support the teams in developing the research plan on an ongoing basis, pointing out any shortcomings and approving the correct research plan.
4. Research:
    - Based on this knowledge and literature reports, each team receives porous samples and determines optimal compression pressure parameters.
    - Sample preparation involves precise weighing and compressing the powder using different forces, optionally 3 or 4.
    - The experiment will start by choosing an AFM Tip with appropriate resonance (usually 50 kHz) before measurement and/or holders for mounting samples to the individual devices.
    - After that, a precise sample analysis following predetermined parameters will be performed using various forces (nN: AFM, µN: tribometer, N: load machine).
5. Results Analysis:
    - Each team will present the results of their research in the form of a short presentation.

- Teams will conclude and discuss outcomes on the base of the samples and reagents.

6. Summary:
   - Discussion of the obtained results.
   - Summary of experience and determination of possible future research.
   - Critical evaluation of suitability and complexity of the method.
   - Question and answers.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Zum Gahr, K.H., (1987). Microstructure and Wear of Materials, Elsevier, Amsterdam
- Bhushan, B., (1999). Principles and Applications of Tribology, Wiley, New York
- Reifenberger, R., (2015). Fundamentals of Atomic Force Microscopy Part I: Foundations, Purdue University, USA
- ASTM Standard G133-05, (2016). Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA.
- ISO 21920-1:2021, (2021). Geometrical product specifications (GPS) — Surface texture: Profile Part 1: Indication of surface texture; European Committee for Standardization: Brussels, Belgium.
- Bhushan, B. (2002). Introduction to Tribology, Wiley, New York

7. Additional notes

The following rules and points (=notes) are granted as an assessment of one laboratory activity:

1) The initial test - 1 point,
2) A report - 4 points in total gathered from the following elements:

- completeness of the report (1 point)
- the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results (1 point)
- the correctness of interpretations, discussions, and conclusions (1 point)

8. Optional information

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Topics 4

1. The subject of the laboratory classes

A case study of structural parameters of porous materials

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In this laboratory module, students will systematically explore the structural intricacies of porous nanomaterials, focusing on meticulously determining structural defects and an in-depth evaluation of functionalization through analyzing characteristic functional groups. Moreover, they will learn about sophisticated analytical methods that allow the study of structurally disordered materials, such as infrared and Raman spectroscopy. They will also know why the lack of long-range order and well-defined scattering planes is considered during porous material classes, rendering classical XRD techniques impractical. It enables them to delve into structurally disordered materials, gaining insights into individual units, whether octahedral and tetrahedral groups in inorganic materials or molecular fragments in organic materials. The analysis will involve interpreting individual spectra referencing unique tables that describe the position of bands corresponding to the vibration of distinct functional groups. This comprehensive approach will help students in practical proficiency in deciphering the intricate properties of nanomaterials, showcasing the power of these specialized spectroscopic techniques.

A foundational emphasis will be placed on understanding molecular interactions and fundamental aspects such as dipole moments, absorption, scattering, and polarizability. Students will develop a nuanced understanding of the nuanced differences between these spectroscopic methods, including their specific advantages, limitations, and optimal applications. This knowledge empowers students to select the most suitable technique for a given experiment judiciously.

In the practical segment of the course, students will actively engage in experiments, applying the theoretical foundations of spectroscopic methods to analyze obtained results. Their explorations will include comparing materials before and after sorption and elucidating the impact of structural modifications induced by interactions with organic or inorganic molecules. Another avenue involves conducting a sorption experiment akin to the UV-Vis experiment, systematically analyzing the sorption potential in the context of structural alterations. Students will craft comprehensive research plans, execute (de)sorption experiments, and meticulously analyze data, fostering essential skills applicable to real-world environmental scenarios.

3. Learning outcomes

Students will explore the structural intricacies of porous nanomaterials, focusing on defects and functionalization through techniques like infrared and Raman spectroscopy. They understand why classical XRD techniques are impractical for porous materials, gaining practical proficiency in deciphering nanomaterial properties. The course emphasizes molecular interactions and equips students to select suitable spectroscopic methods judiciously, fostering essential skills applicable to real-world environmental scenarios.

4. Necessary equipment, materials, etc

The exercise will be performed in a laboratory with specialized devices like infrared and Raman spectrometers. The laboratory is supplied with a piece of personal protective equipment.

Materials for the classes involve:

- porous samples in the form of pellets,
- small laboratory items like scissors, papers, washing solvents (isopropanol),
- holders,

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Laboratory course outline:

1. Knowledge Test:
    - A comprehensive test assessed students' readiness for laboratory exercises based on lecture information and literature resources.
2. Introduction:
    - Presentation of the laboratory's purpose, emphasizing the importance of determining the mechanical properties of the materials.
    - Introduction to the methodology.
    - Discuss the effect of structural distortion, the level of functionality in the context of porous materials, and techniques that can be appropriate to study.
3. Course of the Exercise:
    - Students will be divided into working teams.
    - The teams will develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor will control and support the teams in developing the research plan on an ongoing basis, pointing out any shortcomings and approving the correct research plan.
4. Research:
    - Based on this knowledge and literature reports, each team receives porous samples and determines their structural properties (powders), estimated functionalization level, and the effect of compression on the structure (pellets).
    - The experiment will be realized on powders and pellets prepared before.
    - Structural parameters will be verified using infrared spectroscopy by pressing the material with a unique screw lying on the diamond accessory and collecting a series of spectra related to various porous materials with various pore sizes, specific surface areas, and levels of functionality. At least 10 spectra from one sample will be collected for statistical analysis.

- Alternatively, the sample on the unique holder will be put below the objective, a focal plan will be chosen, and one individual place of the measurement using an objective with a magnification of 50x or 100x will be applied. Then, the power of the laser will be anticlockwise increased to receive a desirable signal-to-noise ratio appropriate. When the sample is burnt, the power will be decreased. At least 10 spectra from one sample will be collected for statistical analysis.

5. Results Analysis:
    - Each team will present the results of their research in the form of a short presentation.
    - Teams will conclude and discuss outcomes on the base of the samples and reagents.
6. Summary:
    - Discussion of the obtained results.
    - Summary of experience and determination of possible future research.
    - Critical evaluation of suitability and complexity of the method.
    - Question and answer session.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Stuart, B.H., (2004). Infrared Spectroscopy: Fundamentals and Applications, John Wiley & Sons, Ltd
- Handbook of Vibrational Spectroscopy, John Wiley & Sons, Ltd
- Fraser-Miller, S.J., Saarinen, J., Strachan, C.J. (2016). Vibrational Spectroscopic Imaging. In: Müllertz, A., Perrie, Y., Rades, T. (eds) Analytical Techniques in the Pharmaceutical Sciences. Advances in Delivery Science and Technology. Springer, New York, NY.
- Dietzek, B., Cialla, D., Schmitt, M., Popp, J. (2018). Introduction to the Fundamentals of Raman Spectroscopy. In: Toporski, J., Dieing, T., Hollricher, O. (eds) Confocal Raman Microscopy. Springer Series in Surface Sciences, vol 66. Springer, Cham.
- Jones, R.R., Hooper, D.C., Zhang, L. et al. (2019). Raman Techniques: Fundamentals and Frontiers. Nanoscale Res Lett 14, 231
- Kaur, H., Rana, B., Tomar, D., Kaur, S., Jena, K.C. (2021). Fundamentals of ATR-FTIR Spectroscopy and Its Role for Probing In-Situ Molecular-Level Interactions. In: Singh, D.K., Pradhan, M., Materny, A. (eds) Modern Techniques of Spectroscopy. Progress in Optical Science and Photonics, vol 13. Springer, Singapore
- Sultan, K., (2022). Practical Guide to Materials Characterization: Techniques and Applications, Wiley-VCH GmbH

7. Additional notes

The following rules and points (=notes) are granted as an assessment of one laboratory activity:

1) The initial test - 1 point,
2) A report - 4 points in total gathered from the following elements:

- completeness of the report (1 point)
- the theoretical introduction (1 point)
- the quality (in terms of correctness) of the obtained results (1 point)
- the correctness of interpretations, discussions, and conclusions (1 point)

8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SUSTAINABLE DEVELOPMENT FOR MATERIALS ENGINEERING

Code: SDME

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

SD genesis

2. Thematic scope of the lecture (abstract, maximum 500 words)

We can see that there has been obvious social and economic development throughout history. However, if we look more closely at specific regions, nations and individual periods, we see that the processes of civilisational development are far more complex. In the lecture the core economic, social and political stratification between countries will be shown, which contributes to the migration of millions of people in search of a better life. Also the question of how to measure well-being and welfare will be raised. The lecture students will be familiarized with the costs of humanity's current standard of living, which is possible by the exploitation of natural capital on an unprecedented scale.

The aspect of human activity which is now one of the most important factors influencing the global carbon and nitrogen cycles will be arised. It increases uncertainty about the future of the planet as we do not know, for example courses of the Earth's climate change. Also the decisions at the regional level regarding the management of natural resources are leading to disasters, such as the depletion of fisheries, the degradation of agricultural areas and the collapse of forest management.

The concept of sustainable development will be presented. It emerged more than two decades ago as an attempt to provide a framework for development management. It was realised that the mistakes of the past were caused by visions and goals that were too limited. Development focused on maximising economic and political gains has led to environmental, social and even economic crises. In the active discussion with the studies examples of societies that look for solutions that are supposed to lead to alleviating the immediate symptoms of the problems, focusing only on rebuilding the economy or biodiversity will be sought. In the meantime they fall into a trap, as short-term-oriented measures rarely succeed in the long term. Sustainable development circumvents the above pitfalls by integrating the three domains: economy, society and environment. Although the concept sounds convincing, difficulties arise at the dissemination and implementation stage. Indeed, much more often than not, solutions are chosen that will provide quick economic or political gain and lead to immediate results. Compared to these, the concept of sustainable development, and the integrated and long-term approach associated with it, may seem too vague and unspecific.

An additional challenge in implementing sustainable development is to change our habits, linked to existing social structures (institutions), psychological structures (beliefs) and physical structures (infrastructure). Sustainability requires changing the mental models that constrain us and the ability to take another point of view. Often we are held back from using innovative tools and methods by inertia and thought patterns. The concepts presented by SD are derived from decades of research and can inspire anyone, as they show the possibilities for action to live safely in a world where the pace of change is faster than ever before. Sustainability is shown an inspiration to test new ideas and continuously experiment and learn.

3. Learning outcomes

Students will gather the basic knowledge of the sources of development (social, economic, and environmental). They will also be equipped with the ability to find the examples of stratification and inequality between countries. Moreover, they are able to point out the benefits and costs of incorporating SD principles.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a traditional interactive board along with the use of multimedia. During the lecture, different examples (e.g. old vs new technologies) will be shown to present course of changes. The topic will be realized within 2 h of classes.

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning general ides of sustainable development rules

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

The Sustainable Development Paradigm, by Marek Ogryzek, Geomatics and Environmental Engineering; 2023, 17, 1; 5-18, Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie. Wydawnictwo AGH,

6. Additional notes

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Topics 2

1. The subject of the lecture

SD from materials engineering approach

2. Thematic scope of the lecture (abstract, maximum 500 words)

Sustain development in particular in materials engineering involves designing, producing, and using materials in a way that minimize environmental impact while meeting societal needs. The student will be familiarized with the core methodologies and ideas taken from the SD area.

The materials selection aspect that involves choosing materials that are renewable, recyclable, and have minimal environmental impact during extraction, processing, and subsequent disposal. The life cycle analysis (LCA) which serves to evaluate the environmental impact of materials throughout their entire life cycle, from extraction to disposal. Another approach focuses on resource efficiency, that maximize resource efficiency by reducing material waste, using recycled materials, and optimizing manufacturing processes itself. Also energy efficiency impose the requirement to implement energy – efficient manufacturing processes and use renewable energy sources to reduce carbon foot print.

The idea of designing for environment (DfE) involves designing products and processes with environmental considerations in mind, including minimizing hazardous materials usage or predesign for disassembly and recycling. One of the exemplary rout is the usage of biodegradable materials, the ones that can break down naturally without harming side-products. It is part of the circular economy that embraces principles of the economy that promotes reuse, remanufacturing, and recycling of materials to minimize waste and conserve resources.

At the lecture student will also be informed about value of collaboration and innovation including foster collaboration among stakeholders across the materials supply chain, like manufactures, designers, policymakers, and consumers that can enhance the probability of successful action. The encouragement for innovation in materials science and engineering to develop new sustainable materials, processes, and technologies is also valuable path. The fundamental role in introduction of the awareness of SD rules is education. It is of pivotal role to higher the understanding of the importance of sustainable materials engineering practices among industry professionals, and general public. It provide education and training on sustainable design principles, LCA methodologies, and best practice for minimizing environmental impact. By integration of SD principles into materials engineering practice one can work towards a more sustainable development, while continuing to advance technology and meet societal needs.

3. Learning outcomes

Student understand and can describe the influence of the incorporation on SD principles in the field of materials engineering. Moreover, he / she provides rational explanation of the influence of the various methodologies on the perspective effect in terms of the materials production (e.g. incorporation the life cycle analysis on the design process).

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a traditional interactive board along with the use of multimedia. During the lecture, discussion with the participants will be conducted to engage them into the subject. The topic will be realized within 2 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Theoretical and applied aspects of sustainable development, Tetyana Nestorenko, Aleksander Ostenda, Publishing house of the University of Technology in Katowice, 2020

6. Additional notes

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Topics 3

1. The subject of the lecture

Technology of materials production in light of SD – the sources

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the lecture the main subject is focused on the sources that fulfill the SD requirements. When seeking sustainable development materials sources, several possibility can be pointed and discussed. Renewable materials belong to the group derived from renewable resources such as bamboo, cork, hemp, and organic cotton. These materials are grown and harvested sustainably, minimizing environmental impact. Recycled materials are made from recycled content, including recycled plastics, metals, glass, and paper. Using recycled materials reduces the demand for virgin resources and helps to reduce waste in landfills. Another group is devoted to natural or bio-based materials, which are derived from natural sources or bio-based materials that are biodegradable and renewable like bio-plastics, natural fibers, biodegradable polymers. Certified sustainable materials are labelled with notification coming from reputable organization like the Forest Stewardship Council (FSC) for wood products or the Global Organic Textile Standard (GOTS) for textiles. These certifications ensures that materials are sourced and produced using sustainable practices.

Next group is termed as low-impact materials which are composed of the materials with low environmental impact throughout lifecycle, including reduced energy consumption during production, minimal waste generation, and biodegradability at end-of-life.

Taking into consideration the origin of the materials the promising group is formed by local and regional materials. By prioritizing materials sourced locally or regionally one can minimize transport – related emission and also support local economies. Locally sourced materials also serve as help in promotion of transparency in the supply chain and reduce environmental foot print.

It is also possible to explore innovative materials derived from waste stream or by-products of other industries. Materials like reclaimed wood, recycled glass countertops, and upcycled textiles offer sustainable alternatives to conventional materials. The important aspect of the design process is life cycle consideration related to evaluation of materials based on their environmental impact throughout their entire life cycle. Factors like resources extraction, production, transportation, use, and end-of-life disposal or recycling should be considered. The aid in the evaluation cycle might be found by the use of collaborative platforms and networks. Sustainable material sourcing platforms and networks connect designers, manufactures, and suppliers committed to sustainability. The platforms provide access to a wide range of sustainable materials and facilitate collaboration on sustainable projects. In the lecture for each pointed source the advantageous and disadvantageous will be discussed.

By leveraging these sources individuals and organizations can make informed decisions and prioritize materials that align with sustainable development goals, reducing environmental impact and promoting responsible resources management.

3. Learning outcomes

Student can make informed decisions and prioritize materials that align with sustainable development goals. He / she understand the role of proper choice of source material in the path of materials' design. The student is capable to perform comparison and evaluation on the materials in respect to their applicability for usage as the source material fulfilling SD goals.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a interactive board supported with the use of multimedia. During the lecture simple experiment will be taken to picture the feature described in theoretical part. Also discussion with the participants will be encouraged to support the remembering process. The topic will be realized within 2 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Handbook of bionanocomposites: green and sustainable materials, edited by Shakeel Ahmed, Suvardhan Kanchi, Singapore: Pan Stanford Publishing, 2018

Man and materials flows: towards sustainable materials management, aut.: Sten Karlsson [et al.]; ed. Sten Karlsson ; Engl. ed. Ann Crossley, Uppsala : Baltic University, 1987

Biopolymers: new materials for sustainable films and coatings, ed. David Plackett, Chichester: John Wiley and Sons, 2011

6. Additional notes

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Topics 4

1. The subject of the lecture

Technology of materials production in light of SD – the wastes

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the lecture sustainable development and recycling of materials are discussed as crucial components of efforts to mitigate environmental impact and promote responsible resource management. SD in materials recycling waste involves several key strategies aimed at minimizing waste generation, maximizing resources recovery, and reducing environmental impact.

The basic approaches are to be discussed. Waste reduction and prevention encourage waste reduction and prevention started by promoting product design for durability, repairability and reuse. Also designing products with fewer disposal components can reduce waste generation.

For the recycling infrastructure development the crucial are investments in recycling infrastructures and facilities to efficiently collect, sort, and process recyclable materials. This involves also establishing municipal recycling programs, implementing advanced sorting technologies, and improving materials recovery facilities (MRFs). Such development is advantageous also for innovation in recycling technologies. The action support the research and development efforts to advance recycling technologies and processes, including chemical recycling, pyrolysis, and mechanical recycling processes. Such innovations can improve the efficiency and effectiveness of recycling operations, especially for challenging materials.

In the lecture also extended producer responsibility (EPR) policies will be provided that implement the producers responsibilities for managing the end-of-life disposal of their products. EPR encourages manufacturers to design products with recyclability in mind and establish take-back programs for recycling on proper disposal.

The mention approach are built in circular economy initiatives which promote circular economy principle that prioritize resource conservation and material reuse. Encourage the development of closed-loops systems where materials are continuously recycled and reintegrated into the production cycle. It covers also the idea of market development for recycled materials. It creates the demand for recycled materials by supporting market development initiatives and procurement policies that prioritize the use of recycled content in manufacturing and construction projects. This stimulates investments in recycling infrastructure and drives innovation in recycling material applications.

3. Learning outcomes

Student can provide information about influence of stream of waste material and by-products on the final assessment of the technology.

She / he is capable to discuss basic ways of waste management.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realised with a board supported with the use of multimedia. During the lecture reference to own experience of the students will be recall to strengthen the understanding of the presented material. The topic will be realised within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.
Case study - presentation of the issues concerning
Discussion - encouraging participants to actively participate in the discussion on the discussed issues
Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Handbook of bionanocomposites: green and sustainable materials, edited by Shakeel Ahmed, Suvardhan Kanchi, Singapore: Pan Stanford Publishing, 2018
Man and materials flows: towards sustainable materials management, aut.: Sten Karlsson [et al.]; ed. Sten Karlsson ; Engl. ed. Ann Crossley, Uppsala : Baltic University, 1987
Environmental materials and waste: resource recovery and pollution prevention, edited by M. N. V. Prasad, Kaimin Shih, Academic Press is an imprint of Elsevier, 2016

6. Additional notes

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Topics 5

1. The subject of the lecture

Circular economy of materials – from the cradle to the grave

2. Thematic scope of the lecture (abstract, maximum 500 words)

In the lecture the concept of "from the cradle to the grave" will be discussed in relation to the materials engineering approach. In general it refers to the entire life cycle of a material, from the extraction of raw materials (named as the cradle) to its disposal at the end of its useful life (named as the grave). In the context of materials, the cradle-to-grave approach involves assessing the environmental and social impacts associated with each stage of the material's life cycle, like extraction, processing, manufacturing, distribution, use, and disposal.

Several stages of the process will be discussed to evaluate material. Extraction of raw materials is starting stage that involves the extraction or harvesting of natural resources, such as mining for metals, logging for wood, or drilling for oil. The environmental impact may include habitat destruction, soil erosion, water pollution, and biodiversity loss. Raw materials undergo processing and manufacturing processes to create usable products. The stage often involves energy-intensive processes, chemical treatments, and emissions of pollutants and greenhouse gases which shall be noted and described.

Materials and final products are transported from manufacturing facilities to distribution centers, wholesalers, retailers, and ultimately to consumers. The activity contributes to carbon emissions, air pollution, and energy consumption. The environmental impact of material during the use phase varies markedly depending on the product type and how it is used. So energy-efficient appliances reduce energy consumption, while inefficient ones contribute to higher energy use and emissions. In the lecture the idea of end-of-life management is also presented as a part of total process. At the end of a product's life cycle, it is disposed of, recycled, or reused. Materials may end up in landfills, incinerators, recycling facilities, or reused in new products. The waste management practices can minimize environmental pollution and resource depletion.

The added value of incorporation of the cradle-to-grave perspective into material engineering perspective enables stakeholders to point opportunities for improvement as well as make more conscious decisions. Application of the entire life cycle of materials bring the opportunity to mitigate environmental impacts, conserve natural resources, and promote social responsibility and awareness.

3. Learning outcomes

Student can identify and describe the concept of "from the cradle to the grave" in relation to the materials engineering. He / she is aware of the impact of each stage of materials production and usage on the broad surrounding. Moreover, the student knows basic methodology to evaluate the materials impact with awareness of their pros and cons.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realized with a board supported with the use of multimedia. During the lecture, discussion with the participants will be conducted to engage them into the subject. The topic will be realized within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.
Case study - presentation of the issues concerning cricular economy of materials.
Discussion - encouraging participants to actively participate in the discussion on the discussed issues
Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Economics and engineering: institutions, practices and cultures, edited by Pedro Garcia Duarte and Yann Giraud, History of Political Economy, vol. 52, 2020
Introduction to materials science and engineering, Yip-Wah Chung and Monica Kapoor, CRC Press, an imprint of the Taylor & Francis Group, 2022

6. Additional notes

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Topics 6

1. The subject of the lecture

Novel materials’ technologies raised on the wave of SD requirements

2. Thematic scope of the lecture (abstract, maximum 500 words)

The final lecture will provide insight into future. In the lecture novel materials technologies will be described as they play a crucial role in advancing sustainable development. They offer innovative solutions to arising environmental challenges by increasing resource efficiency, and promoting social well-being. They can act on a various levels that will be shown within the scope of the lecture. On of the way how novel materials technologies contribute to SD is by focusing on developing materials sourced from renewable resources or recycled materials. Such materials’ approach reduces reliance on finite resources, minimize environmental impact, and introduce circular economy principles in real life.

Another approach involves utilization of advanced materials for development of energy-efficient technologies and products. In such a way lightweight materials in transportation reduce fuel consumption, or smart materials in buildings improve insulation and provide balanced temperature conditions. Also clean energy sources such as solar, wind, and hydroelectric power are more commonly utilized. As innovations in materials engineering enhances the efficiency and also affordability of renewable energy technologies, they become more accessible. Novel materials technologies enables to efficient removal of contaminants and pollutants from waste water and contaminated air, hence ensures access to clean and safe drinking water and reducing air pollution along with SDG. With the use of advanced materials technologies also waste management and recycling processes are facilitated. It is visible in development of biodegradable and compostable materials, and also in technologies for sorting, processing, and recycling of waste. They are also programmed to achieve lower environmental footprint of production processes by optimizing resource use, minimizing waste generation, and lowering energy consumption. It all bring reduced environmental footprint. The impact of novel materials technologies is profound in the field of healthcare and biomedical applications. Therse are e.g. modern drug delivery systems, medical implanting devices, tissue engineering items, or sophisticated diagnostic devices. The intelligent materials bring the possibility to improve patient outcomes by enhanced treatment efficacy, and reduced healthcare-related environmental impacts. Also in the area of agriculture some impact is noticed, where novel materials contribute to sustainable agriculture practices. It is realized by improving soil condition, water conservation, and enhanced crop protection. The products like biodegradable mulches, smart sensors, and nanomaterial additives support agricultural productivity with diminished environmental degradation. The novel materials technologies prioritize social impact and inclusivity by factors such as affordability, accessibility, and cultural relevance. By harnessing the potential of novel materials technologies, stakeholders across industries can accelerate progress towards achieving the Sustainable Development Goals (SDGs).

3. Learning outcomes

Student is capable to point threats and opportunities provided by the use of novel technologies in the field of materials engineering. He / she is aware of the environmental issues as well as technological importance of introduction of sustainable manufacturing process. The student knows and understand the idea of circular economy in relation to production process and its consequences.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

In the work lecture will be realised with a board supported with the use of multimedia. During the lecture with the use of personal equipment like smartphones various recycling strategies will be sought in situ to attract students‘ attention to the issue. The topic will be realised within 3 h of classes

Multimedia presentation - the use of a multimedia presentation, such as Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, SlideDog, for the visual presentation of the discussed issues.

Case study - presentation of the issues concerning novel technologies applicable in relation to SDG

Discussion - encouraging participants to actively participate in the discussion on the discussed issues

Q and A session – series of question asked by the teacher, answers given by the students; for each correct answer the student is granted with points. The student are also encouraged to ask questions to their colleagues.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Technology, globalization, and sustainable development: transforming the industrial state, Nicholas A. Ashford, Ralph P. Hall, New Haven; London: Yale University Press, 2011

Energy-based economic development: how clean energy can drive development and stimulate economic growth, Sanya Carley, Sara Lawrence, London [etc.]: Springer, 2014, DOI 10.1007/978-1-4471-6341-1

Climate change law, technology transfer and sustainable development, Md Mahatab Uddin, London ; New York: Routledge Taylor & Francis Group, 2021

15 INNOVATIVE SUSTAINABLE & ECO FRIENDLY BUSINESS IDEAS (free online source, retrieved from 15 INNOVATIVE SUSTAINABLE & ECO FRIENDLY BUSINESS IDEAS (youtube.com) (access: March, 01st, 2024)

22 Inventions That Are Saving The Earth (free online source, retrieved from 22 Inventions That Are Saving The Earth (youtube.com) (access: March, 01st, 2024)

6. Additional notes

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Course content – auditory classes

Topics 1

1. The subject of the auditory classes

Close inspection of the SD's goals – not only the cartoons.

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

Auditory classes topics are related to basic goals of sustainable development. During the exercise, students will be given a variety of tasks from all the SDGs and their task will be to match them to the relevant SDG. A discussion will be held to identify the features that make the prescription possible and the multi-faceted nature of the tasks, as many of them belong to several SDGs.

The class begins with an introductory discussion with participants about their subjective vision of world development. Students should consider whether the current state of development leads to an improving outlook or a worsening one? The conversation should cover a diverse range of issues with a particular focus on technological developments including materials engineering and their impact on equality, health/disease, environmental status, resource availability. Students engage in a free exchange of ideas.

The idea and objectives of sustainable development will then be presented. On the basis of the discussion, a definition of sustainable development will be drawn up and written up in a visible place in capital letters. A well-known definition of sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Thus, sustainable development implies a balance between economic growth, the quality of people's lives and care for the environment manifested in respect for each other's needs and an awareness of limitations. These have been translated into 17 SD goals, which will be presented and discussed for students. Each of the goals is identified by a pictogram representing a graphic that identifies the set objective. Students will be introduced to them, as well as learning about the sites from which these graphics can be downloaded. For each objective, tasks are assigned to detail the scope of activities to be undertaken. The aim of the exercise is for students to assign tasks from among the prepared suggestions.

Cards with printed tasks should be assigned to the arranged logos of each SDG. The student should act in cooperation with others, but also make independent decisions. The location of the individual tasks should be based on the argumentation and agreement of the majority of the group. During the task, it should be emphasised that it is particularly important for the agenda to include all people and that all goals should be pursued in parallel. Students should discuss possible synergies, as well as conditions that might be obstacles to the implementation of the tasks. Using a string, students make connections between tasks that influence each other (white string - strengthen each other, black string - weaken each other). Once the connections have been made, a phase of mutual influence analysis follows.

3. Learning outcomes

The student is aware of the variety of SDG with the tasks involved under the main headlines. He/she is able to identify the tasks of the goal with their mutual impact.

4. Necessary equipment, materials, etc

The exercise takes place in class-room .
Necessary materials
Piece of papers with printed tasks (for goals 1-17). 17 different colors of markers, similar to the colors of the signs of SDG. 2 ropes with different colors (e.g. white and gray).
Large magnetic table and magnets to stick the papers with task or separate tables to divide the papers into 17 groups.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:
1. Introduction:
- Presentation of the purpose of the activity and discussion of the importance of sustainable goals in aspect of material engineering.
- Discuss the stages of work, organization of the work space, time schedule reminder.

2. The course of the activity:
- Students will be divided into working teams (4 teams). Each team is given at least 4 SDG to be described.
- The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
- The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.

3. Research:
- Groups work separately, however they are also encouraged to general discussion between groups
- The task last approx. 50% of the time.

4. Results analysis:
- Each team will present the results of their work in the form of a short presentation.
- Teams will draw the conclusion and discuss them in relation to the others members of the class.

5. Summary:
- Summary of the activity and a reminder of its goals.
- Discussion of the results obtained and confirmation of the final remarks.
- Summary of experience and determination of possible future actions, including any further research.

- Critical evaluation of suitability and complexity of the method.
- Enlisting content of the report.
- Question and answer session regarding practical aspects of the SD's goals.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:
- A Critical Analysis of the Sustainable Development Goals, Ranjula Bali Swain, a chapter in: Handbook of Sustainability Science and Research, Walter Leal Filho (Ed), World Sustainability Series, Springer, https://doi.org/ 10.1007/978-3-319-63007-6, ISBN 978-3-319-63007-6 (eBook)
- Time to revise the Sustainable Development Goals, Nature, 583 (2020) 331-332
- Sustainable Development Goals (free online source, retrieved from THE 17 GOALS | Sustainable Development (un.org) (access: March, 01st, 2024)
- Ansell, C., Sørensen, E. and Torfing, J. (2022), "ch1_Cocreating the UN's Sustainable Goals", a chapter in: Co-Creation for Sustainability, Emerald Publishing Limited, Leeds, pp. 9-22. https://doi.org/10.1108/978-1-80043-798-220220002, publisher: Emerald Publishing Limited
- Institute for Advanced Sustainability Studies. (2015). Long-term climate goals. Decarbonisation, carbon neutrality, and climate neutrality. Retrieved from: https://www.iass-potsdam.de/sites/default/files/files/policy_brief_decarbonisation.pdf
- REPORT on the implementation and delivery of the Sustainable Development Goals (SDGs) 9.6.2022 - (2022/2002(INI)), Committee on Development, Committee on the Environment, Public Health and Food Safety, Rapporteurs: Barry Andrews, Petros Kokkalis (free online source, retrieved from REPORT on the implementation and delivery of the Sustainable Development Goals (SDGs) | A9-0174/2022 | European Parliament (europa.eu) (access: March, 01st, 2024)
- Sustainable Development Goals and the environment in Europe: a cross-country analysis and 39 country profiles, Report of EEA (European Environment Agency), 2020, no. 21/2020, TH-01-20-560-EN-N - ISBN 978-92-9480-284-2 - doi: 10.2800/044724

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),

- content included in the theoretical introduction (1 point),

- the quality of the given examples (3 points),

- the correctness of interpretations, discussions, and conclusions (4 points),

- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: sustain development goals, task of each goal, the relation between the goals

Topics 2

1. The subject of the auditory classes

Carbon foot print calculators – online activity

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In this class, students will be introduced to the concept of carbon footprint as the total emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG). These include components such as methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). It is the amount of gases produced by a person or other entity (such as a product, service, organisation, company) over a set period of time (usually a year). The carbon footprint includes direct and indirect emissions. Direct emissions result from the combustion of fossil fuels in industrial plants, building heating systems or means of transport. Indirect emissions are related to the production of electricity or heat or the supply chain of specific goods and services. The carbon footprint is expressed in mass units (e.g. kilograms, tonnes) using a universal unit, which is the carbon dioxide equivalent (CO_2e).

Students will be introduced to sources of greenhouse gas emissions such as the extraction and combustion of fossil fuels (which include oil, coal, natural gas), industrial production such as cement, the burning of biomass or land-use change (e.g. deforestation, wetland drainage), which all contribute to carbon dioxide emissions (CO_2). Livestock farming, rice cultivation, landfill sites and municipal wastewater or fossil fuel extraction or biomass burning processes that contribute to methane emissions (CH_4). Fossil fuel combustion processes in power plants, biomass combustion, microbial decomposition processes of nitrogen mineral fertilisers, which contribute to nitrous oxide emissions (N_2O). The use of refrigerants in industrial processes, solvents in the electronics industry, carrier gases in fire extinguishers, the manufacture of insulation materials or plastics, which contribute to chlorofluorocarbon (CFC) emissions. The use of refrigerants, cleaners, solvents and carrier gases in semiconductor and plastic manufacturing processes (e.g. polyurethane foams, polystyrene foams), which contribute to emissions of hydrofluorocarbons (HFCs). The use as heat transfer agents, solvents or carrier gases in industrial processes and in the production of aluminium, which contribute to emissions of perfluorocarbons (PFCs). The use of raw materials in aluminium and magnesium smelting, high-voltage cables and switchgear, and semiconductor manufacturing, which contribute to sulphur hexafluoride (SF_6) emissions.

The carbon footprint is a useful tool to determine the impact of anthropogenic greenhouse gas emissions on global climate change, in particular the increase in the Earth's average surface temperature (global warming) and associated extreme weather events (e.g. heavy rainfall, hailstorms, heat waves, droughts, storm surges, strong winds, storms, hurricanes, tornadoes or tropical cyclones). Students will carry out carbon footprint simulations based on available calculators (UN calculator, US Environmental Protection Agency calculator) or The Greenhouse Gas Protocol.

3. Learning outcomes

The student knows the methodology of calculation of carbon foot print. He / she is also able to describe the factors / activities that influence profoundly on CFP. Additionally, he / she is aware of the importance of action taken to reduce CFP.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with calculators, large piece of papers or access to calculation files to be able to do calculations. The Internet connection is also needed to estimate the input values for the exemplary analysis.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of carbon foot print in aspect of materials' production, usage and recycling.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses either individual or enterprise assessment.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available on-line calculator the carbon foot-print is calculated. If possible choose at least two different calculators for the comparison.
   - The task last approx. 50% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.

- Summary of experience and determination of possible future actions, including any further research.
- Critical evaluation of suitability and complexity of the method.
- Enlisting content of the report.
- Question and answer session regarding practical aspects of the carbon foot print calculation.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:
- Carbon footprinting of universities worldwide: Part I—objective comparison by standardized metrics, Eckard Helmers, Chia Chien Chang, Justin Dauwels, Helmers et al. Environ Sci Eur (2021) 33:30, https://doi.org/10.1186/s12302-021-00454-6, OA source
- Explainer: What Is the Carbon Footprint and Why Does It Matter in Fighting Climate Change?, (free online source, retrieved from What Is the Carbon Footprint and Why Does It Matter in Fighting Climate Change? | Earth.Org (access: March, 01st, 2024)
- Biocode — Carbon footprint calculator (free online source, retrieved from Biocode — Carbon footprint calculator that makes sense (access: March, 01st, 2024)
- CO2-footprint calculator (free online source, retrieved from CO2-footprint calculator - European Commission (europa.eu) (access: March, 01st, 2024)
- Carbon Footprint Calculator For Individuals And Households (free online source, retrieved from carbonfootprint.com - Carbon Footprint Calculator (access: March, 01st, 2024)
- GHG Protocole: Calculation Tools and Guidance (free online source, retrieved from Homepage | GHG Protocol (access: March, 01st, 2024)
- Carbon Disclosure Project (free online source, retrieved from Home - CDP (access: March, 01st, 2024)
- More accurate Greenhouse Gas Calculation using the TopDown weight-based Approach Comparing spend-based vs. weight-based approach, DFGE – Institute for Energy, Ecology and Economy, B.Sc. Nora Kuhn (UBT), M.Sc. Dominik Roppelt (UBT), Dr.-Ing. Thomas Dreier (DFGE), Dr.-Ing. Bernd Rosemann (UBT), Publisher: Dr.-Ing. Thomas Fleissner, DFGE_Whitepaper_Biodiversity&Disclosure_v1.0, 2024
- The Handbook of Carbon Accounting, Arnaud Brohe, Taylor & Francis 2016
- EDGAR – Emissions Database for Global Atmospheric Research; (free online source, retrived from: edgar.jrc.ec.europa.eu (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.

The scope of the issues for the final test involves the following topic: carbo foot print – definition, calculation, parameters that influences on carbon foot print calculated value, Greenhouse Gas (GHG) Protocol, Carbon Disclosure Project (CDP).

Topics 3

1. The subject of the auditory classes

Economic aspect of SD – plastics waste report

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the activity students will be familiarized with The New Circular Economy Action Plan. It focuses on strong increase in recycling rates for several waste streams, including plastic waste or municipal biowaste. Student will discuss different ways of recycling of these waste streams with strong focus on materials engineering's impact within the field. The analysis will bring into consideration also the environmental and socio-economic effects.

The different recycling pathways will be discussed with their influence on economic aspects including market failures, the methodology of economic impacts calculation and scope of information about this impact. In waste management it is common to find market failures as they result from the strengths playing crucial role on the markets, e.g. waste's low prices. The student will check the change of the prices of the recycles by the available sources.

There is a large discrepancy on the valid approaches and methods used to evaluate the economic impacts of recycling policies. Hence the straightforward comparison is handicapped. Moreover, the available date concerning the economic impacts of municipal food/bio-waste and municipal dry recyclables (priority on plastics) is not enough for drawing general conclusion. They dependent on the source of waste streams and local conditions.

Factors like command and control measures such as standards in the form of recycling targets, contents of recycled materials, maximum amounts to be landfilled and specific regulation for several waste streams (e.g. plastics) are aimed at preventing and controlling the environmental burdens derived from harmful management practices. These include excessive dumping and littering. In the action student will choose the item / product / material of interest and will create the recycling path with focus on all factors influencing on the proposed path (including social – and economic ones). With the available data (Internet based) they will calculate the perspective outfit of the proposed path.

3. Learning outcomes

The student has awareness of the importance of recycling materials especially the commodities. He / she has also knowledge about the economic impact on the recycling process.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of economics aspect of SD including plastics waste reports in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses one of the raport's chapter to revise (for bibliographic details please check reading section (no 6)).
   - Students search on the Internet for other report on similar subject for comparison.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the delivered report the participants discuss on the economic aspect of recycling process. Additionally, students compare the results of 2 reports.
   - The task last approx. 60% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of the economic aspect of SD – plastics waste.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:
- report 1 (retrieved from https://www.eea.europa.eu/en/analysis/indicators/waste-recycling-in-europe)
- Review of economic and socio-economic studies on recycling topics, study carried out by ENT Environment and Management for the European Commission, DG JRC, under contract number B.B651793, Martinez Sanchez, V. (ENT), Sastre Sanz, S. (ENT), Puig Ventosa, I. (ENT) 2021
- The material that could change the world... for a third time (free online source, retrieved from https://www.youtube.com/watch?v=hRI0ymx_6aw (access: March, 01st, 2024)
- Fast Facts – What is Plastic Pollution? (free online source, retrieved from https://www.un.org/sustainabledevelopment/blog/2023/08/explainer-what-is-plastic-pollution/ (access: March, 01st, 2024)
- The Lazy Person's Guide to Saving the Ocean (free online source, retrieved from https://www.un.org/sustainabledevelopment/the-lazy-persons-guide-of-ocean-actions/ (access: March, 01st, 2024)
- Recycling in Europe - Statistics & Facts (free online source, retrieved from https://www.statista.com/topics/9617/recycling-in-europe/ (access: March, 01st, 2024)
- HOW SWEDEN TURNS ITS WASTE INTO GOLD (free online source, retrieved from https://www.youtube.com/watch?v=p71xuG_dP7M (access: March, 01st, 2024)
- The Business Of Trash | CNBC Marathon (free online source, retrieved from https://www.youtube.com/watch?v=dbwHnkaUVC0 (access: March, 01st, 2024))

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: economic aspect of SD, plastics waste management, extended producer responsibility (EPR) policy.

Topics 4

1. The subject of the auditory classes

Bioinspired SD – ideas from the Nature

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the activity students will trace materials / processes borrowed from Nature to serve SDG fulfilment. Nature contains biological materials with the ability to change properties like the trunks of trees that stand firm and strong yet can bend in a wind with no break. Creatures like octopuses can change the their skin color as well as the shape of the bodies. Such natural phenomena bring new ideas to materials engineers in an approach named as biomimicry.

Biomimicry takes inspiration from natural solutions and applies it into the principles of engineering. Such solution usually finishes up with higher efficiency, resiliency and sustainability as its utility was previously checked by living creatures, as they survived. Students will be familiarised with core technological-oriented approach that translates nature's pattern into practice. This is hidden behind several rules that will be presented. In the first rule nature is a model that shall be studied carefully and served as inspiration for designs or processes aimed at solving human problems. In the second rule nature bring the reference point as its ecological standards serve to judge the rightness of human innovations. In the third rule nature is a mentor that enable to observe, assess and value the processes.

Biomimicry concerns several sectors of human activity spanning from medicine to research and industry. Its concept is based on an simple idea: nature always operates on the principles of economy and efficiency with generating no waste. In the proposed activity the students will choose the process (material) that is led (produced) along with biomimicking rules and trace the path of creation in respect of the mentioned rule.

3. Learning outcomes

The students has a knowledge of basic biomimicry principles. He / she is also aware of the advantages of using biomimicking approach.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of bioinspiration in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the nature – simulating process / material delivered by the teacher (as examples one can use the sources delivered in reading section (no 6)).
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of nature – inspired process / technology / material should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
   - The task last approx. 50% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of the nature inspired processes and materials.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:

- https://asknature.org/educators/
- Bioinspired Robotics: Smarter, Softer, Safer (free online source, retrieved from: https://www.youtube.com/watch?v=RuLAn3XpYAU (access: March, 01st, 2024)
- How Bio-Inspired Packaging Can Dramatically Lower Food Spoilage (free online source, retrieved from: https://www.youtube.com/watch?v=2ifNBQbEAo8 (access: March, 01st, 2024)
- What is Biomimicry? (free online source, retrieved from: https://www.youtube.com/watch?v=FBUpnG1G4yQ (access: March, 01st, 2024)
- The Innovators Using Nature's Design Principles to Create Green Tech (free online source, retrieved from: https://www.youtube.com/watch?v=6WjBvFwQpYU (access: March, 01st, 2024)
- Future Environments: Bio-Inspired Materials (free online source, retrieved from: https://www.youtube.com/watch?v=ROD0IHAc22s (access: March, 01st, 2024)
- Science Behind the News: Bio-Inspired Materials (free online source, retrieved from: https://www.youtube.com/watch?v=PhBbO0yJFgY (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: nature inspired materials, processes - examples, biomimicking idea, rules of biomimicry.

Topics 5

1. The subject of the auditory classes

Green washing – for and against

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

The activity will focus on the phenomena of green washing, which raised for some products that are labelled as ecologic, but those claims are not proven. Hence the registration offices urge to assure that gathered information like a product's impact on the environment, longevity, reparability, composition is true. The greenwashing practice of giving a false impression of the environmental impact of a product shall be reduced. Several methods will be discussed like banning environmental claims without proof, banning of sustainability labels that are not based on approved certification schemes or established by public authorities. Students will be familiarized with certified sustainable materials which are labelled with notification coming from reputable organization. The examples of such organization are the Forest Stewardship Council (FSC) for wood products or the Global Organic Textile Standard (GOTS) for textiles. These certifications ensures that materials are sourced and produced using sustainable practices. Also more intense educating actions are proposed as informing the public about the importance of recycling and sustainable practices is crucial for environmental responsibility. Awareness campaigns, educational programs, and community initiatives play a significant role in promoting recycling and sustainable development. Students will find examples of such campaigns in their surroundings. Also governments can support recycling efforts through policies and regulations that incentivize recycling, promote eco-friendly practices, and impose penalties for environmental violations. Businesses have a role to play in sustainable development by adopting eco-friendly practices, implementing recycling programs, and reducing waste generation throughout their operations. The extended producer responsibility (EPR) aspect will be discussed. And individual consumers also play a crucial role in sustainable development by making environmentally conscious choices, such as purchasing products made from recycled materials, reducing single-use plastics, and participating in recycling programs. The described actions will be discussed and examples will be found within the activity.

3. Learning outcomes

The student knows the idea of certified sustainable materials. He / she can provide information that can provide true character of the material in respect to its impact on environment.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.
Necessary materials
Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group

on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of green washing occurrence in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the registration concerning green washing act delivered by the teacher (as examples one can use the sources delivered in reading section (no 6)).
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of green washing occurrence should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
   - The task last approx. 50% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of the green washing.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:

- Stopping greenwashing: how the EU regulates green claims, retrieved from: https://www.europarl.europa.eu/topics/en/article/20240111STO16722/stopping-greenwashing-how-the-eu-regulates-green-claims
- Why Being 'Environmentally Friendly' Is A Scam (free online source, retrieved from: https://www.youtube.com/watch?v=3roITeXVWuE (access: March, 01st, 2024)
- H&M and Zara: Can fast fashion be eco-friendly? (free online source, retrieved from: https://www.youtube.com/watch?v=00NIQgQE_d4 (access: March, 01st, 2024)
- Why China's Shein is beating ASOS, H&M and Zara at fast fashion (free online source, retrieved from: https://www.youtube.com/watch?v=9XCKnN6o19k (access: March, 01st, 2024)
- The Ugly Truth Of Fast Fashion | Patriot Act with Hasan Minhaj (free online source, retrieved from:https://www.youtube.com/watch?v=xGF3ObOBbac (access: March, 01st, 2024)
- Greenwashing: Is sustainable fashion a myth? (free online source, retrieved from: https://www.youtube.com/watch?v=s89xhCxVtQc (access: March, 01st, 2024)
- Greenwashing: When Companies Aren't as Sustainable as They Claim (free online source, retrieved from: https://www.youtube.com/watch?v=2NsBcVrPQok (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.

The scope of the issues for the final test involves the following topic: certified sustainable materials, awareness, corporate responsibility.

Topics 6

1. The subject of the auditory classes

SD in the air – materials engineering aspect

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the work the students will search for examples of materials that form construction either using air as an medium (e.g. for aircrafts, balloons, windmills) or that influence on quality of air by emission of the waste substances (e.g. odors, pollutants like NOx from car fumes). In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. For air vehicles the concept of invention of modern composites and nanotechnology will be discussed with strong impact on the costs of the materials implementation, usage and recycling. The cost issue involves various aspects namely economic, technological or social ones including e.g. noise pollution issue and safety regulations. Moreover, the topic of safety of the birds and their migration freedom can be risen in aspects of location of modern windmills farms.

As far as quality of air is concern the strategies towards reduction of pollutants as well as strategies for air purification shall be discussed. Here the concept of modern catalysts for afterburning of vehicle exhaust gases might be included providing newest information about materials concept that support this path. Also the mutual connections between tasks belonging to SDG are to be proposed and discussed. The analysis shall be taken in respect to local, country and global point of view. Within materials engineering field the close inspection of materials previously used as well as modern ones should be conducted. The students should point the materials features that enable (or handicap) the transformation to sustainable position.

3. Learning outcomes

The students understand the role of modern materials applicable in renewable energy sources. He / she is aware of the impact of aviation on air quality. The students also is familiarized with threats of fumes generated by the transport.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
    - Presentation of the purpose of the activity and discussion of the importance of SD for materials operating in wind or used for control of gas products in the air in aspect of materials engineering.
    - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
    - Students will be divided into working duos. Each team choses an example of the material / process related to operation in wind condition delivered by the teacher (as examples one can use the sources delivered in reading section (no 6)).
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
    - Groups work separately, however they are also encouraged to general discussion between groups
    - Based on the available sources the example of materials operating in wind or used for control of gas products in the air should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
    - The task last approx. 50% of the time.
4. Results analysis:
    - Each team will present the results of their work in the form of a short presentation.
    - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
    - Summary of the activity and a reminder of its goals.
    - Discussion of the results obtained and confirmation of the final remarks.
    - Summary of experience and determination of possible future actions, including any further research.
    - Critical evaluation of suitability and complexity of the method.
    - Enlisting content of the report.
    - Question and answer session regarding practical aspects of the SD for material / process related to operation in wind condition.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:

- Climate Change - United Nations Sustainable Development (free online source, retrieved from: (access: March, 01st, 2024)
- Can flying go green? (free online source, retrieved from: https://www.youtube.com/watch?v=ldhilLgVML0 (access: March, 01st, 2024)
- Can sustainable aviation fuel clean up flying? | FT Rethink (free online source, retrieved from: https://www.youtube.com/watch?v=KNGSOt2aOIQ (access: March, 01st, 2024)
- Sustainable Aviation Fuel (SAF) - what it is, what it's made from and its many benefits (free online source, retrieved from: https://www.youtube.com/watch?v=GrAozeUpEkQ (access: March, 01st, 2024)
- Cleaver-Brooks: NOx Reduction & Increasing Efficiency, a Conflict? | November 2012 (free online source, retrieved from: https://www.youtube.com/watch?v=6DsHrbsNYUg (access: March, 01st, 2024)
- All About Wind Energy (free online source, retrieved from: https://www.youtube.com/watch?v=7w6Qj0iDVHE (access: March, 01st, 2024)
- Here's how wind farms affect our environment (free online source, retrieved from: https://www.youtube.com/watch?v=Z6qL4keo_Ns (access: March, 01st, 2024)
- Sustainable Elements for Energy Storage: Reduce (free online source, retrieved from: https://www.youtube.com/watch?v=6cxZOQN6ULc (access: March, 01st, 2024)
- Environmental Odor Sources, Exposure Symptoms, and Sensitive Populations (free online source, retrieved from: https://www.youtube.com/watch?v=5ydmudsf0Ws (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: composites, wind turbines, renewable sources of energy, odor control, gas exhaustive fumes, nitric oxide.

Topics 7

1. The subject of the auditory classes

SD in the water – materials engineering aspect

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the activity the students will search for examples of materials/processes that either use water as an medium (e.g. for electricity production, technological purpose) or that influence on quality of water by emission of the waste substances (e.g. wastes, municipal sewage). The issues of access to a fresh water source and floods will also be discussed.

Within this subject water desalination protocols can be presented and evaluated. This includes the concept of osmosis and reverse osmosis and also (ultra)filtration with filtering membranes composed of different materials and with different porosity and pore sizes. The information will be correlated with the issue of access to pure water and actions devoted to storage and saving of water. In the aspect of materials engineering novel materials can be presented that support these actions like nets for mist collection from humid environment. The plants strategies for water collection can also be inspected to propose some novel materials concepts. Depending on the students' origin they can discussed various strategies utilized in different countries, regions. In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. Also the mutual connections between tasks belonging to SDG are to be proposed and discussed. The analysis shall be taken in respect to local, country and global point of view. Within materials engineering field the close inspection of materials previously used as well as modern ones should be conducted. The students should point the materials features that enable (or handicap) the transformation to sustainable state.

3. Learning outcomes

The students is aware of the necessity of assuring fresh water supply and building efficient station for purification. Moreover, he / she is able to predict the general results of the water shortage and propose the system to lower its usage. He / she is aware of influence of technological processes on the water quality.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of SD for materials / devices operating in water or used for water purification goal in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the material / process related to operation in water condition delivered by the teacher (as examples one can use the sources delivered in reading section (no 6)).
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of materials / devices operating in water or used for water purification goal should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
   - The task last approx. 50% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of the SD for material / process related to operation in water condition.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:

- Water and Sanitation - United Nations Sustainable Development
- The Sustainable Development Goals Explained: Clean Water and Sanitation (free online source, retrieved from: https://www.youtube.com/watch?v=LCKsU4bPFOQ (access: March, 01st, 2024)
- SDG 6 - Clean Water and Sanitation (free online source, retrieved from: https://www.youtube.com/watch?v=YTIPokrtNQ0 (access: March, 01st, 2024)
- Clean Water is Everyone's Problem (free online source, retrieved from: https://www.youtube.com/watch?v=DnFirDGdoiI (access: March, 01st, 2024)
- 2030- SDG 6- Clean Water and Sanitation- Ted talks (free online source, retrieved from: https://www.youtube.com/watch?v=U5TxygvcmU8 (access: March, 01st, 2024)
- Advancing Sustainable Wastewater Management with AI and Deep Learning – Hitachi (free online source, retrieved from: https://www.youtube.com/watch?v=n7-V42y6F5s (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.

The scope of the issues for the final test involves the following topic: the interdependency of water and energy, water scarcity, renewable energy source, waste water, water purification methodology

Topics 8

1. The subject of the auditory classes

SD on the ground – materials engineering aspect

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the activity the students will search for examples of materials that either operate on the ground (e.g. for renewable energy sources in a form of geothermal or solar energy, cutting of forest for agriculture) or that influence on quality of ground by emission of the waste substances (e.g. fertilized landfills for agriculture).

The concepts of providing the nanomaterials as modern and efficiently operating systems for energy harvesting and conversion can be presented. In the classes the route for rising solar / geothermal energy conversion efficiency can be described. It shows how structure of materials, its organization may enhance the technological parameters with constantly diminishing costs. The teacher can present that even by using commonly known and available materials, but with imprinted new organization at nano levels may bring enormous advantages. The disruption of the oxygen production cycle by commercial felling of a local forest stand can be analyzed.

In terms of ground purification novel concept of moder release systems can be discussed that allow for controlled and programmed dosing of fertilizer. It allows to decrease the amount of the used chemical compounds and resort the environmental equilibrium.

In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. Also the mutual connections between tasks belonging to SDG are to be proposed and discussed. The analysis shall be taken in respect to local, country and global point of view. Within materials engineering filed the close inspection of materials previously used as well as modern ones should be conducted. The students should point the materials features that enable (or handicap) the transformation to sustainable position.

3. Learning outcomes

The student knows and identifies materials whose applications contribute to the development of the idea of SD in land applications, e.g. in transport or elements of renewable energy sources infrastructure. He can also select materials that enable sustainable use of these systems.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of SD for materials / devices / technologies operating on the ground in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the materials / devices / technologies operating on the ground delivered by the teacher (as examples one can use the sources delivered in reading section (no 6)).
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of materials / devices / technologies operating on the ground should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
   - The task last approx. 50% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report
   - Question and answer session regarding practical aspects of the SD for materials / devices / technologies operating on the ground.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:
- Sustainable soil management: A major step in achieving the Sustainable Development Goals (free online source, retrieved from: https://www.youtube.com/watch?v=7cJdyL78JsM (access: March, 01st, 2024)
- Sustainable Development Goal 12 - Responsible Consumption and Production - Sami Kara, (free online source, retrieved from: https://www.youtube.com/watch?v=RX2elsVjY-c (access: March, 01st, 2024)
- Life on Land: Soil and the UN Sustainable Development Goals (free online source, retrieved from: https://www.youtube.com/watch?v=5qs-lqoe7Lc (access: March, 01st, 2024)
- Sustainable Development Goal 15 - Life on Land - Tracey Rogers (free online source, retrieved from: https://www.youtube.com/watch?v=N5YR2GMhYcI (access: March, 01st, 2024)
- Sustainable land management - Conclusions and findings from a global research program (free online source, retrieved from: https://www.youtube.com/watch?v=8RdTnkEcbFs (access: March, 01st, 2024)
- The Futuristic Farms That Will Feed the World | Freethink | Future of Food (free online source, retrieved from: https://www.youtube.com/watch?v=KfB2sx9uCkI (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: geothermal energy source, impact of agriculture of land, soil poisoning with fertilizer and antipesticides, water scarcity, cutting of forest.

Topics 9

1. The subject of the auditory classes

SD on my own yard

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

The activity aims to determine the impact of SDG on the lowest level, namely within the area of living of students. Students list 17 SDG and point their own experience to show their impact on the life. In a discussion the group finds advantages and disadvantages of introduction of 17 SDG and propose additional action needed to enforce the real impact of the goals. The students compare the ideas, action between them and asses the target group of stakeholders with their basic traits (e.g. age, occupation, social status, average income, experience). The students draw conclusion on the efficiency of imposing new regulation versus current / past state of being. In particular the students focus on the materials engineering point of view and perspective of application for modern materials. Also recycling aspect is important to stress the awareness of society. The global goals inserted in national agendas are to be presented from the challenges of local goals. The students discuss the financial and social costs of proposed actions.

The SDGs shall reflect local needs, norms, and values, thus supporting that local actors to find them relevant and meaningful. The communities shall integrate the sustainable development goals by identifying hidden resources, build support networks, create social accountability. The activity is aimed at pointing how to translate generic global goals into local action. Moreover, the need for gaining knowledge will be stressed as the understanding of process around us is crucial for taking responsible decision including the one connected with materials usage.

3. Learning outcomes

The student understand the impact of SDG on various level. She / he can point behavior and actions that induce changes in the local environment.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of local actions for achieving SDG in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the local actions for achieving SDG according to owe experience.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of local actions for achieving SDG should be described. Students should take into consideration all 3 aspects of SD, namely environmental, economic and social one.
   - The task last approx. 60% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding practical aspects of the local actions for achieving SDG.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:

- Ansell, C., Sørensen, E. and Torfing, J. (2022), "The Key Role of Local Governance in Achieving the SDGs", Co-Creation for Sustainability, Emerald Publishing Limited, Leeds, pp. 9-22. https://doi.org/10.1108/978-1-80043-798-220220002, publisher: Emerald Publishing Limited
- Open Source Tools for Local Action on the SDGs | Department of Economic and Social Affairs (un.org) (free online source, retrieved from: March, 02nd, 2024)
- Local Sustainability Initiatives — THE LOCAL SDGs PROGRAM (examples of local sustainability initiatives)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.

The scope of the issues for the final test involves the following topic: local actions as efficient tool for achieving SDG, materials engineering in every day.

Topics 10

1. The subject of the auditory classes

Europe vs other continents – various aspects of SD

2. Thematic scope of the auditory classes (abstract, maximum 500 words)

In the work the students compare the attitude along the SDG in various countries and the SDG indexes based on the across-country analysis and country profiles. Students use available reports for 17 SDG realization and asses the multi-country comparison. The discussion is led also in the respect of countries' stage of development including developed / developing / least developed stage and its influence on technological capabilities. The discussion will be lead based on the quote: necessity is the mother of invention. The discussion on the utility of modern patent innovation can be induced to provoke discussion on their utility in a real life conditions. The students use available Internet resources to provide examples of the solution to the urgent, local problems. The stated problem shall be realistic and student can also provide their own proposal for solution, however have to support their idea with pross and cons analysis. Also failure analysis for utilized materials shall be involved as part of the activity. This action will allow possible risks to be anticipated, understood and partially eliminated.

Also, they can search for various approach to solve global problems like excessive amount of plastic waste or water pollution. By comparing different approaches they can see different perspectives of habitants of various regions. The proposal of actions aimed at balance the development shall be pointed with understanding the diversity.

The aspect of balance in the use of resources and waste generation will continue to be emphasized. According to available most update ranking different countries will be compared in relation to this actions including Global Waste Index, EPR index, Environmental Performance Index (EPI), natural disaster risk index, Big Mac Index ect.

3. Learning outcomes

The student understands that various country pay attention to different goals. He / she is aware of the influence of the state of development on the realization of SDGs.

4. Necessary equipment, materials, etc

The exercise takes place in class-room equipped with WI-FI connection.

Necessary materials

Student have to be equipped with electronic device with Internet access. Also large piece of papers or access to text editor are requested to write found information. Favorably, the group on Moodle platform is created where student can store working files or external platform (e.g. Miro) can be also used.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Auditory course outline:

1. Introduction:
   - Presentation of the purpose of the activity and discussion of the importance of state of development of country on realization of SDGs in aspect of materials engineering.
   - Discuss the stages of work, organization of the work space, time schedule reminder.
2. The course of the activity:
   - Students will be divided into working duos. Each team choses an example of the country to evaluate its stage of realization of SDGs.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
3. Research:
   - Groups work separately, however they are also encouraged to general discussion between groups
   - Based on the available sources the example of the evaluative analysis of the stage of achievement of the SDGs for the country is to be proposed with strong focus on the field of materials engineering.
   - The task last approx. 60% of the time.
4. Results analysis:
   - Each team will present the results of their work in the form of a short presentation.
   - Teams will draw the conclusion and discuss them in relation to the others members of the class.
5. Summary:
   - Summary of the activity and a reminder of its goals.
   - Discussion of the results obtained and confirmation of the final remarks.
   - Summary of experience and determination of possible future actions, including any further research.
   - Critical evaluation of suitability and complexity of the method.
   - Enlisting content of the report.
   - Question and answer session regarding the state of development of country on realization of SDGs

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the exercise's topic:
- SDGs and the Environment_A cross-country analysis (pdf file on: Sustainable Development Goals and the environment in Europe — European Environment Agency (europa.eu))
- Red Alert - How to meet the Sustainable Development Goals together (free online source, retrived from: https://www.youtube.com/watch?v=wXASRXbjR08 (access: March, 01st, 2024)
- How We Can Make the World a Better Place by 2030 - (free online source, retrived from: How We Can Make the World a Better Place by 2030 | Michael Green | TED Talks (youtube.com) (access: March, 01st, 2024)
- Global Waste Index 2022 - (free online source, retrived from: Global Waste Index | SENSONEO (access: March, 01st, 2024)
- EPR reviewed countries (free online source, retrived from: EPR reviewed countries | UNECE (access: March, 01st, 2024)
- Environmental Performance Index (free online source, retrived from: Environmental Performance Index by Country 2024 (worldpopulationreview.com) (access: March, 01st, 2024)

Students are obliged to prepare a coherent presentation as the final result of activity including literature source used as the citation.

7. Additional notes

The following rules and points are granted as assessment of one activity:

- team work on performing the activity and preparing a report - 10 points in total prescribed to the following elements:

- completeness of the report (1 point),
- content included in the theoretical introduction (1 point),
- the quality of the given examples (3 points),
- the correctness of interpretations, discussions, and conclusions (4 points),
- the aesthetics of the report (1 point).

8. Optional information

Activity subjects will be available at least one week prior to the date of the classes.
The scope of the issues for the final test involves the following topic: influence of country stage of development on SDGs realization especially in the field of materials engineering in developed / developing / least developed countries.

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UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

Co-funded by the European Union

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

COMPUTER MODELING OF THE STRUCTURE AND PROPERTIES OF MATERIALS

Code: CMSPM

UNIVERSITY OF SILESIA IN KATOWICE

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Course content – lecture

Topics 1

1. The subject of the lecture

Role of computer modeling in materials science

2. Thematic scope of the lecture (abstract, maximum 500 words)

During the introductory lecture, students will be familiarized with the classes of atomistic computer modeling techniques, their essential results, and their importance in materials engineering. Especially, the topic is focused on the role of the Monte-Carlo and the classical molecular dynamics methods in modeling of materials properties and phenomena. The important part of the topic is related to quantum computations of materials' electronic properties based on the Density Functional Theory (DFT).

3. Learning outcomes

- Understanding the role of computational materials science in studying the properties of materials and the development of their fabrication methods.
- Understanding main ideas constituting applicability of the Monte-Carlo, quantum and classical simulations methods.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
- Case study - presentation of specific examples of materials' modeling and methods of their qualitative and quantitative analysis.
- Discussion - encouraging students to participate in the discussion on the issues actively.
- Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should review knowledge about the theory of probability, classical mechanics, and quantum physics. Also, they should refer to the book "Fundamentals of Physics" by Halliday & Resnick.

6. Additional notes

Topics 2

1. The subject of the lecture

Introduction to Monte Carlo simulation methods

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic refers to the application of the so-called Monte Carlo methods in materials science and engineering. In the field of scientific simulations, the Monte Carlo methods are very important and cover many problems that can be modeling only using this method. The name "Monte Carlo" origins from the name of the city of Monaco in which statistical mathematics has application for some predictions in casino games. The main idea is to solve some problem based on a finite number of statistical "tests". In this case, the more the number of tests, the more accurate the result. Important is a definition of the algorithm providing the so-called Monte Carlo steps. This approach has wide applications both in mathematics (integration, solving equations, etc.) and in physics (statistical physics) and materials engineering (phase transitions, processes). The proposed topic focuses on this last thematic group.

Particularly, in the lecture's frame, students will have the chance to get to know the basis of statistical physics, which is the key point for understanding the Monte Carlo approach in simulations. The basic concepts here are the ensemble mean, the statistical sum and the thermodynamic equilibrium of the system. Nevertheless, the main point of the lecture is an introduction to Monte Carlo methods and algorithms. The use of the Monte Carlo method in materials engineering is based on the laws of statistical physics implemented in specific material systems, taking into account the modeled properties. Some of the most useful methods and models are: the Ising model, Potts model, Heisenberg model, Metropolis method and cluster methods. The presented knowledge is supplemented by the detailed description of selected examples related to simulations of phase transitions and processes.

3. Learning outcomes

- Has knowledge of basic statistical physics.
- Understands the main idea of Monte Carlo methods.
- Has knowledge of Monte Carlo algorithms and their applications in materials engineering.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

The lecture is conducted with a traditional board and with the use of multimedia interactive board. During the lecture, there is a discussion with the students related to presented problems.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- M.H. Kalos, P. Whitlock, Monte Carlo Methods I: Basics; Wiley: New York, NY, USA, 1986.
- D.P Landau, K. Binder, Monte Carlo simulations in statistical physics, Cambridge University Press, 2005.

6. Additional notes

Topics 3

1. The subject of the lecture

The classical molecular dynamics method

2. Thematic scope of the lecture (abstract, maximum 500 words)

The role of the classical molecular dynamics (MD) simulations in the contemporary materials science is described. Students learn about the physical foundations of the molecular dynamics simulations. Certainly, the lecture will focus on the basis provided by the classical mechanics including: the Newton equation of motion, the relationship between the work and the energy, the Hamilton equations and the phase space idea. Next, the numerical methods for solving Newtonian equations will be presented: Euler method, Verlet method, Leap-frog method, and Velocity Verlet method. The main part of the lecture is related to the MD simulations method which achievements and limitations will be described. As the selection of a proper interatomic interaction model is an important step in MD simulations, the following force fields will be presented: Lenard-Jones, Stillinger-Weber, Tersoff, and EAM (embedded atom method). The MD simulations are performed under some conditions applied to the considered system of atoms. Usually, the control of the temperature and the pressure is required; therefore, the lecture will provide necessary details of so called thermostating and barostating realized by the means of the Berendsen method. The final step of the MD simulations is computing thermodynamic properties of a studied system from atoms' trajectories. The lecture will describe the methods for calculations physical properties of the crystalline systems: the atomic strain, the elastic constants, the energy of the point defect formation (vacancy, substitutional defect). It is also assumed that after the lecture students will be familiar with the methods used for analysis of the structural changes that occurred in the crystal during the simulations.

3. Learning outcomes

- Learning about classical mechanic of point particles: Newton's equation of motion, forces and potentials.
- Learning about the numerical methods used for the solution of Newton's equations.
- Understanding the interatomic interaction models and methods used for their parameterization.
- Understanding relationship between the molecular dynamics outcomes and the macroscopic and microscopic material's properties.
- Understanding the flow of classical molecular dynamics simulations.
- Learning how to control the temperature and pressure of simulations.
- Learning how to visualize and analyze the molecular dynamics data.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***

- Combined oral and multimedia presentation of the lecture issues.
- Discussion on examples molecular dynamics simulations of crystalline materials.
- Encouraging students to participate in the discussion during the lecture.

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)** **J.M. Haile, Molecular dynamics simulations: Elementary methods, John Wiley & Sons, 1992**
6	**Additional notes**
6.	**---**

Topics 4

1. The subject of the lecture

The LAMMPS parallel molecular dynamics code

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic will focus on the preparation and the use of the LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator) molecular dynamic code. In the following, the Linux operating system will be shortly introduced including BASH command necessary for compiling the LAMMPS parallel version from the sources. The method of the code parallelization and the Secure Shell (SSH) protocol will be also presented. As the LAMMPS compilation requires use of the Message Passing Library (MPI) implementation, the OpenMPI library will be selected and shortly presented. Next, the construction of the script text file which arranges the flow of simulations will be described in details. The main part of the lecture will be focused on the description of the LAMMPS commands. They are related to the generation of the modeled system via selection the units system, boundary conditions, defining the crystal structure, defining the regions and groups of atoms in the simulation box. The setting up of the interaction between atoms will be also demonstrated for various types of interatomic force fields. An important part of the LAMMPS input script concerns commands defining the constraints applied to the system and the selection of the thermodynamic ensemble which controls the course of simulations, *e.g.*, NVT that means that the number of atoms, the volume of the system, and the temperature is kept constants during simulations. The command used for defining variables will be also presented. The nest issues discussed during the lecture will be related to the class of commands which allow compute physical properties of the system during the simulations and to methods of saving of the state of the system.

3. Learning outcomes

-
- Understanding the usage of the LAMMPS massively parallel simulation code.
- Learning how to prepare the system of atoms representing the studied material.
- Learning the commands for initiation and realization of the molecular dynamics simulations.
- Ability to interpret results of theoretical experiment n the context of advanced characteristics of engineering materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Combined oral and multimedia presentation of the lecture issues.
- Case study - writing the LAMMPS input file for the symmetric compression of the silicon nano-sphere.
- Encouraging students to participate in the discussion during the lecture.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- J.M. Haile, Molecular dynamics simulations: Elementary methods, John Wiley & Sons, 1992.
- M. Griebel, S. Knapek, G. Zumbusch, Numerical simulations in molecular dynamics, Springer-Verlag, 2007.

6. Additional notes

Topics 5

1. The subject of the lecture

Fundamentals of Quantum Theory

2. Thematic scope of the lecture (abstract, maximum 500 words)

The most advanced, contemporary modeling of the structure and properties of materials is conducted at the subatomic level using the principles and methods of quantum mechanics (QM). Such modeling, which includes the initial data preparation, control of calculation processes, and interpretation of results, requires knowledge of the quantum description of matter and quantum computational methods applied.

The lecture begins with a reminder of the experimental evidence for the wave-particle duality of light and electrons and corresponding descriptions of the phenomena, including blackbody radiation, photoelectric effect, line spectra of atoms, Compton effect, De Broglie hypothesis, Davisson and Garmer diffraction experiment, multiple-slit diffraction of electron beam. Bohr's theory of atoms in relation to the line spectra of atoms will discussed.

Then, the lecture introduces students to the principles of quantum mechanics, which include the following topics: wave representation of particle quantum state; probabilistic (Born) interpretation of the wavefunction; superposition principle; operators as a quantum representation of classical mechanics observables; eigenvalue equation and the quantum realization of measurements of the observable, expectation value of observable, Heisenberg uncertainty principle, wavefunction evolution in time – time-dependent Schrodinger and stationary states. The variational principle and the Ritz variation method will be described as an approximate approach to Schrödinger equation solution.

Further, the lecture will raise the issue of quantum particle indistinguishability, and its consequence for many-particle wave functions will be discussed (classification of particles, Pauli exclusion principle, quantum exchange interaction of fermions).

In addition, the lecture will expound upon the quantum solutions to the following problems: an electron in an infinite 1D quantum wall (energy quantization), an electron in 3D box, an electron in the presence of potential barriers (tunneling effect), an electron in a hydrogen atom (quantum angular momentum, classification of electron states in atom – quantum numbers), and H_2^+ molecule (bonding and antibonding states).

3. Learning outcomes

On completion of the course,

students will be able to describe:

- Failure of classical physics at the microscopic level
- Postulates of non-relativistic quantum mechanics and their implications
- Quantum properties of angular momentum
- The origin and implications of the Heisenberg uncertainty principle and Pauli exclusion principle.

- Quantization of an electron state in the infinite potential wall and in a hydrogen atom.

will have skills to do the following:

- Apply principles of quantum mechanics to calculate observables for given wave functions.
- Transform mechanical observables to their quantum operator form.
- Formulate the Schrödinger equation for the free electron and an electron in the external potential.
- Solve the Schrodinger equation for simple systems like electrons in a box and electrons in the presence of a finite potential barrier.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
- Case study – solving the Schrodinger equation for simple systems.
- Discussion - encouraging students to participate actively in the debate on the issues.
- Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

S.M. Blinder, Introduction to quantum Mechanics in Chemistry, Materials Science, and Biology, Elseviere Academic Press, San Diego, 2004.

6. Additional notes

Topics 6

1. The subject of the lecture

Quantum methods for many-electron systems – electrons in crystals

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture covers topics related to the quantum description of electrons in a crystal lattice. In the beginning, students will be reminded of selected crystallography issues, like primitive and complex unit cell definition, space groups, Wyckoff positions, reciprocal space, Brillouin zone construction, and standards for numerical description. This part of the lecture ends with formulating the Hamiltonian for the electron system in the lattice of positive ions and explaining its components.

In the subsequent part, the lecture will outline the assumptions and most important results of approximate models of single electrons in a lattice, including the free, nearly-free, and tight-binding electron models. Within the approximate models, the lecture will introduce students to the concepts of the von Karman periodic boundary condition, quantization of electron states, Fermi energy, density of states function, Bloch theorem (and its implications), and electron bands.

The main goal of the next part of the lecture is to familiarize students with modern, advanced quantum methods for modeling the structure and properties of materials. At first, the lecture will outline the three-step approximations necessary to solve the many-body problem with computer algorithms. The lecture will discuss the Born-Oppenheimer approximation, the single electron approximations (Hatree-Fock method and Density Functional Theory based Kohn-Sham method), and approximations for crystal potential shape and single electron Bloch wavefunction construction. The lecture will issue the types of exchange-correlation potentials and their applicability. The difference between the "all-electron" and pseudopotential methods will be outlined. The discussion will be summarized with the main achievements and limitations of modern quantum, Density Functional Theory (DFT) based computational methods.

In the last part, the lecture will comment on selected applications of quantum calculations in materials science and present an overview of the most commonly used DFT-based quantum computing packages.

3. Learning outcomes

On completion of the course,

students will be able to describe:

- Hamiltonian of the system of electrons in solids.
- The approximate models of a single electron in a lattice and their essential results
- Three-step approximations necessary to map the problem of a many-body electron system in a solid to the problem of a single electron in an effective one-electron potential

- Essential results and limitations of the DFT based computational methods

will have skills to do the following:

- Construct the unit cell based on crystallographic data.
- Construct the Brillouin zone for simple 2D reciprocal lattices.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Multimedia presentation - the use of PowerPoint presentations for discussed issues and examples.
- Discussion - encouraging students to participate in the debate on the issues actively.
- Quiz - summarized the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

June Gunn Lee, *Computational Materials Science, An Introduction*, CRC Press, Tylor & Francis Group, Boca Raton, 2017. (ISBN-13: 978-1-4987-4973-2)

6. Additional notes

Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

Introduction to Python programming

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The Python language is one of the most effective modern programming tools. Python is considered the most effective programming language that has been developed so far. Basically, it is the so-called scripting language - does not have a compiler but is executed in real time by a text script interpreter. This approach makes the code extremely flexible and efficient, but due to the lack of a compiled executable file, it is relatively slow compared to e.g. C++. Python's wide applications include algorithm testing, scientific analysis, data presentation and analysis, and graphical user interfaces. This language is so popular that in fact you can find appropriate libraries for almost "all" problems. Some of the more useful libraries are: the NUMPY numerical library (including operations on matrices), the SCIPY scientific library (a rich collection of tools for mathematical analysis), and the MATPLOTLIB library (a graphical interface for presenting all kinds of 2D and 3D charts). All this makes knowledge of PYTHON extremely useful in designing and conducting computer simulations.

In this module it is the basement of laboratory works. The students will get the knowledge of i) the basic “grammar” of the Python language and data structures – simple, tuple, dictionary, and list. This topic includes practical programming using the mentioned above problems with selected scientific libraries (NUMPY, SCIPY, MATPLOTLIB). The above-mentioned problems will be presented and used practically in simple tasks such as: data manipulation and type conversion, operations on matrices, presentation of data in the form of graphs, handling text files, interpolation and extrapolation of measurement data, solving systems of equations.

3. Learning outcomes

By working on this laboratory project, students:
Has knowledge of basic Python programming.
Is able to write computer programs in Python.
Has knowledge of scientific packages and is able to use them.

4. Necessary equipment, materials, etc.

- Computers
- Access to internet

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:

   Presentation of the problems related to the topic of the laboratory lecture:
   - grammar of the Python language,
   - program flow instructions,
   - data types,
   - functions and procedures,
   - libraries.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The teacher presents an introduction to the programming environment, explains in detail the individual tasks to be performed and demonstrates the solution of key problems using simple examples.
   - Students perform tasks aimed at introducing programming. During laboratory classes, the student can interact with the instructor and other students in order to deepen his knowledge and solve assigned problems. The final work is an individual project agreed with the teacher.
4. Research
   - Laboratory classes are carried out with the use specialized free available software.
   - Students write separated programs with following functionality:

     - basic dialog for input and output simple data,

     - charts presentation,

     - fitting functions to experimental data.
5. Result analysis
   - Each team will show the results of their work in the form of a presentation, including source program scripts.
6. Summary
   - Summarizing the lab and reminding of its objectives.
   - All students will prepare individual reports, including source program scripts.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below documents available online:

- Pyton 3.x documentation.
- MATPLOTLIB documentation.
- NUMPY documentation.
- SCIPY documentation

7. Additional notes

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8. Optional information

Topics 2

1. The subject of the laboratory classes

The Monte-Carlo simulations in materials science

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of this thematic group of issues is to practically familiarize students with the methods, models and algorithms used in computer simulations using the Monte Carlo methods.
This topic is organized in the following three blocks:

- The first one contains tasks related to simple examples of Monte Carlo (MC) methods using Python programming - (4h). In the frame of this group of activity students will carry out mathematical calculations (e.g. integration, finding extreme of a function, etc.) using Python packages. In particular, the task to be performed is to calculate the value of selected definite integrals using the geometric interpretation of the integral, calculating the surface area by statistical testing and presenting the simulation course and the obtained results.
- The second task block refers to application of the Metropolis Monte Carlo method in simulations of simple phase transitions (e.g. order-disorder), determination of a critical point (e.g. melting point, the Curie point, etc.) - 4h. Within this block, a simple Ising and Potts interaction model will be used in a two-dimensional network of interacting nodes. The task involves using the Metropolis algorithm when the Ising-type interaction describes the exchange energy (simulations of magnetic transitions) or the Potts-type interaction to describe interatomic bonds (simulations of phase transitions).

As a supplement to the above, students will carry out the MC simulations of selected processes which lead to an optimum of some aim-function – 4h. The idea is to familiarize students with optimization methods through simulated annealing. Many processes take place to optimize the so-called objective function, which may be the energy and/or entropy of the system. An example is the process of crystallization from the liquid phase.

3. Learning outcomes

Is able to apply Monte Carlo approach in sample mathematical problems.
Has practical knowledge of Metropolis algorithm, Ising model and 3D-Heisenberg model.
Is able to design and carry out simple MC simulations

4. Necessary equipment, materials, etc.

- Computers.
- Access to internet

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory course outline:

1. Knowledge test:
   - A test checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
   Presentation of the problems related to the topic of the laboratory lecture:
   - implementation of the Monte Carlo methods using the Python language,
   - implementation of the Metetropolis algorithm using the Python language,
   - implementation of selected optimization algorithms using the Python language.
3. The course of the exercise:
   - Students will be divided into teams.
   - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
   - The teacher presents an introduction to the programming environment, explains in detail the individual tasks to be performed and demonstrates the solution of key problems using simple examples.
   - Students perform tasks aimed at introducing programming. During laboratory classes, the student can interact with the instructor and other students in order to deepen his knowledge and solve assigned problems. The final work is an individual project agreed with the teacher.
4. Research
   - Laboratory classes are carried out with the use specialized free available software.
   - Students write separated programs with following functionality:
     - determination pf the "Pi" digit by the MC method,
     - determination of integral of a function given by data,
     - simulation of phase transition using MC Metropolis algorithm and Ising model,
     - simulation of crystallization process using simulated annealing method.
5. Result analysis
   - Each team will show the results of their work in the form of a presentation, including source program scripts.
6. Summary
   - Summarizing the lab and reminding of its objectives.
   - All students will prepare individual reports, including source program scripts.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Kalos, M.H.; Whitlock, P. Monte Carlo Methods I: Basics; Wiley: New York, NY, USA, 1986.
- D.P Landau, K. Binder, Monte Carlo simulations in statistical physics, Cambridge University Press, 2005

7. Additional notes

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8. Optional information

Topics 3

1. The subject of the laboratory classes

Linux operating system – terminal commands

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The Linux operating system will be used as a platform for simulations and visualization the results of atomistic modeling with LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator) code. The scope of this laboratory classes will be focused on working with the Linux terminal. It includes basic programming in BASH shell by writing shell scripts realizing the following tasks: (1) creating, copying, deleting, and moving text files and folders; (2) editing and reading files; (3) searching in the text file; (4) setting up file permissions; (5) compilation of the source file. An important part of the exercises will be focused on the issues related to the communication between computers (*e.g.*, IP and DNS addressing). Crucial commands implementing the Secure Shell (SSH) protocol will be discussed parallel.

3. Learning outcomes

After completing the laboratory, students:

- can utilize Linux terminal commands for working with files, folders;
- can built a cluster of computers;
- can configure and use SSH shell for remote working and copying files and directories;
- can write BASH shell scripts for the terminal task automation.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers.
- Connection with the internet.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
   a. A brief test on the Linux operating system and inter-computer communications gathered from the lecture to ensure students are well prepared for the laboratory.
2. Introduction:
   a. Introducing the lab objectives.
   b. Students will discuss the procedure for carrying out the laboratory objectives.
3. Team formation:
   a. Students will be divided into teams composed of two persons.
   b. The instructor will serve as a mentor, supporting teams in realization of the laboratory objectives.
4. Research:

   a. Students will test the Linux commands indicated in the thematic scope of the laboratory classes.
   b. Students will write and test BASH scripts realizing tasks provided by the instructor.
   c. Each student's team will create its own cluster composed of two computers and set up network communications.
   d. Students will use the SSH commands for copying, deleting, and creating folders and text files on the remote computer.
   e. Students will compile the C source code and use the constructed cluster for calculating the PI number.
   f. Students will write a program for the text-style communication between computers using the Python programming language.
5. Summary:
   a. Summarizing the laboratory classes and reminding its objectives.
   b. All students will prepare an individual report based on the template provided by the instructor.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

www.gnu.org/software/bash/manual ; docs.python.org

7. Additional notes

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8. Optional information

Topics 4

1. The subject of the laboratory classes

Compilation of LAMMPS sources code and testing simulations

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of this exercise is to set up two versions of the LAMMPS Large-scale Atomic/Molecular Massively Parallel Simulator) code: compiling and using the Message Passing Interface (MPI) library, compiling the LAMMPS code for the serial and parallel execution.

Another task is to learn how to supplement the LAMMPS code with additional packages (e.g., MANYBODY) and start the first simulations which will concern thermal vibrations of the cubic diamond lattice of the silicon. It will be necessary writing the LAMMPS script file containing commands for:

- definition of the crystal lattice;
- definition of the simulation box with a proper boundary conditions;
- selecting interatomic interaction potential;
- selecting the temperature range of simulations;
- setting up conditions of simulations (NVT ensemble);
- running the simulations and writing configuration data to files.
- The next issue will be related to the analysis of the simulations result using both the AtomEye and the OVITO software. Finally it will allow not only observing the thermal motion of the atoms in a vicinity of their equilibrium positions but also calculating the thermal expansion coefficient of the silicon.

3. Learning outcomes

After completing the laboratory, students:

- Understand how to configure and compile LAMMPS source files.
- Use Massage Passing Library (MPI) for preparation the parallel version of LAMMPS.
- Can write simple input file and run molecular dynamics simulations.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers.
- Connection with the internet.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
    a. A brief test on the LAMMPS software and LAMMPS commands as well as the inter-computer communication gathered from the lecture to ensure students are well

prepared for the laboratory.

2. Introduction:
    a. Introducing the lab objectives.
    b. Students will discuss the procedure for carrying out the laboratory objectives.
3. Team formation:
    a. Students will be divided into teams composed of two persons.
    b. The instructor will serve as a mentor, supporting teams in realization of the laboratory objectives.
4. Research:
    a. Students will test several options (Makefile variables) of the LAMMPS code compilation which allow selection of libraries (FFTW, MPI, …), dynamically or statically linking.
    b. Students will test how to supplement the LAMMPS code with additional packages, *e.g.*, MANYBODY.
    c. Each student team, assisted by the instructor, will create its own LAMMPS input file (scrip) realizing MD simulations of the thermal vibration of the Si lattice.
    d. Students will analyze the results of MD simulations using the OVITO as well as AtomEye software. The task will be performed by calculation the average energy, temperature and pressure of the system and making a movie illustrating the vibration of atoms.
5. Summary:
    a. Summarizing the laboratory classes and reminding its objectives.
    b. All students will prepare an individual report based on the template provided by the instructor.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

docs.lammps.org/Manual.html

7. Additional notes

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8. Optional information

Topics 5

1. The subject of the laboratory classes

Molecular Dynamics simulations of selected materials' properties

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The set of LAMMPS commands usually used for creating a system of atoms, defining the interatomic interaction, and running the simulations will be examined. For example, the scripts created during the lecture will use the following commands: units, variable, boundary, lattice, region, create_box, create_lattice, mass, pair_style, pair_coefficient, fix nvt, fix npt, group, thermo_style, timestep, run, write_data, print, dump.
The main part of the classes will be related to simulations of the basic physical properties of the crystal lattice. The definition and method of the calculation of the formation energy of vacancy in silicon crystal lattice will be described. Similar calculations will be performed for more complicated GaAs and GaN crystal lattice. Furthermore, students will learn about calculations of the elastic constants of the crystal with orthogonal and non-orthogonal unit cell. They will write the LAMMPS scripts designed for that type of simulations. The last issue discussed during the laboratory will be related to the simulations of the silicon nano-sphere compression by two parallel stiff plates. Next, the visualization of the dislocations activity will allow understanding the course of plastic deformation of the Si sphere.

3. Learning outcomes

After completing the course, students:

- will be able to use the LAMMPS commands: units, boundary, lattice, region, create_box, create_lattice, mass, pair_style, pair_coefficient, fix, group, thermo_style, timestep, run, write_data, print, dump;
- gaining the ability to model the formation energy of point defects and the bulk modulus;
- will be able to simulate the plastic deformation of silicon nanosphere;
- understand the crucial role dislocations in the explanation of a course of plastic deformation of nanoobjects;
- will be able visualize and perform analyze simulations data.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers.
- Connection with the internet.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Lab course outline:

1. Knowledge check from lecture:
   b. A brief test on the LAMMPS software and extended set of the LAMMPS commands

gathered from the lecture to ensure students are well prepared for the laboratory.
   c. A brief test on methods used for computations of the formation energy of the point defects and the elastic constants.
2. Introduction:
   c. Introducing the lab objectives.
   d. Students will discuss the procedure for carrying out the laboratory objectives.
3. Team formation:
   a. Students will be divided into teams composed of two persons.
   b. The instructor will serve as a mentor, supporting teams in realization of the laboratory objectives.
4. Research:
   a. Students will test several LAMMPS commands: units, variable, boundary, lattice, region, create_box, create_lattice, mass, pair_style, pair_coefficient, fix nvt, fix npt, group, thermo_style, timestep, run, write_data, print, dump.
   b. Each student team, assisted by the instructor, will write the LAMMPS scripts realizing modeling point defects, elastic constants. Then, students will perform MD simulations and calculated the energy of point defects formation. These simulations will be conducted for the Si, GaAs, and GaN crystal lattice.
   c. Each student team, assisted by the instructor, will create its own LAMMPS script realizing MD simulations of the Si nanosphere compression. Students will analyze the results of MD simulations using the OVITO as well as AtomEye software. The task will be performed by visualization and identification dislocations in the plastically deformed nanosphere.
5. Summary:
   a. Summarizing the laboratory classes and reminding its objectives.
   b. All students will prepare an individual report based on the template provided by the instructor.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

docs.lammps.org/Manual.html

7. Additional notes

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8. Optional information

Topics 6

1. The subject of the laboratory classes

Materials modeling with Wien2k package - preliminaries

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Calculations of the electronic structure and examination of the structure and properties of materials using quantum DFT-based methods consist of three stages. In the first step, data files describing the material (crystal structure and chemical composition) and files containing data controlling the course and accuracy of calculations are prepared. Next, basic calculations of the electronic structure are carried out. In the last step, calculations are conducted to determine the properties of the tested materials.

The scope of the laboratory exercise includes several tasks.

At the beginning of the exercise, students learn the basic elements of the WIEN2k computing environment (w2web graphical environment and console commands, alternative to the w2web environment).

In the next step, students will use the StructGen application to prepare structural data files for several materials (pure elements and compounds) with simple and complex crystal structures.

In the following, students will perform steps initializing the files containing the control data and initial electronic charge density distribution. The control data files comprise the parameters that are decisive for the correctness and accuracy of electronic structure calculations, and their values must be tested against convergence of the total energy of the studied system. With the aim of determining the optimal set of control parameters for a given material, students will perform a series of calculations for this material, analyzing the convergence of the total energy with an increase in the value of control parameters.

3. Learning outcomes

On completion of the exercise, students will have skills to do the following:

- Prepare the input structure file based on structural data from literature or using the CIF files provided by crystallographic databases.
- Initialize the control input files.
- Determine the optimal set of control parameters.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers running on the linux system.
- Connection to the network computing servers with WIEN2k installed.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory course outline:

1. Knowledge test:
    - A quiz checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
    - Presentation of the objectives of the laboratory and discussion of the initial input data set essential for the DFT-based electronic structure calculations.
    - Reminder of the elements of crystallography of single- and multi-atomic systems
    - Presentation of the elements of the WIEN2k computing environment in the graphical mode (w2web) covering the session management, the structure generator (StructGen) application and the structure visualization software (XCrySDen, VESTA).
    - Description of the steps initializing the control data input files and initial electronic charge density distribution.
    - Discussion of the contents of the main input data files and the most important results gathered in main output file.
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research
    - For each team, the instructor will assign two materials (single-atom and multi-atom ones) for which calculations of electronic structure and related properties will be continued in the following lessons.
    - With the assistance of the instructor, students prepare for each material appropriate structural data files and prepare structure visualization.
    - With the assistance of the instructor, students will complete the process of initializing the control data files.
    - With the assistance of the instructor, students will perform a full cycle of calculations for each material and optimize the parameters that determine the accuracy of the calculations.
5. Result analysis
    - Each team will show the results of their research in the form of a presentation.
    - Teams will discuss their conclusions regarding the effect of control parameters on the course and calculation results.

6. Summary

- Summarizing the lab and reminding of its objectives.
- All studnets will prepare individual reports.

Laboratory classes are conducted with the use of licensed WIEN2k software. Each student has an individual computer (terminal) and remote access to a computing server with licensed WIEN2k software installed. The students' activity can be continued remotely from personal computers connected to the network.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- S. Cottenier, Density functional theory and the family of (L)APW methods: a step-by-step introduction, 2013 (ISBN 978-90-807215-1-7), available free of charge at: http://www.wien2k.at/reg_user/textbooks/DFT_and_LAPW-2nd.pdf
- B. Blaha *et al.*, User's Guide, WIEN2k 23.1 (Release 01/16/2023), available free of charge at: http://susi.theochem.tuwien.ac.at/reg_user/textbooks/usersguide.pdf

7. Additional notes

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8. Optional information

Topics 7

1. The subject of the laboratory classes

Determination of electronic structure, structural and selected physical properties of selected ordered materials employing DFT-based quantum method

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The exercise aims to familiarize students with the procedures of material property determination based on electronic structure calculations using the WIENk code.

The scope of the laboratory exercise includes several tasks.

In the first stage, students will prepare the input files, determine the optimal set of control parameters, and conduct an accurate and converged cycle of electronic structure calculations for selected elemental and compound materials.

Next, they will perform structure optimization for each material, determine the lattice parameters, and calculate mechanical properties, including elastic moduli C_{ij}, Young's, Bulk and Rigidity Modulus, and Poisson's ratio.

Finally, based on the results of the main calculations, students will complete investigations by determining the electronic properties of considered materials. They will compute, visualize, analyze, and interpret the materials' electronic properties, including band structure (electronic dispersion plots and density of states plots), 2D and 3D electronic charge density distribution, and Fermi surface plots in reciprocal space. For magnetic material, they will analyze magnetic structure at the microscopic level.

3. Learning outcomes

On completion of the course, students will have skills to do the following:

- Initialize the main electronic structure calculations.
- Perform calculations with the desired accuracy.
- Analyze the flow of main electronic structure calculations.
- Perform the volume optimization.
- Compute, visualize, and interpret results for the physical properties of materials.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers running on the linux system.
- Connection to the network computing servers with WIEN2k installed.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory course outline:

1. Knowledge test:

- A quiz checking students' preparation for laboratory exercises based on information provided during the lecture.

2. Introduction:
- Presentation of the objectives of the laboratory and discussion of the initial input data set essential for the determination of electronic properties.
- Presentation of the elements of the WIEN2k computing environment in the graphical mode (w2web) essential for crystal structure optimization and calculation of material mechanical properties.
- Presentation of the elements of the WIEN2k computing environment in the graphical mode (w2web) essential for calculations and visualization of electronic properties of materials (band structure, density of states, electronic charge and spin density distribution).
- Description of the steps initializing the related control data input files and their contents.

3. The course of the exercise:
- Students will be divided into teams.
- The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
- The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.

4. Research
- For each team, the instructor assign a material for which calculations of electronic structure and related properties will be performed.
- Students prepare appropriate structural data files, complete the process of initializing the control data files and perform optimization of precision parameters.
- With the assistance of the instructor, students perform the crystal structure optimization and determine the bulk modulus of tested material.
- With the assistance of the instructor, students perform complementary calculations to determine the electronic properties of the tested material (band structure, Fermi surface, electronic density of states, charge and spin electronic densities) and prepare a graphical presentation of the obtained results.

5. Result analysis
- Each team will show the results of their research in the form of a presentation.
- Teams will discuss their conclusions regarding physical properties of the material studied.

6. Summary
- Summarizing the lab and reminding of its objectives.
- All students will prepare individual reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- S. Cottenier, Density functional theory and the family of (L)APW methods: a step-by-step introduction, 2013 (ISBN 978-90-807215-1-7), available free of charge at: http://www.wien2k.at/reg_user/textbooks/DFT_and_LAPW-2nd.pdf
- B. Blaha *et al.*, User's Guide, WIEN2k 23.1 (Release 01/16/2023), available free of charge at: http://susi.theochem.tuwien.ac.at/reg_user/textbooks/usersguide.pdf

7. Additional notes

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8. Optional information

Topics 8

1. The subject of the laboratory classes

Ab initio modeling of disordered materials containing dopants and point defects using the supercell approach

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The dopants or point defects usually occur in materials in small concentrations. As a result, the distances between them are much larger than the base materials' unit cell size, and there is no interaction between them. In ab initio calculations of periodically ordered systems, the smallest element of the structure is always selected – the unit cell. However, due to translational symmetry, placing the defect in the unit cell of an ordered material causes too high concentration of defects located too close to each other. Basically, such substitution leads to the creation of an ordered material with a new chemical formula but with the same crystal structure as the original material.

From experimental studies of the structure of atomically disordered materials, it is usually possible to conclude which sublattice is atomically disordered and the chemical composition of this sublattice. Two approaches (approximations) are used in quantum DFT calculations for atomically disordered materials.

Within the first one, the calculations for defective materials are carried out using superstructures with sizes significantly larger than the original unit cell size of the material without defects. The dimensions of the superstructures is chosen so as to prevent interactions between defects. For a given defect concentration the superstructures with different local atomic configurations must be considered. Such an approach is usually called the supercell method.

The second approach, Coherent Potential Approximation, is based on the assumption that admixtures or point defects statistically occupy the positions of the selected sublattice and there is no clustering effect. A property of the CPA approximation is that each atom of the disordered sublattice is replaced by some "effective" atom and the original periodicity of the lattice is restored.

This exercise aims for students to acquire the ability to form crystalline superstructures and create disordered systems containing impurities or point defects. Students will perform calculations for silicon semiconductors with n- and p-type impurities and for metallic compounds with either off stoichiometric compositions or with point defects, including vacancies or antisite atoms.

3. Learning outcomes

On completion of the course, students will have skills to do the following:

- Prepare the superstructures modeling the disordered materials using the supercell approach.
- Perform calculations with the desired accuracy.

- Compute, visualize, and interpret results for the physical properties of materials.

4. Necessary equipment, materials, etc.

- Laboratory equipped with desktop computers running on the linux system.
- Connection to the network computing servers with WIEN2k installed.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Laboratory course outline:

1. Knowledge test:
    - A quiz checking students' preparation for laboratory exercises based on information provided during the lecture.
2. Introduction:
    - Presentation of the objectives of the laboratory and discussion of the initial input data set essential for the determination of electronic properties.
    - Presentation of the elements of the WIEN2k computing environment in the graphical mode (w2web) essential for the data preparation within the "supercell" approach
3. The course of the exercise:
    - Students will be divided into teams.
    - The teams develop a research plan and define all the necessary activities to achieve relevant work results. The teams define the role of each team member.
    - The instructor controls and supports the teams in developing the research plan on an ongoing basis, pointing out any shortcomings, and finally approves the correct research plan.
4. Research
    - For each team, the instructor assign a composition of disordered materials for which calculations of electronic structure and related properties will be performed.
    - With the assistance of the instructor students prepare appropriate superstructures data files, complete the process of initializing the control data files and perform optimization of precision parameters.
    - Students will complete electronic structure calculations for ordered base materials.
    - With the assistance of the instructor students perform the superstructure relaxation, conducting the electronic structure calculations with a structure optimization algorithm switched on.
    - Students perform the crystal structure optimization with respect to the volume and atomic positions.
    - In the last step students will compute physical properties following the steps described in Topic 7 and determine the energy formation and site preference of point defects.
5. Result analysis
    - Each team will show the results of their research in the form of a presentation.

- Teams will discuss their conclusions regarding physical properties of the material studied.

6. Summary
- Summarizing the lab and reminding of its objectives.
- All students will prepare individual reports.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- S. Cottenier, Density functional theory and the family of (L)APW methods: a step-by-step introduction, 2013 (ISBN 978-90-807215-1-7), available free of charge at: http://www.wien2k.at/reg_user/textbooks/DFT_and_LAPW-2nd.pdf
- B. Blaha *et al.*, User's Guide, WIEN2k 23.1 (Release 01/16/2023), available free of charge at: http://susi.theochem.tuwien.ac.at/reg_user/textbooks/usersguide.pdf

7. Additional notes

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8. Optional information

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MATERIALS SCIENCE MASTERS

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SMART POLYMERS

Code: SP

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture:

Polymer Functional Materials – intelligent polymers

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to introduce students to topics related to smart polymers. Smart polymers, or stimuli-responsive polymers, are materials composed of polymers that respond dramatically to very small changes in their environment. Scientists studying natural polymers have learned how they behave in biological systems and are now using this information to develop similar artificial polymer substances with specific properties. These synthetic polymers are potentially very useful for a variety of applications, including some related to biotechnology and biomedicine. Smart polymers are becoming more widespread as scientists understand the chemistry and triggers of conformational changes in polymer structures and develop ways to use and control them. New polymer materials are being chemically engineered that sense specific environmental changes in biological systems and adapt in predictable ways, making them useful tools for drug delivery or other metabolic control mechanisms. In this relatively new field of biotechnology, the potential biomedical and environmental applications of smart polymers appear to be limitless. Currently, the most widespread application of smart polymers in biomedicine is targeted drug delivery. Since the advent of sustained-release pharmaceuticals, scientists have faced the problem of finding ways to deliver drugs to a specific site in the body without first degrading them in the highly acidic environment of the stomach. It is also important to prevent adverse effects on healthy bones and tissues. Scientists have developed ways to use smart polymers to control the release of drugs until the delivery system reaches the desired target. This release is controlled by a chemical or physiological trigger. There are linear and matrix smart polymers with different properties depending on the reactive functional groups and side chains. These groups can respond to pH, temperature, ionic strength, electric or magnetic fields, and light. Some polymers are reversibly cross-linked with non-covalent bonds, which can break and reform depending on external conditions. Nanotechnology has played a key role in the development of some nanoparticle polymers, such as dendrimers and fullerenes, which have been used for drug delivery. Traditional drug encapsulation has been done using lactic acid polymers. More recent developments observe the formation of mesh-like matrices that keep the drug of interest integrated or trapped between polymer strands. Smart polymer matrices release drugs through a chemical or physiological structural change reaction, often a hydrolysis reaction, which breaks bonds and releases the drug as the matrix breaks down into biodegradable components. The use of natural polymers has given way to artificially synthesized polymers such as polyanhydrides, polyesters, polyacrylic acids, poly(methyl methacrylates) and polyurethanes. Hydrophilic, amorphous, low molecular weight polymers containing heteroatoms (i.e. atoms other than carbon) have been found to degrade most rapidly. Scientists control the rate of drug delivery by changing these properties, thereby adjusting the rate of degradation.

3. Learning outcomes:

The presented lecture will allow the student to learn the basic intelligent polymer materials, their properties, division and characteristic features. He will learn what the idea of SMART polymers is and how they can be used. The student will be able to indicate the characteristic features that distinguish SMART materials from other engineering materials.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of intelligent polymer materials

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

Students are expected to read below texts related to the lecture:

1. Smart polymers and their applications, Maria Rosa Aguilar, Julio San Román, Woodhead Publishing, 2019
2. Smart Polymers: Applications in Biotechnology and Biomedicine, Second Edition, Igor Galaev; Bo Mattiasson, CRC Press, 2019
3. Smart Polymers: Basics and application; Asit Baran Samui, CRC Press, 2022

6. Additional notes:

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Topics 2

1. The subject of the lecture:

Hydrogel polymeric materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to familiarize students with hydrogel polymer materials. The definition of hydrogels will be presented, which states that hydrogels are colloidal systems in which the dispersed (dispersed) phase is water and the dispersing (forming) phase is mainly natural and artificial polymers or their modifications. The most common example of such a colloid is gelatin jelly. In the world, more and more intensive research is being carried out on hydrogels due to their extraordinary properties, and new applications are being found for them. A number of classifications of hydrogels have been presented in the literature and several views have been presented. Hydrogels are mainly made of biopolymers and/or polyelectrolytes. When it comes to the definitions of hydrogel types, they can be divided into those made of natural polymers and those made of synthetic polymers. Depending on the ionic charges on the bonded groups, hydrogels can be cationic, anionic or neutral. Types of cross-linking agents may also be classification criteria. Hydrogels can be physical, chemical or biochemical. Physical gels can transition from a liquid to a gel phase in response to changes in environmental conditions such as temperature, ion concentration, pH, or other conditions such as mixing two components. Chemical gels use a covalent bond that introduces mechanical integrity and resistance to degradation compared to other weak materials. In biochemical hydrogels, biological factors such as enzymes or amino acids participate in the gelation process. Shape memory hydrogels are thermally stimulated, which means that they stretch under the influence of heat and then return to their original dimensions after cooling. Biocompatible shape memory hydrogels have great potential for use in minimally invasive surgery and drug transport. Shape memory can be used in a minimally invasive arrangement of compact devices or implants that, under the influence of an external stimulus, will take the appropriate shape, for example, a hydrogel can be placed in the human body and after the adsorption of body fluids, it can expand to the desired shape, thus filling the wound. or replace tissue. Permeable hydrogels can be filled with drugs like a sponge, then placed in the body, they will biodegrade and release the drugs locked in the pores. Hydrogels are also used as wound dressings. The benefits of using hydrogel dressings to protect wounds are enormous, especially if you know how to apply the gel properly. Hydrogel dressings are an excellent source of moisture for a dry wound, quickly help cool the affected area, and provide temporary pain relief, up to six hours. Hydrogels are used in many areas. This is due to their specific structure and compatibility with various conditions of use. The flexibility of hydrogels, which results from their water content, allows them to be used in a variety of conditions, from industrial to biological, and the biocompatibility of the materials used to produce them, as well as their chemical behavior in biological environments, which can be non-toxic, extends their application to science. medical. The main applications are dressings, contact lenses, biosensors, pH sensors, tissue engineering scaffolds and drug transport.

3. Learning outcomes:

The presented lecture will allow the student to learn about hydrogel polymer materials, their properties, division and characteristic features. He will learn how polymer hydrogels work and how they can be used. The student will be able to indicate the characteristic features of hydrogels.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of hydrogel polymer materials

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

Students are expected to read below texts related to the lecture:

[1] "A Robust, One-Pot Synthesis of Highly Mechanical and Recoverable Double-Network Hydrogels Using Thermo-Reversible Sol-Gel Polysaccharide," co-authored by Zheng and his UA research colleagues, Qiang Chen, Lin Zhu, Chao Zhao and Qiuming Wang, was published June 14, 2013, online in Advanced Materials.
[2] "Mechanically Tough, Thermally Activated Shape Memory Hydrogels," on Jan. 7, 2013, in ACS Macro Letters.
[3] Immobilizing enzymes by T. Watson, flickr.com, CC BY 2.0

6. Additional notes:

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Topics 3

1. The subject of the lecture:

Polymers as carriers of biologically active compounds. Slow drug delivery system

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to familiarize students with polymer materials that are used as carriers of biologically active compounds.

In any treatment of a health disorder, it is desirable that the drug reaches the site of action at a specific concentration and that the therapeutic dose remains constant for a sufficiently long time necessary to achieve the desired effect. In reality, however, the action of pharmaceuticals is limited by various factors (degradation of compounds before reaching the target; action on other cells; inability to penetrate tissues due to chemical nature). For these reasons, new solutions with increased pharmacological response are being sought. One such solution is the use of polymer-based carrier systems. They are a suitable tool for controlled drug delivery. Controlled release mechanisms require the use of polymers with different physicochemical properties. The most famous polymer systems used in drug delivery systems include: nano- and microparticles, dendrimers, nano- and microspheres, capsosomes and micelles. In these systems, drugs can be conjugated (attached) or enclosed in a polymer matrix. All these systems are widely used in many anticancer, anti-inflammatory, antibacterial therapies and as a complement to vaccines. Work on controlled pharmacokinetics, pharmacodynamics, non-specific toxicity, immunogenicity and biorecognition contributed to the development of a new strategy based on drug delivery systems (Drug Delivery System, DDS). Drug delivery systems are those whose components (formulation ingredients or carriers) ensure precise distribution and/or timely release of active molecules at the target site. This is a new approach that is based on a combination of pharmacology with polymer science, analytics, conjugation chemistry and molecular biology. This solution has a huge impact on the effectiveness of a given therapy. An integral element of drug delivery systems are macromolecular carriers such as nano- and micro-capsules, capsosomes (polymer capsules filled with liposomes), liposomes, micelles or dendrimers to which drug molecules are attached. The main task of polymer carriers is to transport the drug to the site of action. The carrier-drug combination also has a protective function against the interaction of non-specific molecules that may react with the delivered molecule and structurally change it, thereby reducing its effectiveness. In addition, polymeric carriers provide reduced interaction with macromolecules (proteins) that can mask the active ingredient, thereby impairing precise delivery to the molecular target. An important element when using polymer carriers is to design the appropriate type of polymer structure (taking into account the degree of hydrophobicity or the number of covalent bonds between monomers), which will enable the release of the drug under specific conditions. Manipulation of the chemical structure of the polymer can significantly affect the rate and degree of drug release. Another solution is to use appropriate linkers, i.e. molecules connecting the drug with the polymer. Such linkers contain fragments in their structure that are degraded under certain conditions (low pH environment, presence of specific digestive enzymes). Another innovative strategy is the use of so-called smart polymers, the stimulation of which by various factors (temperature, pH, humidity, electric or magnetic field, etc.) induces a change in the structure, which results in the release of the drug.

3. Learning outcomes:

The presented lecture will allow the student to learn the basic intelligent polymer materials, their properties, division and characteristic features. He will learn what the idea of SMART polymers is and how they can be used. The student will be able to indicate the characteristic features that distinguish SMART materials from other engineering materials.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of polymer materials used in medicine as biologically active compounds for the slow release of drugs

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

Students are expected to read below texts related to the lecture:

1. Smart polymers and their applications, Maria Rosa Aguilar, Julio San Román, Woodhead Publishing, 2019

6. Additional notes:

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Topics 4

1. The subject of the lecture:

Shape memory polymers

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to become acquainted with the group of polymer materials capable of remembering shape. Shape Memory Polymers (SMP) are materials that can "remember" their original shape and return to that shape when a stimulus is applied. They are included in the group of so-called "smart materials".

Compared to shape memory alloys, shape memory polymers are much lighter, withstand large deformations that are reversible and are cheaper. Shape memory polymers are easy to process, can be repeatedly programmed and can control the reaction time to stimuli.

The return to the original shape can be triggered by various stimuli. So far, this has been achieved using: heat, light, infrared light exposure, water immersion and the use of electric or magnetic fields. The largest group of intelligent polymers are polymers with thermal shape memory. The adaptive properties of these polymers are revealed by temperature changes.

Shape memory polymers can be stretched elastically and cooled, so that crystallization, or the formation of a glassy phase, fixes the polymer into a non-equilibrium temporary shape. By heating the polymer above the glass transition temperature Tg or melting point, the stored elastic energy is released and the polymer returns to its original shape. When cooled to a sufficiently low temperature, almost all elastomers exhibit shape memory. However, SMP can be designed in such a way that by selecting the appropriate temperature, durability or shape recovery can be controlled.

The key to obtaining such polymers is controlling the crystallization that occurs when the polymer is cooled or stretched. When the material is deformed, the polymer chains are locally stretched and the polymer segments align in the same direction in small regions or domains called crystallites. These domains fix the temporary deformed shape of the polymer. As the number of crystallites increases, the shape of the polymer becomes more and more stable, making it more difficult for the polymer to return to its original shape. If we reheat the polymer to a temperature higher than Tg, the polymer will return to its original shape. Such a polymer is therefore composed of at least two phases, one rigid with a high transformation temperature and the other responsible for regaining shape - it may be a glassy or crystalline phase. The use of shape memory polymers

Shape memory polymers are used in many areas: in construction - foam that expands under the influence of heat, sealing window frames; production of sportswear that becomes porous at elevated temperatures, allowing heat and moisture to be transported; for the production of photonic gratings; cardiovascular stents made of SMP allow a small stent to be inserted along a vein or artery and then expanded to the desired diameter; for the production of surgical sutures.

3. Learning outcomes:

The presented lecture will allow the student to learn the characteristics of shape memory polymers, their properties, division and characteristic features. He will learn what the idea of SMP operation is and how they can be used. The student will be able to indicate the characteristic features of materials that are able to remember given properties, such as their shape.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of shape memory polymers

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

Students are expected to read below texts related to the lecture:

1. Ukielski R., Sobecki, P. P.: Smart polymers with thermally induced shape-memory effect, Polimery 2008, T. 53, nr 11/12, s. 793-798, dostęp:02.10.2020
2. Huang W. M., Ding Z., Wang C. C., Wei J., Zhao Y., Purnawali H.: Shape memory materials, Materials Today 2010, Vol. 13, Iss. 7-8, pp. 54-61, dostęp:02.10.2020
3. Yakacki C. M., Shandas R., Lanning C., Rech B., Eckstein A., Gall K.: Unconstrained recovery characterization of shape-memory polymer networks for cardiovascular applications, Biomaterials 2007, Vol. 28, Iss. 14, pp. 2255-2263, dostęp:14.12.2020

6. Additional notes:

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Topics 5

1. The subject of the lecture:

Electrically conductive polymers

2. Thematic scope of the lecture (abstract, maximum 500 words)

The aim of the lecture is to familiarize students with a group of polymers capable of conducting electricity. The lecture will present three mechanisms of conductivity of polymer materials - electronic, ionic and redox conduction. Electronic conduction - current conduction occurs similarly to metals, due to the existence of conduction bands resulting from the delocalization of electrons in multiple chemical bonds occurring in the main chain, or from the overlapping of empty orbitals along the main chain. Conduction is possible when the valence and conduction bands overlap, or the energy gap between them allows electrons to jump. Similarly to classic semiconductors, the electrical properties of conductive polymers can be modified by doping - removing or introducing electrons into the system. However, unlike inorganic semiconductors, no admixtures of electron-rich or poor elements are used, but partial reduction or oxidation of polymer macromolecules is carried out, which leads to the production of ionoradicals. Depending on the doping method, we distinguish n-doping (reduction) and p-doping (oxidation). Some polymers have conductivity comparable to that of semiconductors, and those doped - even at the level of metals. Electronically conductive polymers can be in neutral (no charge), oxidized (cationic) or reduced (anionic) forms. Ionic conductivity - current conduction is the result of the movement of ions in the matrix, as in the case of classic electrolyte solutions. Polyelectrolytes must have ion-exchange or electron-donating groups attached to the main chain, the charge carrier is a small cation (e.g. Li), moving in steps between the electron-donating groups attached to the main chain. The movement of the cation causes the anion to move in the opposite direction. This type of conductivity increases with increasing temperature because the viscosity of the polymer decreases, resulting in greater ion mobility. Such polymers are called solid electrolytes and are characterized by their ionic number and ionic mobility. Redox conductivity - polymers of this group contain isolated groups attached to the main chain, which can undergo reversible oxidation and reduction reactions. Conduction takes place by electron transfer between redox groups. Polymers whose electrical conductivity changes under the influence of lighting are called photoconductive (electroluminescent) polymers and are described in a separate module.

The most important polymers with conductivity include polymers: containing double bonds: polyacetylene (PA) and polyphenylacetylene (PPA); containing an aromatic ring: polyfluorene (PF) and polyparaphenylene (PPP), polyaniline (PANI), and polyphenylene vinylene (PPV); heterocyclic polymers with a nitrogen atom: polypyrrole (PPy) and polypyridine (PPY); heterocyclic polymers with a sulfur atom: polythiophene (PTh) and polyethylene dioxythiophene (PEDOT), polyfuran (PFu), as well as: polycyanamide (PCN) and polyvinylferrocene (pVFc). Conductive polymers can be obtained classically, by chemical synthesis, biocatalyzed chemical synthesis, electrochemically, photochemically and by solid state polymerization. Electrochemical synthesis - involves the electrolysis of a monomer in a solvent, often containing an electrolyte - anodic oxidation of the monomer is performed to produce cation radicals, which then react with the monomer or each other to produce an intermediate product with a dication structure. The resulting dications, containing a certain system of conjugated bonds, can easily split off hydrogen cations, getting rid of their charge. The products of such cleavage are neutral oligomers, which can then diffuse to the anode, where they will be oxidized again. The above cycle is repeated until the degree of polymerization reaches such a high value that the polymer begins to deposit on the anode in the form of a film. Solid-state polycondensation is a process in which polymer chain growth occurs under conditions in which at least one reactant is in the solid state; the process occurs under the influence of heat in the absence of oxygen and water, in a vacuum or by blowing with inert gas to remove reaction by-products. The combination of high flexibility of polymers with good electrical conductivity makes them excellent substitutes for metals. The polymer semiconductor can be easily applied to a large surface. These polymers do not corrode. Conductive polymers are used to produce wires, membranes, transparent electrodes in portable computers, luminous indicators, composites protecting against the accumulation of electrostatic charges, in photovoltaic cells, and power supply systems, machines and robots on a micro- and nano-scale, in airplanes invisible to radar, in fabrics camouflaging soldiers against night vision goggles, as antistatic coatings.

Polyelectrolytes - solid electrolytes, are used in electrochemical cells, as semi-conductive membranes, ion exchangers, in lithium-polymer batteries, for biosyntheses using ionic liquids to obtain higher enantioselectivity, e.g. in the synthesis of ibuprofen.

Redox-conducting polymers are used as active layers of pH sensors and some types of biosensors sensitive to changes in the redox potential of the system, and are used in the detection and quantitative determination of various complex organic substances, e.g. glucose.

3. Learning outcomes:

The presented lecture will allow the student to learn about polymer materials that are capable of conducting electricity, their properties, division and characteristic features. He will learn about the idea of how this type of polymers work and how they can be used. The student will be able to list the types of polymers that conduct electricity and indicate their characteristic features.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of polymeric materials that conduct electricity.

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

Students are expected to read below texts related to the lecture:

1.Proszowska A., Siódmiak T., Marszał M. P.: Ionic liquids – new possibilities in synthesis of pharmaceutical compounds, Annales Academiae Medicae Silesiensis 2012, Vol. 66, s. 59-65, dostęp:20.09.2020
2. Zhang Q., Wu S., Zhang L., Lu J., Verproot F., Liu Y., Xing Z., Li J., Song X-M.: Fabrication of polymeric ionic liquid/graphene nanocomposite for glucose oxidase immobilization and direct electrochemistry, Biosensors and Bioelectronics 2011, Vol. 26, Iss. 5, pp. 2632-2637, dostęp:20.09.2020

6. Additional notes:

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Topics 6

1.	**The subject of the lecture:**

Self-healing polymers

2.	**Thematic scope of the lecture (abstract, maximum 500 words)**

The aim of the lecture is to familiarize students with polymer materials capable of self-healing. Degradation and damage to common materials are natural consequences of their wear. As a result of research, new materials are designed with increased resistance and durability, but all of them, including modified ones, eventually fail. At the beginning of the 21st century, innovative polymer materials with specialized properties, including the ability to self-repair, were developed. Self-healing leads to regeneration, i.e. the material regaining its original or similar properties. The initiation of the process is initiated by damage to the material, regardless of whether the self-healing process is autonomous or externally assisted. Over the last few years, various types of materials have been developed that have the ability to autonomously or non-autonomously self-repair, enabling the production of safe, long-lasting, damage-resistant products and components with a potentially wide range of applications. Most literature reports on the use of the self-healing mechanism cover the electronics, medical, transportation and anti-corrosion coatings industries. Polymeric materials are susceptible to mechanical, chemical, thermal and UV radiation factors, and their direct impact leads to the formation of micro-damages in the structure of the materials, which are usually invisible at the initial stage and are very difficult to identify. The occurrence of micro-damages causes weakening of the polymer material and, consequently, its permanent damage. The effects of such permanent damage often result in large economic losses and also often contribute to accidents, including fatal ones. Currently, the concept of self-healing materials is based on three systems: microcapsules, microchannels and internal mechanisms. Due to the chemistry of self-healing polymers/polymer composites, the literature divides them into autonomous and non-autonomous materials capable of self-healing. In autonomous self-healing materials, the self-healing mechanism is an automatic response to damage/cracks in the material. Non-autonomous self-healing materials, on the other hand, require an external stimulus. Self-healing materials according to an external mechanism are composed of a matrix with a repair agent and a catalyst embedded in it. Substances supporting self-healing can be placed in microcapsules or a network of microchannels, depending on the size of the damage, the repeatability of the repair and the ability of the material to regain its original properties. The self-healing process is initiated by external/internal damage/rupture of the microchannel or microcapsule network.

3.	**Learning outcomes:**

The presented lecture will allow the student to learn about intelligent polymer materials that are characterized by the ability to self-repair, their properties, division and characteristic features. He will learn the idea behind how self-healing polymer materials work and how they can be used. The student will be able to indicate the characteristic features of this group of intelligent polymers.

4. Didactic methods used:

The lecture will be delivered using multimedia and a traditional interactive whiteboard. The topic will be covered during 2 hours of classes.

Multimedia presentation - using a multimedia presentation, such as Microsoft PowerPoint and Google Slides, for a visual presentation of the issues discussed.

Discussion – encouraging participants to actively participate in the discussion on the topics discussed

Case study - presentation of issues regarding the general characteristics, division and properties of self-healing polymer materials.

Question and answer session – a series of questions asked by the teacher, answers provided by students; Students are encouraged to discuss the problem in a group.

5. Recommended reading:

1. Students are expected to read below texts related to the lecture:

Current knowledge about self-healing polymers in the aspect of application for full-rubber protective gloves; A. Adamus-Włodarczyk, E. Irzmańska, B. Brycki,
DOI: https://doi.org/10.14314/polimery.2018.7.3

6. Additional notes:

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Topics 1

Course content – laboratory classes

1. The subject of the laboratory classes:

Testing the sorption properties of hydrogels used as wound dressings.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory classes is to examine the sorption properties of hydrogel dressings. According to the modern concept of wound treatment, the key factor is to maintain constant moisture within the wound, which is why the production of synthetic and natural, modern dressing materials, the so-called active dressings must take the above aspect into account. Many authors appreciate the sorption properties of polymer hydrogels, which thus find a wide range of applications, including: as artificial implants, contact lenses, enzyme mobilization and other pharmaceutical applications. Of particular interest are natural polymers containing active polysaccharides that build cell walls of algae and herbs. Active dressings are dressings that: maintain high humidity between the wound and the dressing, remove excess exudate and toxic components, allow gas exchange between the wound and the surroundings, are impermeable to bacteria and other microorganisms, are free from toxic substances, protect newly formed tissues and are easy to remove from the wound surface without causing trauma.

3. Learning outcomes:

The student will become acquainted with the sorption properties of hydrogels, determine the influence of salinity and the presence of ethanol on the adsorption process of the hydrogel.

4. Necessary equipment, materials, etc

The laboratory exercise takes place in a laboratory equipped with a fume hood, distilled water installation and personal protective equipment.
Materials needed for classes:
- hydrogel material in dressings 2x2 cm,
-NaCl,
-ethanol,
- beakers,
-10 ml pipettes

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:

1. Introduction

• Presentation of the purpose of the laboratory and discussion of the need to study the adsorption of hydrogel polymeric materials used as wound dressings

• Discussion of the stages of the experiment along with a reminder of the safety rules applicable in the chemical laboratory.

2. The course of the exercise:

• Division of students into working groups.

• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.

3. Experimental part:

• The group receives 4 samples of commercially available polymer hydrogels in the form of wound dressings.

• Prepare the hydrogel - cut a 2x2 cm square, measure the diameter (d/cm) and weigh the mass of each (m/g). 2.

• Prepare 4 beakers containing water at room temperature, water at 37 °C, 3% aqueous NaCl solution, and ethanol.

• Place hydrogel samples (previously weighed and measured) into the prepared beakers. Turn on the time meter and treat this moment as the moment of starting the measurement.

• After 5, 10, 15, 30, 60, 120 minutes, repeat the following actions: ▯ Remove the samples, dry, weigh, measure, take a photo, put back into the appropriate solution.

• Record the results from each series in a table and take the average.

4. Results analysis:

• The group will present the results of its research in the form of a report.

• Based on the experimental data for the four tested environments, plot three relationships (create the graphs in a spreadsheet, remembering to edit the axes correctly): a. d = f(t), b. m = f(t), c. $v_{adsorbed\ H2O}$ = f(t).

• Calculate the approximate water absorption rate of the tested hydrogels (for the four tested conditions) as r = Δm/Δt.

• Determine the effect of salinity and the presence of ethanol on the sorption process in hydrogel systems.

• Determine the effect of increased temperature on the sorption process in hydrogel systems.

5. Summary:

• A summary of the lab provided by the instructor and a reminder of its goals.

• Summarize experiences and identify possible future actions, including possible further research.

• Critical assessment of the suitability and complexity of the method.

• Detailing the content of the report.

6. Recommended reading:

Students should read the given literature related to the topic of the course:
Therapeutically active dressings – biomaterials in a study of collagen glycation; Anna Pielesz, Jadwiga Paluch; Polim. Med. 2012, 42, 2, 115–120

7. Additional notes

The laboratory report will be assessed according to the following criteria:
- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

Scope of issues necessary to complete the exercise: polymer hydrogels, sorption properties of polymer materials.

Topics 2

1. The subject of the laboratory classes:

The use of the FTIR technique in the analysis of the polymer-drug complex.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory classes is to use the FTIR technique to analyze polymer-drug complexes used in controlled drug release systems. Time-controlled drug delivery systems (DDS) are forms of medicine that cause the slow release of the active substance into the body. This feature means that DDS have many advantages over traditional forms of the drug. The effective concentration in the body is maintained much longer, so dosing is less frequent and the drugs are safer and more effective. Conjugates are complexes that contain drug carriers to which the drug is usually bound by a covalent bond. It is also possible to use proteins, peptides or DNA as an active substance instead of a drug. Natural or synthetic polymers are used as macromolecules, but proteins and antibodies can also be used. The binding of a drug to a carrier is often accompanied by a change in its distribution, which is beneficial if its increased accumulation in the target tissue occurs. The biodistribution of the bound drug depends on the properties of the carrier. There are two approaches to drug delivery: active and passive.

Active transport uses specific antibodies, sugars, peptides or proteins as carriers or fragments that can selectively bind to receptors or antigens of target cells. This results in higher drug concentrations in target tissues than when free drug is administered. Passive transport is mainly used in the treatment of cancer. The unique anatomical and physiological characteristics of the tumor tissue are used here, primarily increased vascular permeability (EPR) and retention of small and large molecules in the tumor tissue. The obtained polymer-drug complexes are subjected to many tests, including: in-vitro, in-vivo, spectral, thermal, particle size, surface morphology, drug penetration and release efficiency are determined. In order to assess the interaction of the complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine, a drug used in cancer therapy, the following methods are used, among others: FTIR spectrophotometric analysis. The infrared spectrum of any compound or drug provides information about the groups present in that particular compound.

3. Learning outcomes:

The student will become familiar with the FTIR spectrophotometric technique and use it to analyze the polymer-drug complex. Student beyond the possibilities of using polymeric materials in a controlled drug delivery system.

4. Necessary equipment, materials, etc

The laboratory exercise takes place in a laboratory equipped with an FTIR spectrophotometer. Materials needed for classes:

-PLGA (polylactide-glycolide co-polymer),
-capecitabine,
- complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine),
- spatula.
Equipment used for classes:
- FTIR spectrophotometer

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:
1. Introduction
• Presentation of the purpose of the laboratory and the principle of operation of the FTIR spectrophotometer
• Discussion of the stages of analysis along with a reminder of the safety rules applicable in the chemical laboratory.
2. The course of the exercise:
• Division of students into working groups.
• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.
3. Experimental part:
• The group receives 3 samples: 1. PLGA (polylactide-glycolide co-polymer), 2. capecitabine, 3. complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine),
• Use a spatula to place the samples
• Each group records FTIR spectra in accordance with the instructions of the instructor/spectrophotometer operator for three received samples
• The group analyzes the received reports
4. Results analysis:
• The obtained FTIR spectra are analyzed by the groups, determining the characteristic groups contained in the spectra with the support of the lecturer and additional materials in the form of tables with characteristic vibrations of the groups and access to online libraries
• Students perform comparative analysis of the spectra of the drug, PLGA and the complex
5. Summary:
• A summary of the lab provided by the instructor and a reminder of its goals.
• Summary of analyzes and identification of possible future actions, including possible further research.
• Critical assessment of the suitability and complexity of the method.
• Detailing the content of the report.

6. Recommended reading:

1. Honey PJ (2014). Smart polymers for the controlled delivery of drugs - a concise overview. Acta Pharm Sin B 4(2): 120-127.

2. Allemann E, Gurny R (1993). Drug-Loaded Nanoparticles: Preparation Methods and Drug Targeting Issues. Eur J Pharm Biopharm 39(5) 173-191.

7. Additional notes

The laboratory report will be assessed according to the following criteria:
- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

The scope of issues necessary to perform the exercise: controlled drug release system, polymers as drug carriers, FTIR technique

Topics 3

1. The subject of the laboratory classes:

Polymers used in targeted therapy - DSC analysis of the polymer-drug complex.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory classes is to use the DSC technique to analyze polymer-drug complexes used in controlled drug release systems. Time-controlled drug delivery systems (DDS) are forms of medicine that cause the slow release of the active substance into the body. This feature means that DDS have many advantages over traditional forms of the drug. The effective concentration in the body is maintained much longer, so dosing is less frequent and the drugs are safer and more effective. Conjugates are complexes that contain drug carriers to which the drug is usually bound by a covalent bond. It is also possible to use proteins, peptides or DNA as an active substance instead of a drug. Natural or synthetic polymers are used as macromolecules, but proteins and antibodies can also be used. The binding of a drug to a carrier is often accompanied by a change in its distribution, which is beneficial if its increased accumulation in the target tissue occurs. The biodistribution of the bound drug depends on the properties of the carrier. There are two approaches to drug delivery: active and passive.

Active transport uses specific antibodies, sugars, peptides or proteins as carriers or fragments that can selectively bind to receptors or antigens of target cells. This results in higher drug concentrations in target tissues than when free drug is administered. Passive transport is mainly used in the treatment of cancer. The unique anatomical and physiological characteristics of the tumor tissue are used here, primarily increased vascular permeability (EPR) and retention of small and large molecules in the tumor tissue. The obtained polymer-drug complexes are subjected to many tests, including: in-vitro, in-vivo, spectral, thermal, particle size, surface morphology, drug penetration and release efficiency are determined. In order to assess the interaction of the complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine, a drug used in cancer therapy, the following methods are used, among others: DSC thermal analysis (Differential Scanning Calorimetry).

3. Learning outcomes:

The student will become familiar with the DSC technique and its suitability for determining polymer-drug complex interactions through the analysis of characteristic temperatures and thermal transformations.

4. Necessary equipment, materials, etc

The laboratory exercise takes place in a laboratory equipped with a DSC spectrophotometer.
Materials needed for classes:
-PLGA (polylactide-glycolide co-polymer),
-capecitabine,

- complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine),
- spatula.

Equipment used for classes:

- DSC differential scanning calorimeter

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:

1. Introduction

• Presentation of the purpose of the laboratory and the principle of operation of the DSC differential scanning calorimeter

• Discussion of the stages of analysis along with a reminder of the safety rules applicable in the chemical laboratory.

2. The course of the exercise:

• Division of students into working groups.

• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.

3. Experimental part:

• The group receives 3 samples: 1. PLGA (polylactide-glycolide co-polymer), 2. capecitabine, 3. complex of PLGA nanoparticles (polylactide-glycolide co-polymer) with capecitabine),

• Approximately 5 mg of sample should be placed in an aluminum pot and clamped, then placed in the calorimeter.

• Carry out the measurement in the scanning temperature range from 50 to 300 ° C with a heating rate of 10 ° C / min.

• Each group registers thermograms for three received samples in accordance with the instructions of the leader/calorimeter operator

• The group analyzes the received thermograms.

4. Results analysis:

• The groups analyze the received DSC thermograms by determining the characteristic temperatures and transformations contained in the thermograms with the support of the lecturer and auxiliary materials received from the lecturer

• Based on the thermograms, prepare a table containing temperatures characteristic of capcitabine, PLGA and the complex.

• Students perform comparative analysis of thermograms of the drug, PLGA and the complex

• In the report, students answer the questions: what information does the analysis of carrier-drug complexes provide us with?; What will prove that the crystallinity of the drug has been significantly reduced in the nanoparticles?; Is the drug homogeneously dispersed in the PLGA matrix?

5. Summary:

• A summary of the lab provided by the instructor and a reminder of its goals.

• Summary of analyzes and identification of possible future actions, including possible further research.
• Critical assessment of the suitability and complexity of the method.
• Detailing the content of the report.

6. Recommended reading:

Students should read the given literature related to the topic of the course:

1. Honey PJ (2014). Smart polymers for the controlled delivery of drugs - a concise overview. Acta Pharm Sin B 4(2): 120-127.
2. Allemann E, Gurny R (1993). Drug-Loaded Nanoparticles: Preparation Methods and Drug Targeting Issues. Eur J Pharm Biopharm 39(5) 173-191.

7. Additional notes

The laboratory report will be assessed according to the following criteria:
- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

The scope of issues necessary to perform the exercise: controlled drug release system, polymers as drug carriers, DSC technique

Topics 4

1. The subject of the laboratory classes:

Degradation studies in an artificial biological environment of selected polymer materials used in medicine

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory classes is to become acquainted with the phenomenon of degradation of polymer materials used in regenerative medicine. Polymers for medical applications, due to the constant contact of the stent with the body's environment, must meet very stringent requirements, primarily in terms of biocompatibility and biotolerance. A) plastics must be made of high-purity monomers, the chemical and molecular structure is stable during processing into final products and sterilization, B) the mechanical, physical and chemical properties of materials must be adapted to the function to be performed by the products made of them, C) materials they cannot cause allergies, allergic and toxic reactions, inflammation and foreign body reactions, as well as cancerous changes, D) implants in contact with blood should not cause changes in blood components, induce thrombosis, or affect the proper regeneration processes of surrounding tissues, E) the biologically active environment should not affect the physical, chemical and mechanical properties of implants (biostable polymers) F) the degradation time should be adjusted to the tissue regeneration time (biodegradable polymers). G) point C and D also refer to degradation products of resorbable polymers. Both in the case of synthetic and natural, biostable or biodegradable polymers, over time there is a gradual loss of the original physicochemical properties of these compounds. In the case of biostable plastics, such processes are called the aging process. Under the influence of factors such as light, heat, humidity, air, loads, microorganisms, active chemical compounds and organic substances, irreversible changes occur in the structure of the material, which work towards reducing the length of macromolecule chains and lowering the molecular weight. This affects properties such as viscosity, mechanical strength, elasticity, surface structure, state of matter, melting point, and causes deterioration of functionality, durability and reliability. These changes take place both through chemical and physical changes caused by processing, storage and exploitation. Polymer aging is accompanied by decomposition reactions: Destruction - irregular disintegration of polymers into low-molecular compounds, different from the monomer. Degradation - reduction of molecular weight by decomposition of the polymer not into low-molecular products but into fragments with high, although lower molecular weights than the initial polymer (e.g. through mechanical interaction - rolling) Depolymerization - decomposition of polymers into monomers or oligomers. One of the most popular groups of polymers used in medicine are polylactides. Polylactides are materials with very good mechanical properties. Hydrolytic degradation of PLLA, due to the existing crystalline domains, occurs no earlier than after 40 weeks, and complete resorption of the polymer in-vivo may take up to 2-6 years. PLLA applications include orthopedics, oral surgery, tissue fusion and regeneration, bone fixation elements (screws, nails), interference screws for ligament reconstruction (Pl-Fix, Arthrex), biodegradable sutures (DePuy), internal fixators, scaffolds.

3. Learning outcomes:

The student will become familiar with methods of measuring the degradation dynamics of biodegradable polymers used in medicine

4. Necessary equipment, materials, etc

The laboratory exercise takes place in a laboratory equipped with a fume hood, distilled water installation and personal protective equipment.
Materials needed for classes:
-poly(l-lactide);
- composite based on poly(l-lactide) with the addition of alginate fibers (CaAlg)
- Distilled water
-Ringer's solution: solution of sodium chloride, potassium chloride, calcium chloride and water, pH= 7-7.5 - - Solution simulating human body fluid (Simulated Body Fluid - SBF), pH=7.2-7.4
- beakers,
-10 ml pipettes
Equipment needed for classes;
- analytical balance
- conductivity meter
-pHmeter

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:
1. Introduction
• Presentation of the purpose of the laboratory and discussion of the need to study the degradation dynamics of biodegradable polymers used in medicine
• Discussion of the stages of the experiment along with a reminder of the safety rules applicable in the chemical laboratory.
2. The course of the exercise:
• Division of students into working groups.
• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.
3. Experimental part:
• The group receives 2: poly(l-lactide) and a composite based on poly(l-lactide) with the addition of alginate fibers (CaAlg)

• Each group puts the weighed samples into beakers containing incubation fluids 1. Distilled water, 2. Ringer's solution; 3. SBF solution

• The groups measure changes in the pH of the incubation fluid for two types of plastics, at different stages of degradation (after 1 hour and 2 hours) using a pH meter

• The groups measure changes in the electrical conductivity of the incubation fluid for two types of plastics, at different stages of degradation (after 1 hour and 2 hours) using a conductivity meter

• Students measure changes in the mass of samples made of two types of materials, at different stages of degradation (after 1 hour and 2 hours) using an analytical balance

4. Results analysis:

• The group will present the results of its research in the form of a report.

• Based on experimental data for the three tested environments, plot three relationships (create the graphs in a spreadsheet, remembering to edit the axes correctly): a. pH = f(t), b. m = f(t), c. σ= f (t).

• Assess structural changes in samples after the incubation process

• Perform a comparative analysis of changes occurring in samples depending on the incubation fluid used

5. Summary:

• A summary of the lab provided by the instructor and a reminder of its goals.

• Summarize experiences and identify possible future actions, including possible further research.

• Critical assessment of the suitability and complexity of the method.

• Detailing the content of the report.

6. Recommended reading:

Students should read the given literature related to the topic of the course:

1. Gunatillake P.A., Adhikari R., "Biodegradable synthetic polymers for tissue engineering", European Cells and Materials, 5:1-16, 2003.
2. Lim I.A.,, "Biocompatibility of Stent Materials ", MIT Undergrad. Res. J. 11:33–37, 2004.

7. Additional notes

The laboratory report will be assessed according to the following criteria:

- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

Scope of issues necessary to complete the exercise: polylactides, biocompatibility, bioactivity, biodegradation, regenerative medicine

Topics 5

1.	**The subject of the laboratory classes:**

Polyaniline - electrically conductive polymer, synthesis and properties

2.	**Thematic scope of the laboratory classes (abstract, maximum 500 words)**

The aim of the laboratory classes is to synthesize polyaniline - a conductive polymer. Polyaniline is obtained as a result of interfacial polymerization. Interfacial polymerization - is a type of polymerization with gradual growth in which the polymerization reaction takes place at the boundary of phases that do not mix with each other (usually liquid phases). The monomer is in one liquid phase and the initiator is in the other. The resulting polymer is immediately "pulled" out of the reaction system so as to maintain a large phase contact surface at all times. As a result of this polymerization, fibers or very thin films are obtained. Depending on the type of interphase boundaries, interfacial polymerization methods are divided into three cases: liquid-solid, liquid-liquid and liquid-emulsion. In the method involving liquid-liquid and liquid-emulsion interfaces, monomers may contain either one or both liquid phases. In the case of a liquid-solid, polymerization begins at the phase boundary and causes the polymer to attach to the surface of the solid phase. In the liquid–liquid case with the monomer dissolved in only one phase, polymerization occurs at the interface only on the side where the monomer is present, whereas while monomers are dissolved in both phases, polymerization occurs at the interface on both sides. In order to obtain polyaniline in the form of nanofibers, polymerization is carried out in a two-phase system with aniline dissolved in an organic solvent and an oxidant (ammonium peroxydisulfate) dissolved in an aqueous acid solution. The organic phase may be an organic solvent such as: benzene, hexane, toluene, carbon tetrachloride, chloroform, methylene chloride, diethyl ether, carbon disulfide or o-dichlorobenzene.

3.	**Learning outcomes:**

The student will become familiar with the interfacial polymerization procedure, which will result in obtaining polyaniline - an electrically conductive polymer.

4.	**Necessary equipment, materials, etc**

The laboratory exercise takes place in a laboratory equipped with a fume hood, distilled water installation and personal protective equipment.

Materials needed for classes:

-aniline,

- ammonium peroxydisulfate $(NH_4)_2S_2O_8$

-chloroform,

-$HClO_4$,

-distilled water,

- beakers,
-10 ml pipettes,
- spatulas

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:

1. Introduction

• Presentation of the purpose of the laboratory and discussion of the polyaniline synthesis process

• Discussion of the stages of interfacial polymerization along with a reminder of the safety rules applicable in the chemical laboratory.

2. The course of the exercise:

• Division of students into working groups.

• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.

3. Experimental part:

• The group receives reagents and laboratory glassware necessary to carry out the synthesis

• Prepare an aqueous solution of $HClO_4$ acid in a beaker and add 2 mg of the oxidant $(NH_4)_2S_2O_8$

• In the second beaker, prepare a solution of 0.32 M aniline in chloroform

• Pour the aqueous acid solution gently into the beaker with aniline and subject the mixture to induction

• Observe the reactions occurring at the phase boundary

• After a short induction time, a green product - polyaniline - appears at the interface, which migrates to the aqueous phase, filling it completely.

• As the reaction proceeds, the green product darkens and eventually stops changing, indicating the reaction is complete

4. Results analysis:

• The group will present the results of its research in the form of a report.

• Describes in detail the course of synthesis along with the calculations necessary to prepare the solutions

• Describes schematically the equations of the reactions taking place

5. Summary:

• A summary of the lab provided by the instructor and a reminder of its goals.

• Summarize experiences and identify possible future actions, including possible further research.

• Critical assessment of the suitability and complexity of the synthesis method.

• Detailing the content of the report.

6. Recommended reading:

Students should read the given literature related to the topic of the course:

1.Huang J., Kaner R. B.: A General Chemical Route to Polyaniline Nanofibers, Journal of American Chemican Society 2004, Vol. 126, Iss. 3, pp. 851-855, dostęp:15.07.2020

2.Raaijmakers M. J. T., Benes N. E.: Current trends in interfacial polymerization chemistry, Progress in Polymer Science 2016, Vol. 63, pp. 86-142, dostęp:15.07.2020

7. Additional notes

The laboratory report will be assessed according to the following criteria:

- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

Scope of issues necessary to complete the exercise: electrically conductive polymers, polyaniline, interfacial polymerization

Topics 6

1. The subject of the laboratory classes:

Shape memory polymer analysis.

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory classes is to become familiar with the properties of shape memory polymers. Intelligent shape memory polymers (SMP) are innovative chemical compounds that have the ability to regain shape as a result of appropriate stimuli, e.g. temperature, pH and light. Shape memory polymers are gaining increasing interest due to their scientific and technological importance. They are used in industry, medicine and tissue engineering because they are a good replacement for metallic materials due to their flexibility, biocompatibility and a wide range of modifications. SMPs are most often separated by a mechanism that releases immobilized mobile segments. In this way, we are able to distinguish between shape changes caused by phase transitions and those caused by molecular changes. The changes caused by the phase transition depend on the transition temperature (T_{trans}). This may be the melting temperature (T_m) of part of the material and then its re-crystallization to establish a temporary shape, or the glass transition temperature (T_g). It is worth emphasizing some basic differences between these two subtypes of SMP. Polymers with a glass transition are characterized by greater freedom to adjust T_{trans} by introducing comonomers - monomers forming copolymers with an assigned polymer - faster shape change cycle time (glass transition is a process occurring faster than crystallization), smaller range of transition temperatures and the inability to create bidirectional SMPs. (can be read later in this article.) The second fundamental mechanism for causing shape change is molecular triggers. The main representatives of this type of triggers are; water, UV radiation, inductive electromagnetic interactions and reversible covalent bonds, as well as coordination between metals and ligands. Inducing a shape change occurs either by lowering the phase change temperature (for example, the breakdown of hydrogen bonds in a molecule under the influence of water), or by the reversible formation and breaking of existing bonds (for example, oxidation and reduction of disulfide bridges by exposure to UV light). An important feature of molecular triggers is their greater selectivity. By adding metal particles susceptible to heating by electromagnetic induction to polymers, we are able, for example, to create SMPs with local shape-changing properties. Depending on the planned application, as well as the mechanism of action of a specific SMP, they may be given various forms. Initially, the dominant form was free, high-density polymers. As the industry developed, new spatial variants of SMP were gradually created to meet the requirements of potential applications. The new, most popular forms of SMP are shape memory surfaces, shape memory nanoparticles and hydrogels. On a micro scale, they function essentially identically to SMP of a classic form with a mechanism that works in an analogous way.

3. Learning outcomes:

The student will become acquainted with a group of polymer materials that have the ability to remember their original shape. It will be possible to analyze a polymer that responds to temperature changes.

4. Necessary equipment, materials, etc

The laboratory exercise takes place in a laboratory equipped with a fume hood, distilled water installation and personal protective equipment.

Materials needed for classes:

-10 cm sample of polymer elastomer with shape memory ability

Equipment needed for classes:

-Weights 100 g, 200 g, 0.5 kg

- electric heater

-tripod

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Scheme of laboratory classes:

1. Introduction

• Presentation of the purpose of the laboratory and discussion of the analysis of the speed of return to the original shape of the SMP when loaded under the influence of temperature

• Discussion of the stages of the experiment along with a reminder of the safety rules applicable in the chemical laboratory.

2. The course of the exercise:

• Division of students into working groups.

• Groups develop a research plan with the support of the leader and define all necessary activities to achieve appropriate work results.

3. Experimental part:

• The group receives a 10 cm long shape memory polymer sample

• Students prepare an experimental stand; attach one end of the sample to the stand using metal grippers,

• Using their hands, they extend the sample by holding its other end,

• They measure the length of the stretched sample,

• Attach a weight (100 g, 200 g and 0.5 kg) to the stretched sample and place an electric heater (50 °C) behind the stand; when turned on, they measure the time needed for the sample to return to its original length,

• They repeat the procedure for each load five times.

4. Results analysis:

• The group will present the results of its research in the form of a report.

• Based on the experimental data for the three tested loads, plot the relationship $l_{sample}= f(t)$

• Determine the effect of increased temperature on the recovery process of a shape memory polymer sample.

5. Summary:

• A summary of the lab provided by the instructor and a reminder of its goals.

• Summarize experiences and identify possible future actions, including possible further research.

• Critical assessment of the suitability and complexity of the method.

• Detailing the content of the report.

6. Recommended reading:

Students should read the given literature related to the topic of the course:

1. Body Temperature Triggered Shape-Memory Polymers With High Elastic Energy Storage Capacity; Yuan Meng, Jisu Jiang, Mitchell Anthamatten; DOI: 10.1002/polb.23990
2. Shape Memory Polymers: Plastic with a Brain, and Some Muscle (youtube.com)
3. Mitch Anthamatten Explains a Shape-Memory Cycle Involving Strain Induced Crystallization (youtube.com)
4. Shape memory polymers (youtube.com)

7. Additional notes

The laboratory report will be assessed according to the following criteria:

- completeness of the report; (1 point)
- theoretical introduction (1 point)
- quality (in terms of correctness) of the results obtained; (3 points)
- correctness of interpretation, discussion and conclusions; (4 points)
- report aesthetics. (1 point)

Total 10 points.

8. Optional information:

Scope of issues necessary to complete the exercise: Shape memory polymers (SMP)

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MATERIALS SCIENCE MASTERS

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

LEAN MANAGEMENT

Code: LM

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

Introduction to Lean Management

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to give students fundamental knowledge about lean management and introduce them to lean thinking. The agenda includes an introduction to the lean history, the sources of lean manufacturing, the Toyota Production System, the definition of lean, the notion of lean management, waste and value, fundamentals and main principles of lean (continuous improvement, respect for people, eradication of waste), five principles of lean: value, value, stream, pull, flow and perfection. Lean management has a long story. John Krafcik used lean production in the late 80' of XX c., but the concept originates from Toyota Production System TPS and W.E Deming's work. There is still no universal definition of lean. The lean is defined as a system designed in such a way as to ensure that it addresses the needs of people in the organisation and allows the provision of better effects for key stakeholders: customers, investors, associations, communities, and suppliers;

a methodology which uses the power of collective knowledge, the scientific method and understanding of values to redesign functions in an organisation so that they function from the point of view of the customer's interests; a central improvement strategy, a comprehensive approach to organisational change and improvement; an approach to process improvement at the workplace. The Lean Thinking philosophy focuses first on acting economically, i.e., improving actions' efficiency by eliminating or minimising waste and controlling the flow of added value. Lean Management is founded on the two most important values: respect for people and continuous improvement. Lean is founded on five principles: value, value stream, flow, pull and perfection.

Nowadays, lean management is successfully used in different branches and types of organisations (business, NGO, public services); the case studies will show, on the one hand, the uniqueness of lean thinking, on the other hand – the flexibility and adaptability of the concept.

3. Learning outcomes

- Students will know the central notions of the lean management concept.
- Students will know the history of lean management.
- Students will understand the main fundamentals of the lean.
- Students will be able to think and find the opportunity for improvements.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.

Case study - presentation of examples of using lean in different branches and types of organisation

Discussion - encourage students to participate actively in the debate on the issues.

Clips – short movies that present the use of lean and its results.

Quiz - summarised the essential information.

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

No special pre-lesson preparation is expected before the lecture. Students could review knowledge about the fundamentals of management/project management/business process management/process engineering if they were included in the academic programme on the engineering studies. It is not mandatory.

Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6.	**Additional notes**

Topics 2

1. The subject of the lecture

Lean management as a process-driven concept

2. Thematic scope of the lecture (abstract, maximum 500 words)

Lean management is a concept based on the system and process approach. The lecture aims to introduce students to the fundamentals of the system and process thinking. The agenda includes introductions to the management theories (Scientific Management, Administrative Theory, The Theory of Bureaucracy, Behavioural theory, System theory, Contingency theory), the premises for the development of the process approach (economic, technological, business concepts/evolution of public management), functional silos versus process-driven approach, the definition of Business Process Management BPM and the process, ingredients of the process, the management concept based on the process approach: quality management, lean management, business process reengineering, business process management, Six Sigma, Lean Six Sigma. Adopting a process management system should be a strategic decision of top management in an organisation. The design and implementation of an organisation's quality management system are influenced by a) its organisational environment, changes in that environment, and the risks associated with that environment; b) its varying needs; c) its particular objectives, d) the products it provides, e) the processes it employs, f) its size and organisational structure. The essence of the process approach includes establishing the organisation's processes to operate as an integrated and complete system. The management system integrates processes and measures to meet objectives. Processes are defined as interrelated activities and checks to deliver intended outputs. In the international standard, the ISO 9000 process approach is described as detailed planning, and controls can be defined and documented as needed, depending on the organisation's context (ISO 9000:2015). An organisation's objectives are achieved through improving, managing, and controlling essential business processes. BPM is a body of methods, techniques, and tools that can be used to discover, analyse, redesign, execute, and monitor business processes. Processes can be defined as a set of interrelated or interacting activities that use inputs to deliver an intended result (ISO 9000:2015). To describe the random process, the set of ingredients should be used: event, activity, task, decision point, actors, object, outputs, outcomes (negative, positive), outcomes (material, immaterial – change), customer (internal, external), value (benefits/costs), objective of process and KPI (Key Performance Indicators).

3. Learning outcomes

- Students will know the conditions and stages in the evolution of the management concept from the late XIX c to XXI c.
- Students will know the central notions of the process management concepts.
- Students will know the history of business process management.
- Students will know the ingredients of the process.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.

Case study - presentation of examples of process approach

Discussion - encourage students to participate actively in the debate on the issues.

Clips—short movies present the evolution of the management concept from the late XIX c to the XXI c.

Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

No special pre-lesson preparation is expected before the lecture. Students could review knowledge about the fundamentals of management/project management/business process management/process engineering if they were included in the academic programme on the engineering studies. It is not mandatory.

Recommended for advanced studies: Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo A. Reijers, Fundamentals of Business Process Management, Springer-Verlag Berlin Heidelberg 2013,

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6. Additional notes

Topics 3

1. The subject of the lecture

Problem-solving methods and tools

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to give students a theoretical background for using problem-solving methods and tools to improve safety, effectiveness, and quality of work and services. Problem-solving is defining the problem, identifying the list of solutions, prioritising and selecting the best option, taking the limitations, and preparing the implementing and controlling plan according to the PDCA cycle. The above methods will be discussed:

- Brainstorming.
- 5Whys.
- 5W2H.
- Ishikawa Diagram.

Brainstorming is a group technique for creating new ideas. The group takes a specific problem and generates as many ideas as possible in a limited time.

The 5WHYs technique asks a "why" question five times to find the causes of problems in an organisation's processes. It is related to techniques such as the Ishikawa Diagram, Kaizen, Gemba, Six Sigma, Kata, etc. The 5 Whys method includes the following steps: forming a team, defining a problem, asking the 5 Whys, noting results, and formulating recommendations for corrective and preventive action.

5W2H is a problem-solving method based on a protocol that asks questions: what, why, where, when, who, how, and how many. It can be used for project, event, and process analysis.

The Ishikawa diagram is one of the many management tools created by Dr. Kaoru Ishikawa. One such tool in root cause analysis is Dr. Ishikawa's Fishbone diagram, also known as the Cause and Effect Diagram and eponymously as the Ishikawa Diagram. The basic foundation of the Fishbone is straightforward and practical. Used and understood even by non-specialists, the Cause and Effect diagram is used as a team brainstorming tool to provoke, tease and evoke more and more ideas and issues (causes) to be captured that can go into any particular conclusion (effect) reached.

The framework for each method includes its origin, primary purpose, steps in problem-solving, benefits, and limitations. The lecture will show and discuss an example of using these methods.

All mentioned methods and tools develop the critical thinking of the users.

3. Learning outcomes

- Students will know the conditions and stages of using the problem-solving methods.
- Students will know each method's benefits and limitations and how to choose the proper method for a dedicated problem.

- Students will know how to stimulate the team's creativity and engage team members in problem-solving.
- Students will deepen their critical thinking abilities to find the opportunity for improvements.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.
Case study - presentation of examples of using the problem-solving methods and tools
Discussion - encourage students to participate actively in the debate on the issues.
Clips – short movies that present the use of lean and its results.
Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

No special pre-lesson preparation is expected before the lecture. Students could review knowledge about the fundamentals of management/project management/business process management/process engineering if they were included in the academic programme on the engineering studies. It is not mandatory.
Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6. Additional notes

Topics 4

1. The subject of the lecture

Organisation and standardisation of the work and workplace

2. Thematic scope of the lecture (abstract, maximum 500 words)

Proper organisation and standardisation of work processes play a central role in creating an effective and safe workspace and stimulating employees to focus on the quality of the products. The well-organised workspace and process lead to the reduction of the variation in the process and product metrics. The lecture aims to teach students about the role of standardisation in process improvement. The agenda includes an introduction to the standard work, the documentation for the standard work- SOP Standard Operating Procedure and Instructions, the standardisation of the workplace – 5S, and the benefits and limitations of the standardisation. SOP is used in an organisation to establish the best practice (executing a process) in given circumstances, to standardise work, to teach the best practice, to implement and utilise knowledge and experience in an organisation (transform a piece of tacit knowledge into open knowledge), to share a knowledge and best practices in organisations, to monitor and control the work in a process, to improve the process. A typical process description (Standard Operating Procedure SOP) includes the information related to the general information about the document (date of issue, number of issues, confirmation,.), introduction – aim of the process/document, definitions, inputs in the process, process owner and others involved in this process/responsibilities, description of process stages (via word, drawing, charts etc.), metrics of effectiveness and efficiency, monitoring of process (tools and methods), nonconformities in process – list of corrective and preventative actions to eliminate nonconformities, attachments/forms, templates and other connected documents, references external, internal, change history/revision.

The 5S method is a multiphase transformation of an organisation's management towards improved effectiveness, quality, and work safety. It is mainly applied to organise workstations and offices. It consists of the following five phases: “sort,” “set in order,” “shine,” “standardise,” and “sustain.” Implementing 5S improves employees’ awareness concerning organising a safe workstation and developing self-discipline and responsibility. 5S increases employees’ satisfaction with work improvements, safety, and participatory management.

3. Learning outcomes

- Students will know the methods and tools of standardisation.
- Students will know the conditions and stages of using standards.
- Students will know the benefits and limitations of standardisation.
- Students will deepen their critical thinking abilities to find the opportunity for improvements.

4.	Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.
Case study - presentation of examples of types of standardisations in a workspace
Discussion - encourage students to participate actively in the debate on the issues.
Clips – short movies that present the use of lean and its results.
Quiz - summarised the essential information.

5.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should be familiar with the definitions, notions, and principles of lean management and business process management discussed in the previous lectures and workshops.
Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6.	Additional notes

Topics 5

1. The subject of the lecture

Lean manufacturing

2. Thematic scope of the lecture (abstract, maximum 500 words)

The purpose of the lecture is to present the fundamentals of lean in production plants and production processes. The agenda includes Lean manufacturing, Jidoka and Andon, the Poka-Yoke system, the designing of the infrastructure and machines in the production area, 3 P Method (production, preparation and process), the U-line, TPM – Total Productive Maintenance, SMED - Single Minute Exchange of Die, visual management on the production line, standard work.

Andon has its conceptual roots in the Jidoka system created by Sakichi Toyoda. Jidoka refers to an intelligent machine which automatically stops when a problem appears. It is an integral part of the Toyota production system, creating operational excellence. The Andon system in Lean manufacturing assumes that stopping work at the moment will save the organisation from major and costly issues in the future. Andon makes it possible to empower employees who are entitled to interrupt a process if there are too many tasks or documents to process.

3P is an event-driven process for developing new products and the standards and workflows that support them, taking product design and production to the next level. 3P's concurrent development process allows the product design to dictate the methods used to produce it. It provides an opportunity to gather insights for improving products/processes. Those insights can be implemented as they emerge, allowing organisations to cut costs, save time, and deliver better consumer solutions.

TPM (Total Productive Maintenance) is a holistic approach to equipment maintenance that strives to achieve perfect production. The utilisation of TPM resulted in the minimising occurrence of breakdowns, small stops or slowed running, and defects, and, in addition, it values a safe working environment (minimising the number of accidents). TPM emphasises proactive and preventative maintenance to maximise the operational efficiency of the equipment. It blurs the distinction between the roles of production and maintenance by strongly emphasising empowering operators to help maintain their equipment. Implementing a TPM program creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment, this can improve productivity (increasing uptime, reducing cycle times, and eliminating defects).

SMED (Single-Minute Exchange of Die) is a system that reduces the time it takes to complete equipment changeovers. The essence of the SMED system is to convert as many changeover steps as possible to "external" (performed while the equipment is running) and to simplify and streamline the remaining steps. The name Single-Minute Exchange of Die comes from the goal of reducing changeover times to the "single" digits. A successful SMED program benefits from lower manufacturing costs, smaller lot sizes, faster changeovers, improved responsiveness to customer demand, lower inventory levels, and standardisation. Each method and tool will be illustrated by example or case study to give students a broader understanding of its benefits and limitations. The possibility of using elaborate methods in the services industry will be discussed.

3. Learning outcomes

- Students will know the conditions and stages of lean manufacturing methods and tools.
- Students will know each method's benefits and limitations and how to choose the proper method for a dedicated problem.
- Students will learn about the possibilities of adapting lean manufacturing methods in the service industry.
- Students will deepen their critical thinking abilities to find the opportunity for improvements.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.

Case study: presentation of examples of using lean manufacturing methods and tools. Discussion: Encourage students to participate actively in the debate on the issues.

Clips – short movies that present the use of lean and its results.

Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should be familiar with the definitions, notions, and principles of lean management and business process management discussed in the previous lectures and workshops.

Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6. Additional notes

Topics 6

1. The subject of the lecture

Lean culture and lean leadership

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture will familiarise students with creating a lean culture (a culture of continuous improvement).

One of the most popular models describing organisational culture is one that Shein proposed. The criterion for distinguishing the elements of culture is their visibility for the observer and permanence (resistance to change). Schein distinguished three levels of organisational culture: the visible level – artefacts (visible organisational structures and processes); the partly visible level – held values, beliefs, and standards (strategies, goals, philosophy, justification for existence); the invisible level – fundamental assumptions (unconscious and taken for granted, perception, thinking and feelings, the basic source of values and actions). Lean management is defined as a cultural change, and Lean culture is simultaneously a factor influencing the implementation of the concept of Lean management and its effect. Lean culture is an essential success factor of Lean management in organisations. Lean culture is a harmonised, consistent, and coherent model of behaviour that results from shared learning in the process of organisational improvement based on the fundamental premises, systems, and methods of Lean management. The holistic and comprehensive approach to changing a Lean Culture should include fundamentals of Lean (lean thinking, lean principles), techniques and tools (pieces of training) and Lean Management System (structure, procedures, resources). Changing the organisational culture is a long and complex process that needs proper preparation and design. The manager/leader should be aware of the human and social aspects of the organisational change. The adequate leadership and engagement of the employees play a critical role in the organisational culture and work culture shift.

The lecture agenda includes a definition of organisational culture according to the Shein model, a model of lean culture with descriptions of its elements and the framework for lean leadership, Gemba, standard leadership work, and Kaizen.

"Gemba" comes from Japanese, meaning "the real place". In Lean management, "Gemba" is the most crucial place for a team as it is where real work happens. Taichi Ohno, the father of the Toyota Production System, created Gemba. He believed that people can learn the most from everyday experiences gained in workplaces. Gemba is not a method in the exact sense of the word but an approach to solving problems and undertaking organisational activities. It is based on observing and analysing situations without relying on predetermined judgements. It comprises the following actions of leaders: visiting a workplace, observing a process, and talking to people.

In Japanese, Kaizen means good change (kai—good, zen—change). Kaizen assumes that everything can be improved, and the pursuit of continuous improvement is the duty of every employee in an organisation. It is based on employees' bottom-up initiative and commitment to enhancing activities and processes by offering proposals for improvement.

3. Learning outcomes

- Students will know the definition and understand the organisational and lean culture.
- Students will know the expectations for the lean leader.
- Students will know how to use the Gemba and standards in the process improvement.
- Students will learn how to create an engaged workspace by using Kaizen.
- Students will deepen their critical thinking abilities to find the opportunity for improvements.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Multimedia presentation - using PowerPoint presentations to discuss issues and provide examples.
Case study - presentation of examples of lean culture
Discussion - encourage students to participate actively in the debate on the issues.
Clips – short movies that present the use of lean and its results.
Quiz - summarised the essential information.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should be familiar with the definitions, notions, and principles of lean management and business process management discussed in the previous lectures and workshops.
Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

6. Additional notes

Course content – workshops

Topics 1 – Workshop 1

1. The subject of the workshop/practical classes

Business process management – process ingredients

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The workshop aims to familiarise students with the analysis of process ingredients. A process consists of the following elements: sources of input, process input, actions, process output, recipients of output, feedback related to the assessment and improvement of a process's effectiveness and efficiency, and process owner. Each of the listed elements of a process determines the quality of the final effect; therefore, it has to be controlled using appropriate methods and criteria.

The sources of input into a process are processes taking place earlier and involving internal or external suppliers, customers or other interested parties. The theory of quality management refers to the internal customer concept. An internal customer can be a subsequent employee, process or group of persons in an organisation's chain of creating quality and value. It is generally accepted that a relationship exists between an external customer's and an internal customer's satisfaction.

Process input should be understood as a set of the properties of resources necessary for executing a process and achieving a result in the form of the intended quality of a service or product. Input comprises tangible, financial, human, and information resources owned (or controlled) by an organisation.

Processes consist of actions. They are purposefully and logically arranged sequences of deeds with a clearly defined beginning and end. A process may possess an extensive structure referred to as process architecture.

Process output or the result of a process is the effect of performed actions (the effects of a process, i.e. equipment, software, services, processed materials, tangible products)

External and internal customers are recipients of output. All of them use process results to perform further actions in subsequent processes.

Feedback is a systemic feature of a process that allows its adaptation and continuous improvement based on its monitoring and final assessment results.

In the process approach, the so-called process owner is responsible for process execution.

Based on the process description, students will be asked to answer the questions and prepare a short note with some pictures and other forms of visualisation (i.e., a flowchart).

3. Learning outcomes

By working on this workshop, students:

- will gain practical skills in the process analysis,

- will discuss the possibilities and benefits of using the visualisation of the process flow,
- will develop their competencies in teamwork,
- will know how to present the research results to the audience to convince them of the proposed change.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should be equipped with a flipchart or whiteboards, coloured markers, post-it-notes
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. whiteboard).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
   a. A brief test on critical concepts from the lecture to ensure students are well-prepared for the workshop.
2. Introduction:
   a. Introducing the workshop's objective
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for answering the questions aimed at defining the ingredients of the process.
   c. The instructor will serve as a mentor.
4. Research:
   Based on the process description, students will answer the following questions:
   a. Who is the customer (internal, external)? What are the requirements of the customers?
   b. What are the possible outcomes of this process?
   c. What are the starting and ending points and activities in this process?
   d. What are the decision points?
   e. What are the objects in this process?
   f. Who are the actors in this process?
   g. What are the inputs for this process?
   h. Who/what delivers inputs?
   i. What is the objective of the process, and how to measure it (KPIs in this process)?
   j. Who can be considered to be the process owner?

5. Results analysis:
    a. Students will prepare the notes and the visualisation of the process flow.
    b. Each team will present the results of their research in an oral presentation.
    c. Teams will discuss and compare their results among teams.
    d. Students will create conclusions regarding the analysis
6. Summary:
    a. Summarize the workshop and remind yourself of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading: Marlon Dumas, Marcello La Rosa, Jan Mendling , Hajo A. Reijers, Fundamentals of Business Process Management, Springer-Verlag Berlin Heidelberg 2013,
Students should prepare a theoretical introduction to the workshop (Lecture Topic 2).
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

8. Optional information

Topics 2 – Workshop 2

1. The subject of the workshop

Waste audit

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The exercise aims to familiarise participants with waste categories, identification, and process improvement ideas. According to the Lean concept, wastage is any activity that consumes resources without creating value for the customer. Japanese names waste are Muda, Mura, and Muri. Within this general Muda category, it is helpful to distinguish between type one muda, which consists of activities that cannot be eliminated immediately, and type two muda, which consists of activities that can be eliminated quickly through kaizen. Mura is defined as unevenness in an operation. Managers can often eliminate unevenness through level scheduling and careful attention to the pace of work. The last type of waste is Muri, which means having too much to carry, contain, or deal with. Muda, mura, and muri are often related; eliminating one eliminates the others. Usually, to investigate waste, it can be used 7wastes and TIMWOODS. The Lean theory describes seven significant areas where you can identify Muda activities, more popular as the seven wastes of Lean. There are as follows:

1. Transportation: This type of waste occurs when resources (materials) are moved without adding value to the product.

2. Inventory: Excessive inventory often results from a company holding "just in case" inventories.

3. Motion: This kind of waste includes the movements of employees (or machinery), which are complicated and unnecessary.

4. Waiting: The goods or tasks are not moving.

5. Overproduction: Producing more means exceeding the customer's demand, which leads to additional costs.

6. Over-processing: Adding extra features to a given product that nobody will use but increases your business costs.

7. Defects: Defects can cause rework or lead to scrap.

TIMWOODS includes Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects, and Skills. Skills mean not using people's capabilities, talents, and interests.

During the workshop, students identify the wastes using the TIMWOODS in the example process.

3. Learning outcomes

By working on this workshop, students:

- will acquire competencies in waste recognition and waste identification,
- will improve competencies in formulating the conclusions from the process observation,
- will develop skills in teamwork,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and Post-it notes.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. whiteboard).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
   a. A brief test on key concepts from the lecture to ensure students are well-prepared for the workshop.
2. Introduction:
   b. Introducing the workshop's objective
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for answering the questions aimed at waste audit.
   c. The instructor will serve as a mentor.
4. Research:

Based on the clip presentation, students will asked to answer the following questions:

- Watch the clip carefully.
- Identify the types of waste using the TIMWOODS (Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects, Skills).
- Give examples of waste.
- Answer the questions:
- What action should be taken to minimise or eliminate this waste?

- What kind of preventive action would be taken to prevent such waste from occurring?

5. Results analysis:
   a. Students will prepare the note.
   b. Each team will present the results of their research in an oral presentation.
   c. Teams will discuss and compare their results among teams.
   d. Students will create conclusions regarding the analysis
6. Summary:

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should prepare a theoretical introduction to the workshop (Lecture Topic 1). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS. Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

8. Optional information

Topics 3 – Workshop 3

1. The subject of the workshop classes

The lean principles

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The practical exercises aim to analyse the process using the five lean principles (value, value stream, flow, pull, and perfection), which are described below.

Value means determining precisely the value of a particular product/service. Explanation: Value for the specific process should be defined from the point of view of all (internal and external) customers. Customer opinion surveys, quality function deployment, stakeholder analysis, and customer voice can be used.

Value stream means Identifying a value stream for each product/service. Explanation: Identify the course of the process from the perspective of the customer and the organisation; assess the constituent activities and actions from the point of view of value creation. Value stream mapping, SIPOC, and block diagrams can be used.

Flow means ensuring an undisturbed flow of value. Explanation: eliminating wastage sources. Process reorganisation through bottom-up creativity and employee commitment; the management's competencies and commitment are of primary importance. Methods and tools that can be used.: training, Kaizen, 5S, standardisation of activities and processes, standard operating procedures, visualisation CRM, Pareto principle, Ishikawa diagram.

Pull means creating value when the customer expects it. Explanation: making processes free from any disturbances or downtime and performing only actions required by the customer (a pull system). Methods and tools can be used: Andon, process automation and computerisation, Kanban, and FIFO delivery systems.

Continuous improvement. Explanation: continuous improvement through the commitment of the organisation's employees and management under the PDCA cycle. Methods and tools that can be used: Kaizen, appropriate motivational system, empowerment people, learning organisation concept, knowledge management, project management, change management, Hoshin Karni, Strategic Balanced Scorecard, Six Sigma, institutionalisation of organisational solutions, standardisation.

During the workshop, students will analyse the case study to identify the Lean principles.

3. Learning outcomes

After completing the workshop, students:

- will understand the five lean principles,
- will understand the consequences of the lack of use of the lean principles,
- will deepen the competencies in teamwork,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and Post-it notes.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. Whiteboard).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
   a. A brief test on key concepts from the lecture to ensure students are well-prepared for the workshop.
2. Introduction:
   b. Introducing the workshop's objective
3. Team formation:
   a. Students will be divided into teams.
   b. Teams will be responsible for answering the questions aimed at learning principles.
   c. The instructor will serve as a mentor.
4. Research:
   Based on the clip presentation, students will asked to answer the following questions:
   - Watch the clip carefully.
   - Answers the questions:
     - Who is a customer/are customers in this process? Who defines value?
     - What is the value? How value can be measured/assessed (indicators)?
     - What are the actions in this process? Map a process.
     - What kind of waste can be observed in this process?
     - Is this a pull process?
     - How this process could be improved? What should be changed?
5. Results analysis:
   a. Students will prepare the note with visualisation.
   b. Each team will present the results of their research in an oral presentation.
   c. Teams will discuss and compare their results among teams.
   d. Students will create conclusions regarding the analysis
6. Summary:

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should prepare a theoretical introduction to the workshop (Lecture Topic 1). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS. Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

8. Optional information

Topics 4 – Workshop 4

1. The subject of the workshop classes

Problem-solving – 5Whys

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The practical exercises aim to introduce students to problem-solving and give them the experience of using the 5Whys method. The 5WHY technique asks a "why" question five times while looking for the causes of problems occurring in processes in an organisation. It is related to such techniques as the Ishikawa Diagram, Kaizen, Gemba, Six Sigma, Kata, etc. The research shows that this technique allows building a culture of continually asking questions as a basis for improvement. It makes it possible to identify the most deeply hidden phenomena not visible in cursory observations. Steps in 5Why's included organising a team, defining a problem, asking 5 Whys, noting results and formulating recommendations for corrective and preventive action. This technique allows building a culture of continually asking questions as a basis for improvement. Also, it makes it possible to identify the most deeply hidden phenomena which are not visible in cursory observations. The five whys technique has been criticised as a poor tool for root cause analysis. It could be caused by the tendency of investigators to stop asking after getting to the first root causes of the problem, lack of knowledge related to the problem (the investigator is not a specialist in the specific area), lack of support because of poorly prepared or not well-combined team, results are not repeatable, the tendency to isolate the single root causes (lack of the more comprehensive analysis dedicated to all root causes). Students will solve the problem using 5Why's methods during the workshop and discuss the results.

3. Learning outcomes

After completing the workshop, students:

- will understand the problem-solving process,
- will know how to use 5Why's to solve the problem,
- will deepen the competencies in teamwork,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and Post-it notes.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. Whiteboard).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
2. A brief test on key concepts from the lecture to ensure students are well prepared for the workshop.
3. Introduction:
4. Introducing the workshop's objective
5. Team formation:
   a. Students will be divided into teams/pairs.
   b. Teams will be responsible for problem formulating and solving it.
   c. The instructor will serve as a mentor.
6. Research:

   Students will be asked to follow the instructions:
   a. Work in pairs and assign the following roles: one student is a person who asks questions, and the other student is interviewed
   b. Formulate the problem - example: An Erasmus student signed up too late for their courses, and a student was late for their lectures
   c. Use the 5 Why's technique to find the root causes of the problem
   d. Formulate recommendations for corrective and preventive action
   e. Change the roles
   f. Discuss the advantages and disadvantages of the 5Whys
7. Results analysis:
   a. Students will prepare the note with visualisation.
   b. Each team will present the results of their research in an oral presentation.
   c. Teams will discuss and compare their results among teams.
   d. Students will create conclusions regarding the analysis
8. Summary:

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should prepare a theoretical introduction to the workshop (Lecture Topic 3). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS. Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

8. Optional information

Topics 5 – Workshop 5

1. The subject of the workshop classes

Value Stream Mapping

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The practical exercises introduce students to process mapping with value stream mapping. Value stream mapping allows a simultaneous combination of making an organisation lean (for example, by eliminating redundant actions or sources of waste) and improving the quality of processes and their output. It consists of analysing all process actions, starting from a customer and moving along the value stream towards resources necessary for providing a service. A value stream map is a drawing presenting the flow of information and materials in fulfilling an order for a selected group of products or services. Value Stream Mapping (VSM) is the basic technique and tool in Lean Management. VSM helps to analyse all actions within a process, starting from a customer and moving along the value stream towards resources necessary for conducting a process, producing a product or providing a service. The essence of mapping is to show the actions that create value and to eliminate or minimise the actions that do not contribute to the creation of values (sources of waste). Thus, the mapping of a value stream allows the successful application of all Lean principles:

- Determining precisely the value of a particular product/service,
- Identifying a value stream for every process/service,
- Ensuring an undisturbed flow of value,
- Creating value when the customer expects it,
- Pursuing continuous improvement.

The key notions in VSM include value and waste.

VSM was developed for business enterprises in the production sector. Therefore, using this tool in services and the public sector can result in numerous dilemmas and problems.

Usually, VSM is executed in three stages:

Stage 1: Drawing a map of the current state („as is" model of process)

Stage 2: Creating an ideal map of the same process – future state („to be" model of process)

Stage 3: Defining a plan of changes to be implemented to achieve process flow as close to the ideal one as possible

In business, the most critical process indicators used in VSM are:

- The total duration of a process (L/T Lead Time - L/T is understood as the nominal time of carrying out a process as determined by applicable regulations,
- P/T Processing Time - P/T is understood as the factual time of carrying out a process,
- VAT Value added time), costs, compliance, and quality (including customer satisfaction).
- Cycle Time is how often a particular process completes a part,
- Takt Time is a customer demand calculation that tells how often a particular process should complete a part to meet demand.

- Changeover is the time it takes to go from the last good part of one product run to the first good part of the following product run. Quick changeover is critical to Lean. It provides the flexibility to match the product mix to actual demand, a conversion or complete change from one thing, condition, or system to another, as in equipment, personnel, methods of production, etc.: a changeover to automated equipment.

During the classes, students use the VSM to analyse and improve the process and discuss the project's results.

3. Learning outcomes

After completing the workshop, students:

- will understand the process mapping,
- will know how to use value stream mapping to improve the process effectiveness,
- will know how to set and measure the process indicators,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will deepen the competencies in teamwork,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, post-it notes, and a set to prepare the cup of coffee.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. whiteboard).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
2. A brief test on key concepts from the lecture will ensure students are well-prepared for the workshop (the notions of value and waste are fundamental).
3. Introduction:
4. Introducing the workshop's objective
5. Team formation:
    a. Students will be divided into teams.
    b. Teams will observe the process, prepare the VSM (as-is and to-be model), test the process, and draw conclusions for further improvements.
    c. The instructor will serve as a mentor.
6. Research:

Students will be asked to follow the instructions:

a. The purpose of the exercise is to prepare a process map based on the example of preparing one cup of coffee

b. . ee

c. Customer requirements: instant coffee with milk in 2 min.

d. Case study stages:

1. Organizing into groups of 5-6 students
2. Observing the process (make a clip)

Summarising the workshop and reminding of its objectives.

The workshop is divided into three stages:

- Stage 1: Drawing a map of the current state („*as is”* model of process)
- Stage 2: Creating an ideal map of the same process – future state („*to be”* model of the process)
- Stage 3: Defining a plan of changes to be implemented to achieve process flow as close to the ideal one as possible

In stage 1, students are asked to:

1. Defining customer and value that a customer expects,
2. Determining which actions and activities in value stream flows – prepare a process map, collect data in a table,
3. Measuring time and other quantities used in process mapping,
4. Identifying the sources of wastes (i.e. TIMWOODS),
5. Evaluating each activity/action in a process from the point of view of a customer,
6. Labelling activities (VA, NVA, NNVA)

In stage 2, students should create an ideal map of the same process – the future state („to be" model of the process). Compare the process indicators in as-is and to-be models (L/T Lead Time, P/T Processing Time, C/T Cycle Time, VAT Value Added Time, NVAT/BVA Non-Value Added Time). Finally, students will be asked to:

1. Discussing the as-is model.
2. Choosing activities/actions which should be eliminated from the process.
3. Preparing a to-be model of the process (map of the process, table).

In stage 3, the student will be asked to prepare a list of corrective and preventive actions and a change plan.

7. Results analysis:

a. Students will prepare the process map with waste audit and the timeline.

b. Each team will present the results of their research in an oral presentation.

c. Teams will discuss and compare their results among teams.

d. Students will create conclusions regarding the analysis

8. Summary

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:
Maciąg, J. Value Stream Mapping (VSM) as a Tool for Creating a Lean Culture in a University. Global Lean for Higher Education, Taylor and Francis, a Productivity Press 2020, 39-63,
Students should prepare a theoretical introduction to the workshop (Lecture Topic 1,2,3). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

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8. Optional information

Topics 6 – Workshop 6

1. The subject of the workshop classes

Standard Operating Procedure

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The practical exercises aim to deepen students' knowledge of standardisation and its role in process improvement by using the PDCA cycle (Plan, Do, Check, Act). SOP is used in an organisation to establish the best practice (executing a process) in given circumstances, to standardise work, to teach the best practice, to implement and utilise knowledge and experience in an organisation (transform a piece of tacit knowledge into open knowledge), to share a knowledge and best practices in organisations, to monitor and control the work in a process, to improve the process. A typical process description (Standard Operating Procedure SOP) includes the information related to the general information about the document (date of issue, number of issues, confirmation,.), introduction – aim of the process/document, definitions, inputs in the process, process owner and others involved in this process/responsibilities, description of process stages (via word, drawing, charts etc.), metrics of effectiveness and efficiency, monitoring of process (tools and methods), nonconformities in process – list of corrective and preventative actions to eliminate nonconformities, attachments/forms, templates and other connected documents, references external, internal, change history/revision. SOPs help to achieve consistency, improve quality assurance and safety, save time and money, simplify employee management referring to the strategic and operational processes, help to collect knowledge and boost the learning cycle in the organisation, simplify audits and enhance the employee's autonomy. There are some threats, according to SOP, related to a lack of up-to-date documents, poor training, misunderstanding, a mismatch between SOP and daily work practices, limitations of innovation, etc. During the workshop, students prepare the SOP based on the process description and discuss the project’s result.

3. Learning outcomes

After completing the workshop, students:

- will understand the role of standardisation in the process improvement (PDCA cycle),
- will know how to prepare the SOP to improve the process effectiveness,
- will know how to use the different forms of visualisation to make the SOP more readable and understandable for the employees,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will deepen the competencies in teamwork,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and post-it notes.
- Online classes need an online platform dedicated to educational purposes (e.g., Teams), with functionalities related to dividing students into smaller groups and visualisation (e.g., whiteboard).
- The expected handout: the universal pattern for the SOP (in Word, Excel).
- This workshop is based on the results of the process mapping taken from Workshop No. 5 (VSM) (results of the to-be model are needed to prepare the SOP).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
2. A brief test on key concepts from the lecture ensures students are well-prepared for the workshop (especially the notion of standardisation and its manifestation within an organisation are essential).
3. Introduction:
4. Introducing the workshop's objective
5. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for preparing the SOP, testing it and drawing the conclusions for further improvements.
    c. The instructor will serve as a mentor.
6. Research:
   Students will be asked to follow the instructions:
    a. The purpose of the exercise: Preparing a SOP for the process of preparing a cup of coffee
    b. Case study stages:
    1. Organizing into groups of 5-6 students.
    2. Completing the information about the process (Workshop No. 5).
    3. Completing the SOP.
    4. Discuss the correctness and completeness of the SOP.
    5. Exchanging the SOP with the counter group – testing and discussing the SOP. Correctness and completeness, formulating the recommendations for improvement.
    6. Prepare the plan of a SOP implementing
7. Results analysis:
    a. Students will prepare the process SOP.
    b. Each team will present the results of the SOP testing and discuss them with the counter group.

c. Students will create conclusions regarding the analysis.

8. Summary:

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

Students should prepare a theoretical introduction to the workshop (Lecture Topic 4). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

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8. Optional information

Topics 7 – Workshop 7

1. The subject of the workshop classes

Workflow management - Kanban

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The practical exercises aim to teach students how to properly and effectively manage the workflows in an organisation. Kanban is one of the forms of visualising the course of processes and ensuring effective communication during activities. Kanban blends Japanese words: kan (to see) and ban (a board). Kanban made it possible to convey a pull signal, a signal to start production or a signal that materials, subassemblies or semi-finished products were needed. Kanban allows a complete understanding and practical application of the pull principle. It strengthens teamwork and a sense of responsibility for tasks and processes. It ensures the transparency and clarity of actions and processes during task execution. It facilitates communication. The Kanban, which is used to manage services and administration processes effectively, consist of three columns: to do (in this column, the list of the tasks planned to do are placed), in progress (the task is moved to this column when it took to proceed), done (in this column the completed tasks are placed). There are some rules for using Kanban effectively:

- Visualize the flow.
- Limit WIP (work in progress).
- Manage a workflow.
- Standardise rules for process execution.
- Implement feedback loops.
- Improve cooperation.

Kanban is beneficial to process management. It allows a complete understanding and practical application of the pull principle. It strengthens teamwork and a sense of responsibility for tasks and processes. It ensures the transparency and clarity of actions and processes during task execution. It facilitates communication. Kanban is very useful in remote work and online teams. Before we start using Kanban, it is worth knowing some limitations. It may be too simple for more advanced users, unsuitable for very complicated and complex processes, risk losing information collected in Kanban, and too detailed information that describes each task and definition of done can be unclear and imprecise. Some IT tools that can be used for electronic Kanban include Jira, Asana, Trello, Planner, and Microsoft 365. During the workshop, students design and practice workflow management using Kanban (paper or electronic version) and discuss the project's result.

3. Learning outcomes

After completing the workshop, students:

- will deepen the understanding of the pull idea,
- will know the principles of Kanban,

- will know how to use the different forms of Kanban board,
- will know how to improve teamwork,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will deepen the competencies in teamwork,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and Post-it notes.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. Whiteboard, Planner).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
2. A brief test on key concepts from the lecture is needed to ensure students are well prepared for the workshop (especially the Lean principles, which are essential to remember).
3. Introduction:
4. Introducing the workshop's objective
5. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for preparing the kanban board (paper or electronic version)
    c. The instructor will serve as a mentor.
6. Research:
   Students will be asked to follow the instructions:
    a. The purpose of the exercise: Preparing a kanban board to manage the work flow in the chosen process
    b. The research stage:
        1. Organizing into groups of 5-6 students.
        2. Choosing the example workflow/process flow.
        3. Preparing the list of tasks.
        4. Describe each task with detailed information (person assigned, deadline, checklist, etc.).

5. Use Kanban to manage workflow – improvise the actual workflow in the team.
6. Discuss the advantages and disadvantages of the Kanban board.

7. Results analysis:
    a. Students will prepare the Kanban board.
    b. Each team will present the results of their research in an oral presentation.
    c. Teams will discuss and compare their results among teams.
    d. Students will create conclusions and best practices regarding the analysis
8. Summary:

Summarising the workshop and reminding of its objectives.

6.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should prepare a theoretical introduction to the workshop (Lecture Topic 1).
Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7.	Additional notes

8.	Optional information

Topics 8 – Workshop 8

1. The subject of the workshop classes

Organising a teamwork

2. Thematic scope of the workshop classes (abstract, maximum 500 words)

The aims of the practical exercises are broadening students' competencies related to teamwork and using the methods and tools of visual management (i.e. Kanban, (daily huddles - visual management board) and deepening their understanding of continuous improvement culture. Students will discuss the problems in teamwork and workflow, learn how to formulate the proper rules for teamwork and use workflow management (Kanban). The workshop will also elaborate on the tools for team motivation and giving correct and consistent feedback. The agenda includes problems in teamwork, problems in a team workflow, rules for teamwork, workflow management (kanban), motivation and consistency, feedback (daily huddles - visual management board), and further CI of teamwork. Before starting a team, the team's purpose and scope should be defined. It is essential to pose several questions, as follows:

Questions

- Who is our customer?
- What are their expectations?
- What is the primary purpose of our team?
- What is the role of the organisation?
- What are the primary purposes for the team and its members individually?

It is essential to get back to some initial sources, such as legal and internal regulations (unit, department, team, project teams) and the scope of the processes assigned to the team. The scope and the purpose should be clear and understandable for each team member. The next step is to formulate/reformulate/refresh the rules for the team, including the daily huddles.

Organise and successfully conducting meetings should follow the rules:

1. Set the scope and rules for the daily/operational meetings
2. Choose the form of the board (electronic/traditional)
3. Desing the board (according to the informational needs of the teams)
4. Set the frequency of the meetings (fix the day/days during the week and the time)
5. Every time, appoint the meeting facilitator and the writer for the meeting (the rotation system)
6. The time dedicated to the meeting is less than 15 min. (the meeting is divided into stages – the first is related to the review of the tasks done and discussion on problems, and the second is dedicated to the planning of the tasks (Kanban), the last stage could be devoted to discussing problems etc.). Each of the team members should take an active role in the meeting.

The benefits of the meetings at the boards are good workflow planning and organisation, appropriate communication in a team, engagement and motivation through co-creation and active participation, and regular feedback. The manager should recognise some limitations related to daily huddles, like lack of discipline, lack of engagement of team members, taking over control by the team leader, lack of team responsibility, and going back to old routines/bad habits.

3. Learning outcomes

After completing the workshop, students:

- will know how to effectively organised the team (formulate the purpose and the rules for a team),
- will know how to use the different forms of visual management to boost teamwork,
- will know how to improve teamwork through the proper motivation and feedback,
- will know how to present the results of the research to the audience to convince them of the proposed change,
- will deepen the competencies in teamwork,
- will develop competencies in formulating the improvement ideas and its critical overview.

4. Necessary equipment, materials, etc

The exercise could be conducted in the classroom or online.

- The classroom should have a flipchart or whiteboard, coloured markers, and Post-it notes.
- Online classes need an online platform dedicated to educational purposes (i.e. Teams) with functionalities related to dividing students into smaller groups and visualisation (i.e. Whiteboard, Planner).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop course outline:

1. Knowledge check from lecture:
2. A brief test on key concepts from the lecture to ensure students are well prepared for the workshop (especially the Kanban, which is important to remember).
3. Introduction:
4. Introducing the workshop's objective
5. Team formation:
    a. Students will be divided into teams.
    b. Teams will be responsible for designing the team board and organising the meeting at the board.
    c. The instructor will serve as a mentor.
6. Research:
   Students will be asked to follow the instructions:

a. The purpose of the exercise is to design the team board and organise the meeting for the board.
b. The research stage:
1. Organizing into groups of 5-6 students
2. Define the purpose and the scope of the team
3. Define the list of rules for the team
4. Design the team board (including the Kanban board)
5. Organise the short meeting at the board
6. Discussing the advantages and disadvantages of the team board
7. Results analysis:
   a. Students will prepare the team board and formulate the purpose and rules for teamwork.
   b. Each team will present the results of their research in an oral presentation.
   c. Teams will discuss and compare their results among teams.
   d. Students will create conclusions regarding the analysis
8. Summary:

Summarising the workshop and reminding of its objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Recommended reading:

Students should prepare a theoretical introduction to the workshop (Lecture Topic 1). Recommended for advanced studies: Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/

7. Additional notes

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8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER’S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

STUDENT INTERNSHIP IN A RESEARCH TEAM

Code: SIRT

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content

Topics 1

1. The subject of the laboratory classes

Week 1 - Introduction to Teamwork and Research Team Structures

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the first week of the module, students have the opportunity to meet with a selected research team operating within the university's structures. This meeting allows them to understand how a professional research team functions and how its work is integrated into the academic and research activities of the university. During the meeting, the research team presents its current projects and achievements, demonstrating how it applies its knowledge and skills to solve real-world problems in materials engineering.

Students gain insight into the team's structure, where key roles mirror those they will assume in their PBL project. This enables them to observe how professional teamwork operates and how the division of roles impacts the effectiveness of research project execution.

The meeting also provides an opportunity to ask questions and discuss the daily challenges researchers face, as well as the organizational methods they use. Students can inquire about the tools and analysis techniques employed, as well as the practical aspects of working on projects funded through various sources, such as grants or industrial collaborations. This is also a chance to understand the role of interdisciplinarity in research and the importance of collaboration between different university units.

This week, students are also introduced to the principles of the PBL methodology and the research problem they will work on over the following weeks. The goal is to understand why the given problem is significant in the context of materials engineering and its practical implications.

3. Learning outcomes

After completing this week, students will be able to:

- Understand how research teams operate, including work organization principles, role and responsibility distribution, task and project management, and the importance of collaboration and communication for research efficiency.
- Apply the principles of professional research teams to their own team dynamics.
- Conduct self-assessment to identify their strengths and areas for development, enabling them to choose an appropriate role within the team.
- Recognize the responsibilities tied to their selected roles and be prepared to carry out assigned tasks.
- Plan a team work schedule by setting milestones and objectives for the upcoming weeks of the project.
- Anticipate potential organizational challenges and establish priorities for actions.

- Collaboratively define communication and progress reporting rules, choosing appropriate channels and meeting frequencies.
- Develop teamwork skills by setting communication standards and adopting effective reporting practices.
- Reflect on their actions, discussing the first week's achievements and challenges with their mentor.
- Accept feedback and identify areas for improvement.

4. Necessary equipment, materials, etc

- A conference room or laboratory where the meeting with the research team can be organized.
- Access to an e-learning platform (e.g., Moodle) or other project management tools (e.g., Trello, Asana) to enable students to plan schedules and manage tasks effectively.
- Multimedia presentation equipment to allow the research team to showcase their projects and technologies.
- Notebooks or tablets for students, providing the ability to take notes and access literature or supplementary materials during the meeting.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Preparation of an introductory meeting

Plan the meeting where you will present the goal, scope, and context of the research problem to the students. Prepare an introductory material that includes:

- A description of the problem, its significance in materials engineering, and its practical context.
- Expectations for the students and the intended learning outcomes.
- Think through key questions to ask students at the end of the meeting to stimulate their critical thinking and deepen their understanding of the project.

Organization of a Meeting with the University's Research Team

- Plan an inspiring meeting between students and an active research team at the university. Coordinate in advance with the research team to ensure they present their projects, working methods, and the challenges they face in their daily operations.
- Share key aspects with the research team that could inspire students (e.g., work organization, role distribution, research tools, collaboration with industry). Such a meeting will help students understand professional standards and the realities of working in a research environment.

Discussion of Roles in the Project Team

- Explain the importance of roles in the context of their project and describe the competencies required for each role.
- Facilitate self-assessment and role selection by asking students about their strengths, organizational skills, and preferences for teamwork.

Support in Establishing a Work Schedule

- Guide students through the planning process, helping them set key milestones and weekly goals.
- Suggest realistic timelines for specific tasks and discuss potential challenges they may encounter during project implementation. Recommend a method for tracking progress (e.g., a shared project management tool).

Establishing Communication and Reporting Rules

- Discuss the importance of effective communication and proper reporting of activities with the team. Propose a format that suits them, such as weekly summaries of each member's work.
- Together, agree on communication channels (e.g., regular online/offline meetings, workgroups in project management apps) and the frequency of meetings for each project stage.

Weekly Individual or Group Review Meeting

- Hold a short meeting at the end of the week to review team progress and address any questions. Analyze the team structure and schedule, ensuring everything is on track for the next steps.
- Encourage reflection on their initial experiences and invite questions about their roles and work organization. Provide preliminary feedback and suggest areas of focus for the following week.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Scientific articles and materials on work organization methods in research teams and examples of research projects in materials engineering.
- Basic introductory materials on PBL methodology and the structure of professional research teams, helping students understand the roles and responsibilities within such teams.
- Guidelines for self-assessment of competencies and strengths to assist students in selecting suitable roles within the team.

7. Additional notes

Encourage students to actively ask questions during the meeting with the research team to fully leverage the opportunity to gain knowledge and inspiration from the professionals' expertise and experiences.

8. Optional information

Consider providing students with a short video or webinar featuring industry professionals discussing the specifics of working in research teams within the industry. This could further complement the knowledge shared by the university's research team and offer a broader perspective.

Topics 2

1. The subject of the laboratory classes

Week 2 - Analysis of the Research Problem and Literature Review as Part of Teamwork in the University Research Group

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the second week of the module, students, working as members of the university research team, focus on an in-depth analysis of the research problem and a comprehensive literature review. The goal is to gain extensive knowledge about existing solutions and technologies and to identify key research challenges. Students analyze scientific articles, industry reports, and other resources to understand previous achievements and development opportunities within the topic.

At the beginning of the week, each student prepares a brief report or presentation based on their literature review to share their findings during a team meeting.

Following the presentations, a brainstorming session is held where the team collaboratively discusses findings and ideas for solving the problem. The aim of the brainstorming session is to generate as many concepts as possible for consideration in the project's next stages. Students discuss potential approaches, identified research gaps, and challenges that may arise during the project's implementation.

At the end of the week, students develop a preliminary plan for further research activities, incorporating the most promising concepts from the brainstorming session and the results of the literature analysis.

3. Learning outcomes

After completing this week, students will be able to:

- Search and analyze literature related to the research problem, identifying key issues and challenges.
- Critically evaluate the credibility and relevance of scientific sources.
- Prepare and present a report or presentation summarizing a literature review at a team meeting.
- Collaborate effectively within a team by sharing information, brainstorming ideas, and generating innovative solutions.
- Identify research gaps and challenges relevant to the project, as well as areas requiring further investigation.
- Develop a research plan that aligns with the project’s needs and leverages available resources.

4. Necessary equipment, materials, etc

- Access to the university's library resources, including electronic databases (e.g., Scopus, Web of Science) for reviewing scientific literature.
- Computers with internet access for each team member, enabling literature search and analysis.
- Project management and team organization tools (e.g., Asana, Trello).
- A conference room or meeting space for team discussions and brainstorming sessions, equipped with a whiteboard or flipchart for noting ideas.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Workshop on Literature Analysis and Critical Thinking

At the beginning of the week, organize a short workshop on critical literature analysis. Explain to students the principles of selecting and evaluating credible sources.

Preparation of a Literature Review Report or Presentation

Each student prepares a brief presentation or report to share during the team meeting, allowing them to present their findings to the group.

Brainstorming Session

After presenting their reports, the team conducts a brainstorming session to generate ideas and concepts for solving the problem. During this session, students record all proposals, which can later be analyzed for feasibility and alignment with the project.

Discussion of Ideas and Selection of Best Concepts

Following the brainstorming session, the team collaboratively analyzes the ideas and selects those that best align with the project's goals. The discussion enables students to evaluate the feasibility and relevance of the proposed solutions.

Mentor Support in Identifying Research Gaps and Planning Activities

The mentor assists students in identifying research gaps and helps formulate a preliminary plan of activities for the upcoming weeks.

Feedback Session and Weekly Summary

At the end of the week, the mentor organizes a feedback session to review the team's progress and provide guidance for planning further research activities.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Scientific articles and industry reports related to research methods in materials engineering and techniques for critical literature analysis.
- Guides on effective brainstorming session organization to help students generate and document ideas efficiently.

- Materials on principles of working in research teams to ensure students understand how to collaborate effectively and share results.

7. Additional notes

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8. Optional information

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Topics 3

1. The subject of the laboratory classes

Week 3 - Practical Approach to Experiments: Planning, Execution, and Analysis of Results

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the third week of the module, students, working as part of the university research team, engage in the practical phase of the project, focusing on conducting planned experiments. Being part of the research team provides them with access to professional methods, equipment, and the support of specialists who act as mentors and guides throughout their activities. Students have the opportunity to not only apply theoretical knowledge in real-world research but also to understand how professional research teams organize experiments and analyze data.

At the beginning of the week, the research team assists students in preparing a detailed experimental plan, discussing key variables, measurement techniques, and research objectives. Each student is assigned a specific role, ensuring efficient collaboration and a clear division of tasks. Under the guidance of specialists, they conduct experiments in accordance with established standards and protocols, systematically documenting their results.

The research team, as a source of mentorship, actively participates in analyzing the results at the end of the week. They help students critically evaluate the collected data, interpret its significance, and verify its alignment with the project's hypotheses. Through collaboration with the research team, students gain experience in data analysis, precise documentation, and assessing the consistency of results with the project objectives. Additionally, they learn the principles of teamwork in a real research environment.

3. Learning outcomes

After completing this week, students will be able to:

- Prepare a detailed experimental plan that aligns with the project requirements and adheres to established research standards.
- Conduct experiments in the laboratory following the guidelines of the research team, utilizing available equipment and resources.
- Document research findings and maintain accurate records of experiments in accordance with the principles used in research teams.
- Perform preliminary analysis of results with the support of the research team, evaluating their alignment with the project's hypotheses.

4. Necessary equipment, materials, etc

- Laboratory equipment tailored to the type of experiments the students will conduct.
- Computers with access to data analysis and documentation software (e.g., Excel, MATLAB, Origin).

- Laboratory notebooks or a digital system for recording experimental results and maintaining documentation in real-time.
- Supporting materials, such as laboratory protocols and instructions.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Preparing an Experimental Plan with the Research Team

At the beginning of the week, students, together with members of the research team, prepare a detailed experimental plan, discussing key variables and research techniques. The research team supports them in aligning the methodology with the project goals and assists in selecting appropriate tools and protocols.

Laboratory Training and Safety Guidelines

The mentor and members of the research team review the safety rules for laboratory work and conduct a brief training session on using specialized equipment.

Conducting Experiments with Mentorship from the Research Team

Under the guidance of the research team, students conduct experiments, receiving support for performing more complex procedures or analyses. This allows them to learn advanced methods and make effective use of available laboratory resources.

Documenting Results According to Research Team Standards

Students document the experimental results in accordance with the requirements of the research team, learning professional standards for maintaining research documentation.

Preliminary Analysis of Results and Consultation with the Research Team

After completing the experiments, students collaborate with the research team to analyze the collected data, enabling joint conclusions and assessing the alignment of results with the project's objectives.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Guides on laboratory procedures and safety rules for working in the lab.
- Students should refer to the literature review they conducted in previous weeks.

7. Additional notes

- Encourage students to systematically document results and observations during experiments in accordance with the research team's requirements, as this will facilitate later analysis and the preparation of the final report.
- Emphasize the importance of precision and reliability in documenting results and interpreting data, highlighting that teamwork requires accountability for the quality of the information provided.

8. Optional information

Topics 4

1. The subject of the laboratory classes

Week 4 - Summary and Analysis of Research Project Results

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In the fourth week of the module, students focus on summarizing and analyzing the results obtained during their experiments. Under the guidance of research team members, students work on preparing a final report that presents the results clearly and in accordance with scientific standards. The work on the final report includes precise documentation of findings, drawing key conclusions, and formulating recommendations for future research.

After completing the report, students prepare a project presentation to deliver to the research team and mentor. This presentation not only summarizes their results and achievements but also develops their skills in scientific communication and professional presentation of their research.

The final meeting with the research team allows students to receive feedback and reflect on the impact of their work on the field of materials engineering.

3. Learning outcomes

After completing this week, students will be able to:

- Analyze and interpret research results, formulating conclusions aligned with the project's objectives and scientific standards.
- Prepare a professional final report, adhering to the principles of scientific data presentation and research documentation.
- Develop communication skills by preparing and delivering a professional presentation of their results.
- Formulate recommendations based on the data obtained and propose directions for future research.
- Gain experience in assessing the significance of project results for advancing research and development in the field of materials engineering.
- Collaborate effectively with the team in preparing the report and presentation, leveraging the expertise of research team members.

4. Necessary equipment, materials, etc

- Computers with access to software for text editing and creating presentations (e.g., Word, PowerPoint, LaTeX).
- Documentation from previous experiments and access to collected research results.
- Software for data visualization and analysis (e.g., Excel, MATLAB, Origin).
- A conference room or project presentation space equipped with multimedia tools.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Analysis of Results and Team Discussion

Students conduct a detailed analysis of the results under the guidance of the research team, discussing their significance and alignment with the project objectives. This discussion encourages critical evaluation of their data and its relevance to the research.

Review of Professional Scientific Reports

Students examine examples of professional scientific reports to understand writing standards, structure, and scientific style. Analyzing these reports helps them align their documentation with professional research requirements.

Preparation of the Final Report with Research Team Support

The research team assists students in preparing the final report, helping them precisely formulate conclusions and present results in accordance with professional scientific standards.

Final Project Presentation and Discussion of Future Research Directions

At the end of the week, students deliver the final version of their presentation, summarizing the project's achievements, presenting results and recommendations, and proposing potential directions for further research in materials engineering.

Reflection and Final Evaluation

To conclude the week, introduce a reflection session where students discuss their experiences related to the project. They can address questions such as:

- What competencies have they developed, and how will these impact their future research activities?
- What did they do well, and what areas need improvement?
- How do they evaluate teamwork and their own communication skills?

This summary, in the form of a written self-evaluation, will help students draw conclusions from the project and identify areas for further development.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Guides on Effective Scientific Presentations – Familiarize students with techniques for communication, content organization, and engaging the audience to ensure that the presentation of results is clear and comprehensible.

7. Additional notes

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8. Optional information

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

DEGRADATION OF MATERIALS IN THE NATURAL ENVIRONMENT

Code: DMNE

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

Introduction to the degradation of materials in the natural environment: Overview of engineering materials, causes of degradation, impact of the natural environment on engineering materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to familiarize the student with the issue of degradation of engineering materials in the natural environment, which refers to the gradual deterioration of properties. The degradation process is an inevitable phenomenon. Therefore, the lecture will discuss the effects of this process, which may lead to loss of functionality and shorten the life of materials. The lecture aims to present and review available engineering materials, such as metals, ceramics, polymers, and composites, along with a discussion of the basic mechanisms of their degradation. Explains concepts related to the degradation of materials and the impact of degradation products on the natural environment. Issues include the assessment of changes in the operational properties of materials resulting from their use and structural changes caused by physical and chemical changes under the influence of long-term environmental factors. The lecture describes the principles of designing devices and structures, including numerical methods that take into account all practical aspects, such as the durability and functionality of materials, focusing especially on the operating conditions in a specific natural environment. Cases of damage caused by degradation processes that led to disasters and disruptions in industries such as energy, chemicals, and refining will also be discussed. These examples illustrate how material degradation can impact various industrial systems' safety and operational efficiency. The lecture will discuss basic environmental factors, such as humidity, temperature, UV radiation, air pollution, as well as salts and electrolytes that accelerate degradation processes. Factors that minimize the degradation of engineering materials will be discussed, such as the selection of appropriate materials, the use of protective coatings, quality controls and regular technical inspections. The impact of proper maintenance and operation of devices on the degradation rate will also be discussed. The lecture aims to deepen understanding of the impact of the environment on materials and the importance of appropriate design and maintenance to ensure their long-term functionality.

3. Learning outcomes

- **Knowledge:** The student will be able to define the degradation processes of engineering materials in the natural environment
- **Comprehension:** The student will be able to describe the factors influencing the degradation processes
- **Application:** The student will be able to select engineering material depending on the environment in which the material will work

- **Analysis:** The student will be able to discuss the impact of the natural environment on engineering materials
- **Synthesis:** The student will be able to reason about the problems of material degradation when designing materials
- **Evaluation:** The student will be able to assess the impact of the natural environment on engineering materials

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

- *Visuals*

When planning the lecture material, it is planned to be presented in the form of slides, diagrams, charts, and mind maps. Such ways of presenting material support learning, especially for students with a pictorial memory type.

- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:
- Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018
- Environmental Degradation of Metals, Chatterjee U.K., Bose S.K., Roy S.K, CRC Press, 2001
-Advances in Ceramics: Characterization, Raw Materials, Processing, Properties, Degradation and Healing, Sikalidis C., In Tech, 2011.

6. Additional notes

The topics will be covered in one lecture

Topics 2

1. The subject of the lecture

Degradation of metallic materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture focuses on a deep analysis of the causes and effects of the degradation of metallic materials, especially in the context of their destruction by electrochemical and corrosion processes in various natural environments. During the lecture, the critical factors of the degradation processes of metallic materials, such as temperature, humidity, and the presence of aggressive chemicals, will be discussed. The lecture focuses on chemical and electrochemical processes that are responsible for the breakdown of the metallic structure in the natural environment. The lecture will also highlight the importance of various environments, such as soil, air, and water, as factors influencing the rate and mechanism of metal degradation. For example, soil can be an aggressive environment due to the variability of its chemical composition, acidity and resistivity. Geographic differences that may significantly affect metal degradation processes will be presented and discussed. It will also show how metals are degraded in the air, especially in coastal areas, and what destructive processes occur under the influence of various types of water, such as rainwater, sewage, and water supply. Additionally, the lecture will present other factors that may lead to the degradation of metals, such as irregularities in the material itself, the presence of contaminants on the surface and errors during the production of the metallic material. Through these detailed analyses and examples, lecture participants will have a more complete picture of the complexity of metal degradation processes and their impact on the natural environment through chemical and electrochemical processes and indirectly through negative consequences for infrastructure and human health. It will be determined how metal degradation products affect ground and surface waters and the impact of heavy metals on toxicity to aquatic ecosystems.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the mechanisms and effects of metal degradation.
- **Comprehension:** The student will be able to indicate technological problems related to the degradation of metals.
- **Application:** The student will be able to select metallic materials depending on the environment in which the material will be used.
- **Analysis:** The student will be able to determine the degree of degradation depending on the metallic material used.
- **Synthesis:** The student will be able to discuss the mechanisms of metal degradation in the natural environment.
- **Evaluation:** The student will be able to describe the destructive effects of the natural environment on metallic materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

- *Visuals*

When planning the lecture material, it is planned to be presented in the form of slides, diagrams, charts, and mind maps. Such ways of presenting material support learning, especially for students with a pictorial memory type.

- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018
- Environmental Degradation of Metals, Chatterjee U.K., Bose S.K., Roy S.K, CRC Press, 2001
- Advances in Ceramics: Characterization, Raw Materials, Processing, Properties, Degradation and Healing, Sikalidis C., In Tech, 2011.

6. Additional notes

The topics will be covered in one lecture.

Topics 3

1. The subject of the lecture

Degradation of ceramic materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic of the lecture concerns the degradation of engineering materials from the group of ceramic materials and focuses on degradation mechanisms based on dissolution. Key thermodynamic and kinetic processes that determine the rate of degradation in the natural environment will be discussed. During the lecture, ceramics will be divided into groups according to their resistance to degradation, taking into account the purity of the material, crystallographic structure, and grain size. Individual ceramic degradation environments resulting from factors such as the presence of salt will be presented. Degradation factors that have a particularly significant impact on the strength of the material in atmospheric conditions, such as moisture, solar radiation, rainfall, and changes in air pressure and movement, will be discussed.

The lecture highlights the role of ceramics as an engineering material supporting sustainable development. Ceramics have a low impact on the natural environment and are recyclable, which is essential from both an ecological and economic point of view. Current research on the degradation of ceramics will be presented, which aims not only to improve its durability but also to minimize the negative impact on the environment. During the lecture, the impact of ceramic degradation processes on human health will be discussed, as ceramics may contain toxic substances or heavy metals that can enter the food chain and affect the health of humans and animals. Presenting these aspects of the lecture allows participants to understand the complexity of the issue of the degradation of ceramic materials and their importance for sustainable technological development and environmental protection. Optimization of production processes and modern technologies can contribute to reducing degradation and better use of the potential of ceramics in various fields of engineering and industry.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the mechanisms and effects of degradation of ceramic materials.
- **Comprehension:** The student will be able to identify technological problems related to the degradation of ceramics.
- **Application:** The student will be able to select appropriate ceramic materials depending on the natural environment in which the material will be used.
- **Analysis:** The student will be able to determine the degradation products of ceramics that depend on the natural environment.
- **Synthesis:** The student will be able to discuss the mechanisms of degradation of ceramics under the influence of environmental factors.
- **Evaluation:** The student will be able to describe the destructive effects of the natural environment on ceramic materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

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- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.
2. Advances in Ceramics: Characterization, Raw Materials, Processing, Properties, Degradation and Healing, Sikalidis C., In Tech, 2011.
3. Plactics in the Environment, Gomiero A., In Tech, 2019.

6. Additional notes

The topics will be covered in one lecture

Topics 4

1. The subject of the lecture

Degradation of polymeric materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic of the lecture focuses on the problem of degradation of polymeric materials, which constitute a significant part of sea and ocean pollution. The lecture will discuss various degradation mechanisms, such as depolymerization, degradation, and destruction, as well as the factors influencing these processes. Factors influencing degradation processes will be discussed, such as chemical factors, including acids, bases, and gases, and physical factors, such as temperature and UV radiation, which accelerate the degradation and decomposition processes of polymers. The lecture will discuss the areas of application of the degradation of polymer materials, as well as examples of problems resulting from their degradation in the energy industry, automotive industry, and everyday use. Particular emphasis is placed on the impact of polymer degradation on the natural environment, such as tap water, seas and oceans, and air quality. The lecture also discusses current trends in the production of polymer materials, which are aimed at minimizing the negative impact of polymer decomposition products on the environment. The latest research on new technologies enabling the biodegradation of polymers or their recycling to reduce the amount of waste and pollution will be presented. During the lecture, the benefits of polymer degradation, such as their use for purifying tap water, will be presented. This approach not only reduces the problem of pollution but also uses polymer waste in an environmentally beneficial way. Through such analyses and examples, lecture participants are familiarized with the complex challenge of polymer degradation and ways to effectively manage this problem in the context of sustainable development.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the mechanisms and effects of degradation of polymeric materials.
- **Comprehension:** The student will be able to indicate the problems and benefits resulting from the impact of the environment on polymers.
- **Application:** The student will be able to properly select polymer materials depending on the natural environment in which the material will be used.
- **Analysis:** The student will be able to determine polymer degradation products that depend on the natural environment.
- **Synthesis**: The student will be able to indicate individual mechanisms of degradation of polymer materials under the influence of environmental factors.
- **Evaluation:** The student will be able to describe the effects of polymer degradation on environmental sustainability.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

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- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.
2. Plactics in the Environment, Gomiero A., In Tech, 2019.
3. „Electrochemistry for Materials Science", W. Plieth, Elsevier, 2008

6. Additional notes

The topics will be covered in one lecture

Topics 5

1. The subject of the lecture

Degradation of composite materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic of the lecture concerns the degradation of engineering materials from the group of composites, materials consisting of several phases with different properties. Areas in which composite materials are used, such as the energy industry, construction, and heating, will be discussed. The topic of the lecture focuses on the degradation processes of one of the most popular materials, concrete, under the influence of natural environmental factors, such as acid rain, temperature, and biological factors. The loss of protective properties of the concrete reinforcement cover due to the ingress of atmospheric gases, carbonation processes, and atmospheric precipitation will be discussed. The lecture will also present the impact of concrete degradation on flora and fauna. The degradation processes of glass wool will be discussed, including changes in properties under the influence of environmental factors. The lecture will also discuss the degradation of laminates due to osmotic mechanisms. The latest composite materials that are resistant to degradation in difficult environmental conditions and the environmental benefits resulting from their use will be presented. Innovative technologies and composite materials will be presented to minimize the negative effects of degradation and improve the durability of structures. The lecture will emphasize the importance of modern composites in reducing infrastructure maintenance costs and their positive impact on the natural environment. The aim of the lecture is to comprehensively present the issues of composite degradation and methods of preventing its effects, which is crucial for materials engineering and environmental protection. Participants will gain a full understanding of degradation processes and practical solutions that can be applied in various industries.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the mechanisms and effects of degradation of composite materials.
- **Comprehension:** The student will be able to indicate the effects of degradation of composite materials in the natural environment.
- **Application:** The student will be able to select appropriate composite materials to minimize the impact of the natural environment on degradation processes.
- **Analysis:** The student will be able to determine the degradation products of composites in the natural environment.
- **Synthesis:** The student will be able to indicate individual mechanisms of degradation of composite materials under environmental factors.
- **Evaluation:** The student will be able to describe the effects of composite degradation on environmental sustainability

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

- *Visuals*

When planning the lecture material, it is planned to be presented in the form of slides, diagrams, charts, and mind maps. Such ways of presenting material support learning, especially for students with a pictorial memory type.

- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.
1. „Electrochemistry at the Nanoscale“,P. Schmuki, S. Virtanen, Springer, 2009.
2. „Electrochemistry for Materials Science”, W. Plieth, Elsevier, 2008

6. Additional notes

The topics will be covered in one lecture

Topics 6

1. The subject of the lecture

Methods of preventing degradation of engineering materials in the natural environment

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture topic concerns the degradation of engineering materials from the group of composites, materials consisting of several phases with different properties. Areas in which composite materials are used, such as the energy industry, construction, and heating, will be discussed. The topic of the lecture focuses on the degradation processes of one of the most popular materials, concrete, under the influence of natural environmental factors, such as acid rain, temperature, and biological factors. The loss of protective properties of the concrete reinforcement cover due to the ingress of atmospheric gases, carbonation processes, and atmospheric precipitation will be discussed. The lecture will also present the impact of concrete degradation on flora and fauna. The degradation processes of glass wool will be addressed, including changes in properties under the influence of environmental factors. The lecture will also discuss the degradation of laminates due to osmotic mechanisms. The latest composite materials that are resistant to degradation in challenging environmental conditions and the environmental benefits resulting from their use will be presented. Innovative technologies and composite materials will be presented to minimize the negative effects of degradation and improve the durability of structures. The lecture will emphasize the importance of modern composites in reducing infrastructure maintenance costs and their positive impact on the natural environment. The aim of the lecture is to comprehensively present the issues of composite degradation and methods of preventing its effects, which is crucial for materials engineering and environmental protection. Participants will gain a full understanding of degradation processes and practical solutions that can be applied in various industries.

3. Learning outcomes

- **Knowledge:** The student will be able to determine ways to prevent the degradation of engineering materials in the natural environment.
- **Comprehension:** The student will be able to identify ways to protect materials against degradation of engineering materials in the natural environment.
- **Application:** The student will be able to properly select the method of protecting engineering materials in order to reduce the rate of degradation processes.
- **Analysis:** The student will be able to determine the impact of protective coatings on the degradation products of materials and their effects on the natural environment.
- **Synthesis:** The student will be able to indicate individual ways of protecting engineering materials against the destructive effects of degradation under the influence of environmental factors.

- **Evaluation:** The student will be able to describe the effects of the use of protective coatings and material additives on material degradation processes and their impact on environmental sustainability.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

The main part is a presentation of new material. This part will be a series of mini-lectures, each focusing on a given problem. The organization of the lecture will include deduction based on the theory of phenomena, induction or phenomena, testing of hypotheses, analysis of the problem to be solved, the effect of a given trial, and a debate on how a given problem can be solved. The main part based on mini-lectures will be diversified to take into account different learning styles.

It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

- *Visuals*

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- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.
2. „Electrochemistry at the Nanoscale“,P. Schmuki, S. Virtanen, Springer, 2009.
3. „Electrochemistry for Materials Science”, W. Plieth, Elsevier, 2008

6. Additional notes

The topics will be covered in one lecture

Topics 7

1. The subject of the lecture

Procedures, norms and standards for testing material degradation processes in the natural environment

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic of the lecture concerns procedures and standards determining the susceptibility of engineering materials to degradation in the natural environment. Research methods and requirements for various engineering materials will be presented. The ISO 9227 standard will be discussed, which defines procedures for testing the durability of engineering materials and assessing the effectiveness of protective and paint coatings. This standard describes how to perform tests that simulate real environmental conditions, allowing for a realistic assessment of durability and corrosion resistance. The ASTM D2457-21 standard, which is used to assess the gloss of protective coatings, will also be discussed. Gloss can be an indicator of the quality and durability of a coating, and its assessment helps identify surface defects that affect protective properties. The lecture will also discuss the ISO 17556 standard regarding the degradation of plastics, natural and synthetic polymers, and materials with additives, such as plasticizers or dyes. Assessing these processes is crucial to understanding the long-term behavior of materials and their impact on the environment. The lecture discusses the ISO 14001 standard, which specifies the requirements for an effective environmental management system. It emphasizes the effective use of material degradation products, waste reduction, and increased environmental protection efficiency. The standard helps organizations minimize the negative impact of their activities on the environment through systematic environmental management. The ISO 10993 standard regarding the degradation of ceramics, especially chemical dissociation during in vitro tests, will be presented. These guidelines are important for understanding the response of ceramic engineering materials in contact with various chemical environments, crucial for applications in medicine and technology. To sum up, the lecture discusses a comprehensive approach to assessing the susceptibility of engineering materials to degradation, presenting key standards and test procedures. The ISO 9227, ASTM D2457-21, ISO 17556, ISO 14001, and ISO 10993 standards provide tools for assessing the durability of materials and the effectiveness of protective coatings, which is crucial for their long-term and effective use in various applications.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the standards used to determine and test methods for engineering materials degradable in the natural environment.
- **Comprehension:** The student will be able to refer to the ISO control standard in order to minimize the effects of degradation of engineering materials in the natural environment.
- **Application:** The student will be able to properly select the procedures used in ISO standards in order to properly select the method of protection of engineering

materials and to perform accelerated in vivo tests of degradation processes in an environment imitating the conditions of the materials' working environment.

- **Analysis:** The student will demonstrate knowledge of ISO standards regarding the degradation of individual engineering materials.
- **Synthesis:** The student will be able to identify ISO standards dedicated to particular groups of materials, defining procedures for testing degrading materials in the natural environment.
- **Evaluation:** The student will be able to apply the ISO standard depending on the tested engineering materials.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Interactive lecture:

The lecture will include classic lecture content based on taking notes. It will also be based on an interactive part consisting of a conversation about specific material cases and a discussion about the problems discussed.

The internal organization of lecture:

The lecture will consist of an introduction, body, and conclusion.

The introduction to the lecture consists of three parts: (1) an introduction to defining the purpose of the course, (2) a statement regarding the material covered in the previous classes, and (3) new material.

The lecture is intended to attract the listener's attention with topics illustrating the latest scientific reports and demonstrations of interesting phenomena referring to current events in the subject of the lecture.

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It also draws attention to the new terms we are introducing. Students still need to take notes because the process of note-taking has benefits for learning and retention. Additionally, teaching aids will be used, such as:

- *Visuals*

When planning the lecture material, it is planned to be presented in the form of slides, diagrams, charts, and mind maps. Such ways of presenting material support learning, especially for students with a pictorial memory type.

- *Examples*

Examples will be used to illustrate the concept discussed. The examples will refer to real examples of everyday life and those that students have encountered in their lives. This method of teaching will allow you to better remember the content discussed. Students to remember them.

- *Restatements*

During the lecture, key and important points of the lecture will be repeated in scientific and lay language so that each student has a chance to understand the topic. The use of scientific vocabulary will also expand students' vocabulary.

The lecture ends with a short summary specifying the most important points of the lecture. The summary will be conducted by both the instructor and the students. In the case of students, the presented form of summary is oral.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. ISO 9227:2022 Corrosion test in artificial atmospheres – Salt spray tests
2. Standard Test Method for Specular Gloss of Plastic Films and Solid Plastics
3. ISO 17556:2019 Plastics – Determination of the ultimate aerobic biodegradability od plastic materials In soil by measurig the oxygen dem and In a respirometer Or the Mount od carbon dioxide evolved
4. ISO 14001:2015 - Environmental management systems

6. Additional notes

The topics will be covered in one lecture

Course content – laboratory classes

Topics 1 – Lab 1

1. The subject of the laboratory classes

Degradation of engineering materials in the aquatic environment

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory is to investigate the influence of the aquatic environment on the degradation of various engineering materials, such as metals, ceramics, polymers, and composites. This study will determine how various parameters of the aquatic environment, including temperature, pH, and chemical composition of the solution, affect the durability and degree of degradation of these materials. Based on the conducted research, it will be possible to determine which materials are most resistant to degradation in various conditions of the aquatic environment. These results can be used to select appropriate materials for applications in aquatic environments, such as in the chemical, marine or water supply industries. The microscopic observations carried out will provide detailed information on degradation mechanisms, which will allow for a better understanding of the processes occurring in materials and their interactions with the aquatic environment.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the impact of the aquatic environment on the degradation processes of engineering materials.
- **Comprehension:** The student will be able to explain the result of the experiment.
- **Application:** The student will be able to use the knowledge of material degradation processes in the aquatic environment in specific situations.
- **Analysis:** The student will be able to determine the degree of degradation of metals, polymers, ceramics and composites in an aqueous environment.
- **Synthesis:** The student will be able to perform tests to assess the degradation rate of engineering materials in an aquatic environment.
- **Evaluation:** The student will be able to evaluate the quality of engineering materials working in an aquatic environment.

4. Necessary equipment, materials, etc

- Equipment: pH meter, conductometer, analytical balance, laboratory dryer
- Laboratory glassware: plastic containers
- Samples of stainless steel, ceramics, polymer balls and concrete
- samples of tap water, distilled water and fresh water from nearby water reservoirs
- Metallographic microscope

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students perform laboratory exercises in small groups of a maximum of 4 people in the laboratory. The exercises are conducted by the instructor.

Case method: Students use knowledge from the lecture to analyze the problem implemented during laboratory exercises. Students start a conversation about the analyzed problem.

Project-based learning: Students, individually or in groups, create a report on the completed laboratory exercise.

Scheme of laboratory classes:

1. Introduction

— Presentation of occupational health and safety (OHS) rules in a chemical laboratory. Each student is obliged to sign the Occupational Health and Safety Rules for working in the laboratory.

— Introduction to the subject of the laboratory exercise.

— A short test is checking students' preparation for the topic of a given exercise based on the content covered during the lecture. The questions will concern the theoretical part of a given laboratory exercise.

— Presentation of the stages of the exercise, the goal, and the expected results of the exercise.

— Dividing students into groups and assigning workstations to each group, along with outlining the scope of work.

3. The course of the exercise

— Presentation of the operating instructions for measuring devices along with their calibration.

— Performing a series of experiments on laboratory exercises:

Perform a microscopic assessment of metals, ceramics, polymers, and composites in their initial state.

- Determine the pH and conductivity of individual waters.
- Weigh the samples on an analytical scale of individual engineering materials with an accuracy of 4 decimal places.
- Leave a container with distilled water as a control sample.
- Immerse the tested samples in water samples and place them in a laboratory dryer heated to 60°C.

  - After 30 minutes, remove the tested sample from the dryer and bring it to ambient temperature.
  - Measure the pH and conductivity of individual samples.
  - Repeat the tests for immersion times of 60 minutes and 90 minutes.
  - Weigh the engineering material samples after 90 minutes of immersion in the test waters.
  - Perform a microscopic assessment of individual engineering materials.
  - Present in the table changes in pH and conductivity of the tested waters and changes in the mass of the tested engineering materials.
- Explanation of the impact of tap and fresh water constituting the natural environment on the degradation processes of basic engineering materials.
- The leader monitors the progress of student groups' work and provides necessary assistance. The leader serves as a mentor, supporting teams in developing a research plan and report and identifying any errors.

3. Data analysis and interpretation
- A group of students analyzes and prepares tables or charts and reports as appropriate.
- The instructor leads a discussion about the results obtained and helps students interpret the results obtained during the laboratory exercise. The instructor tries to ensure interactivity in classes in order to acquire knowledge more effectively.

4. Summary and Conclusions
- Group discussion about the results obtained and conclusions drawn from the laboratory exercise.
- Comparison of experimental results with theoretical results or those reported in ISO standards.
- Discussion of the connections between theory and practice and the significance of the results of material degradation in the natural environment.

5. Work organization and completion
- The instructor gives tips on organizing the workstation for a given laboratory exercise and the correct use of laboratory equipment and chemical reagents.
- At the end of the laboratory exercise. The instructor reminds students about the next date of laboratory classes.

6. Preparing a report
- The instructor discusses the requirements and rules for assessing the report created by students after completing the laboratory exercise.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.

7. Additional notes

- The topics will be covered within one laboratory class
- ASSESSMENT

The following will be assessed:

- substantive preparation (20%)
- ability to properly plan and conduct a laboratory exercise (20%)
- ability to observe, analyze results and draw appropriate conclusions (20%)
- activity during classes (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 2 – Lab 2

1. The subject of the laboratory classes

Analysis of degradation products in the natural environment using stripping voltammetry

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory exercise aims to become familiar with the analysis of degradation products of materials working in the aquatic environment. The analysis will be performed using electrochemical methods, such as stripping voltammetry. During the exercise, samples of tap and groundwater will be tested to identify degradation products of engineering materials. The exercise will enable you to determine the amount of ions and other substances in the tested samples, which are products of the degradation of engineering materials in the aquatic environment. Based on the data obtained, it will be possible to determine the degree of degradation of engineering materials in the aquatic environment, identify the materials most exposed to degradation and the environmental conditions that accelerate this process, as well as compare ion concentrations in tap and groundwater, which may provide information about local differences in the degree degradation of materials. The laboratory will provide practical knowledge of electrochemical methods, enabling a thorough analysis of water samples for the presence of degradation products of engineering materials. The data obtained will provide valuable information on both degradation mechanisms and the quality of the aquatic environment.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the degradation products of engineering materials present in groundwater and tap water.
- **Comprehension:** The student will be able to explain the result of the experiment.
- **Application:** The student will be able to use the knowledge of material degradation products to assess the impact of its products on the surrounding environment.
- **Analysis:** The student will be able to determine the degree of degradation of materials based on the resulting degradation products.
- **Synthesis:** The student will be able to analyze the degradation products of materials using electrochemical methods.
- **Evaluation:** The student will be able to assess the quality of engineering materials based on their degradation products.

4. Necessary equipment, materials, etc

- Electrodes: working carbon or platinum (10 x 10 x 2 mm), reference electrode, auxiliary electrode in the form of a platinum wire
- Apparatus: electrochemical testing kit, magnetic stirrer
- Laboratory glassware: electrochemical vessel, baguettes, beakers
- Electrolytes for cleaning electrodes

- Water samples and cation standards, chemical reagents - KNO_3
- Argon cylinder

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students perform laboratory exercises in small groups of a maximum of 4 people in the laboratory. The exercises are conducted by the instructor.

Case method: Students use knowledge from the lecture to analyze the problem implemented during laboratory exercises. Students start a conversation about the analyzed problem.

Project-based learning: Students, individually or in groups, create a report on the completed laboratory exercise

Lab course outline:

Scheme of laboratory classes:

1. Introduction
    - Introduction to the subject of the laboratory exercise.
    - A short test checking students' preparation for the topic of a given exercise based on the content covered during the lecture. The questions will concern the theoretical part of a given laboratory exercise.
    - Presentation of the stages of the exercise, the goal and the expected results of the exercise.
    - Division of students into groups and assignment of workstations to each group along with an outline of the scope of work.

2. The course of the exercise
    - Presentation of the operating instructions for measuring devices along with their calibration.
    - Performing a series of experiments on laboratory exercises:
        - Rinse the electrodes and electrochemical cell with distilled water and acetone.
        - Prepare samples of the tested water and 0.1M KNO_3 solution.
        - Place the vessel and electrodes on the analyzer stand.
        - Pour 1 ml of the collected water sample and 10 ml of 0.1 M KNO_3 into the container.
        - Start the electrochemical test kit software control program.

- Record the voltammetric curve as instructed by the instructor.
- Save the obtained curve to a file with the .csv extension.
- Perform the measurement three times for each tested sample.
- Perform a quantitative analysis of the tested ion in the sample by adding 10 ml of a 1mM standard of the selected cation to the analyzed sample.
- Vent the test solution with argon using gas flow for 10 minutes to remove air bubbles from the solution.
- Record 3 voltammograms for each standard.
- After performing the measurements, determine the calibration curve based on which the concentration of the tested cations in the tested water samples will be determined.

— Determination of the amount of catins present in water as a result of the degradation of engineering materials.

— The leader monitors the progress of student groups' work and provides necessary assistance. The leader serves as a mentor, supporting teams in developing a research plan and report and identifying any errors.

3. Data analysis and interpretation

— A group of students analyzes and prepares tables or charts and reports as appropriate.

— The instructor leads a discussion about the results obtained and helps students interpret the results obtained during the laboratory exercise. The instructor tries to ensure interactivity in classes in order to acquire knowledge more effectively.

4. Summary and conclusions

— Group discussion about the results obtained and conclusions drawn from the laboratory exercise.

— Comparison of experimental results with theoretical data.

— Discussion of the significance of the results obtained.

5. Organization of work and completion

— The instructor gives tips on organizing the workstation for a given laboratory exercise and the correct use of laboratory equipment and chemical reagents.

— At the end of the laboratory exercise. The instructor reminds students about the next date of laboratory classes.

6. Preparation of the report

— The instructor discusses the requirements and rules for assessing the report created by students after completing the laboratory exercise.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

1. J. Wang, Analytical electrochemistry, 2nd ed. New York: John Wiley; 2000 2.
2. P. Zanello, Inorganic electrochemistry: Theory, practice and application, The Royal Society of Chemistry; 2003

7. Additional notes

- The topics will be covered within one laboratory class
- ASSESSMENT

The following will be assessed:
- substantive preparation (20%)
- ability to properly plan and conduct a laboratory exercise (20%)
- ability to observe, analyze results and draw appropriate conclusions (20%)
- activity during classes (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 3 – Lab 3

1. The subject of the laboratory classes

Electrochemical protection – material selection depends on the working environment

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The laboratory will cover the voltage series of metals and will focus on the experimental investigation of their chemical activity and their potential applications for electrochemical protection. During the exercises, students will conduct a series of experiments to assess how various metals react with water, oxidizing and non-oxidizing acids, and how they displace each other from salt solutions. The theoretical part will be presented, introducing students to the subject of the laboratory and the principles of electrochemical protection. The laboratory will present students with the reactions of various metals with water and acids, observing the evolution of gases and color changes that indicate the progress of the reaction. Additionally, they check whether a given metal can displace another of its salts, which allows for the determination of the order of metals in the voltage series and the selection of metals for the conditions in which the material operates. The laboratory will allow you to characterize metals depending on their chemical activity and indicate practical applications of the results, such as methods of protecting pipelines or ship hulls. The lab ends with a summary that highlights the importance of understanding the chemical properties of metals in the context of their durability and the effectiveness of electrochemical protection methods in various environments.

3. Learning outcomes

- **Knowledge:** The student will be able to determine the chemical nature of individual metals.
- **Comprehension:** The student will be able to assign a material to a specific arrangement in an electrochemical series.
- **Application:** The student will be able to use the knowledge of the arrangement of metals in the electrochemical series to determine their behavior in the natural environment.
- **Analysis:** The student will be able to select metals depending on the natural environment in order to minimize the risk of their degradation.
- **Synthesis:** The student will be able to determine the chemical properties of metals and electrochemical protection methods.
- **Evaluation:** The student will be able to practically apply the obtained results, e.g. in the construction industry.

4. Necessary equipment, materials, etc

- Metals: magnesium chips and aluminum, zinc, iron and copper sheets,
- Laboratory glassware: test tubes, baguettes
- Solutions in the form of aqueous solutions of 1M $CuSO_4$, $FeSO_4$, HCl

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students perform laboratory exercises in small groups of a maximum of 4 people in the laboratory. The exercises are conducted by the instructor.

Case method: Students use knowledge from the lecture to analyze the problem implemented during laboratory exercises. Students start a conversation about the analyzed problem.

Project-based learning: Students, individually or in groups, create a report on the completed laboratory exercise.

Course of laboratory classes

1. Introduction
   - Introduction to the subject of the laboratory exercise.
   - A short test checking students' preparation for the topic of a given exercise based on the content covered during the lecture. The questions will concern the theoretical part of a given laboratory exercise.
   - Presentation of the stages of the exercise, the goal and the expected results of the exercise.
   - Dividing students into groups and assigning workstations to each group, along with outlining the scope of work.

2. The course of the exercise
   - Presentation of reagent sets and samples used during exercises.
   - Performing a series of reactions consistent with the topic of laboratory exercises:
     - Wash and dry the glass tubes.
     - Pour 1 cm^3 of 1M $CuSO_4$ solution into five test tubes, and then place the tested metal in each test tube - Mg, Al, Zn, Fe, Cu - in the solution.
     - Observe the occurring phenomena and write down the reaction equations.
     - Pour 1 cm^3 of 1M $FeSO_4$ solution into five test tubes, and then place the tested metal in each test tube - Mg, Al, Zn, Fe, Cu - in the solution.
     - Observe the occurring phenomena and write down the reaction equations.

- The leader monitors the progress of student groups' work and provides necessary assistance. The leader serves as a mentor, supporting teams in developing a research plan and report and identifying any errors.

3. Data analysis and interpretation
   - A group of students analyze and prepare reaction equations and reports accordingly.
   - The instructor leads a discussion about the results obtained and helps students interpret the results obtained during the laboratory exercise. The instructor tries to ensure interactivity in classes in order to acquire knowledge more effectively.

4. Summary and conclusions
   - Group discussion about the results obtained and conclusions drawn from the laboratory exercise.
   - Discussion of the significance of the obtained results.

5. Organization of work and completion
   - The instructor gives tips on organizing the workstation for a given laboratory exercise and the correct use of chemical reagents.
   - At the end of the laboratory exercise. The instructor reminds students about the next date of laboratory classes.

6. Preparation of the report
   - The instructor discusses the requirements and rules for assessing the report created by students after completing the laboratory exercise

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

1. P. Schmuki, S. Virtanen, „Electrochemistry at the Nanoscale“, Springer, 2009
1. W. Plieth, „Electrochemistry for Materials Science”, Elsevier, 2008
3. A. Eftekhari, „Nanostructured Materials in Electrochemistry”, Wiley-VCH, Weinheim, 2008

7. Additional notes

The topics will be covered in one laboratory classes

8. Optional information

Exercise instruction will be available

Topics 4 – Lab 4

1. The subject of the laboratory classes

Chemical nickel plating

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The aim of the laboratory exercises is to familiarize students with the processes of chemical protection of metals through electroless autocatalytic nickel plating. During classes, students will learn about one of the most popular methods of protecting materials from degradation. Students will learn the role of chemical reactors in nickel plating processes. During the laboratory, the thickness of the nickel layer obtained at different times of immersion of the samples will be tested. The layer thickness is important for the effectiveness of corrosion protection, so its accurate determination is crucial. Additionally, students will assess the quality of nickel coatings using microscopic observation, which will allow them to examine the uniformity of the surface. The tightness of the coating is an important factor affecting the durability of cathodic protection of metals in aggressive corrosive environments. The laboratory exercises will allow students to understand the mechanisms of electroless autocatalytic nickel plating as a method of metal protection. The acquired knowledge will have practical application in designing corrosion protection for metal structures operating in extreme environmental conditions. The laboratory will end with an analysis of the results, a summary, and a discussion on the importance of cathodic protection of metals for their durability and functionality in various industrial and technological applications.

3. Learning outcomes

- **Knowledge:** The student will be able to select appropriate parameters to protect metals in nickel plating processes.
- **Comprehension:** The student will be able to select appropriate chemical protection depending on the natural environment in which the material will work.
- **Application:** The student will be able to use the knowledge of chemical protection of metals to control its practical and visual properties.
- **Analysis:** The student will be able to select the appropriate bath for the nickel plating process to minimize the risk of degradation processes.
- **Synthesis:** The student will be able to determine the chemical properties of the obtained coating and chemical protection methods.
- **Evaluation:** The student will be able to practically apply the obtained results in places where it is necessary to protect metals against degradation.

4. Necessary equipment, materials, etc

- Necessary equipment: analytical balance, metallographic microscope, thermostat
- Samples of steel and aluminum sheets
- Chemical reagents: NiCl2•6H_2O, NH_4Cl, NaH^2PO•H^2O, sodium citrate
- Laboratory glassware: laboratory beaker, glass baguette
- Acetone,
- sandpaper

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students perform laboratory exercises in small groups of a maximum of 4 people in the laboratory. The exercises are conducted by the instructor.

Case method: Students use knowledge from the lecture to analyze the problem implemented during laboratory exercises. Students start a conversation about the analyzed problem.

Project-based learning: Students, individually or in groups, create a report on the completed laboratory exercise.

Scheme of laboratory classes:

1. Introduction
   - Introduction to the subject of the laboratory exercise.
   - A short test checking students' preparation for the topic of a given exercise based on the content covered during the lecture. The questions will concern the theoretical part of a given laboratory exercise.
   - Presentation of the stages of the exercise, the goal and the expected results of the exercise.
   - Dividing students into groups and assigning workstations to each group, along with outlining the scope of work.

2. The course of the exercise
   - Presentation of reagent sets and samples used during exercises.
   - Perform the exercise in the order:
     - Clean the steel and aluminum sheet samples with sandpaper and mark them with the code provided by the instructor.
     - Determine the geometric surface of each sample.

- Degrease metal samples and weigh them on an analytical scale with an accuracy of 4 decimal places.
- Prepare a nickel plating bath using the chemical reagents provided by the instructor.
- Immerse steel and aluminum samples in a nickel plating bath heated to 95°C.
- Keep the samples in the bath for 15, 30, 45 and 60 minutes.
- After drying, weigh the sample on an analytical balance and calculate the thickness of the obtained coating according to the formula determined by the instructor.
- Carry out microscopic observations of the obtained coatings

— The leader monitors the progress of student groups' work and provides necessary assistance. The leader serves as a mentor, supporting teams in developing a research plan and report and identifying any errors.

3. Data analysis and interpretation

— A group of students analyze and prepare charts and reports accordingly.

— The instructor leads a discussion about the results obtained and helps students interpret the results obtained during the laboratory exercise. The instructor tries to ensure interactivity in classes in order to acquire knowledge more effectively.

4. Summary and conclusions

— Group discussion about the results obtained and conclusions drawn from the laboratory exercise.

— Discussion of the significance of the obtained results.

5. Organization of work and completion

— The instructor gives tips on organizing the workstation for a given laboratory exercise and the correct use of chemical reagents.

— At the end of the laboratory exercise. The instructor reminds students about the next date of laboratory classes.

6. Preparation of the report

— The instructor discusses the requirements and rules for assessing the report created by students after completing the laboratory exercise

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

1. W. Nohse, "The investigation of electroplating and related solutions with the aid of the hull cell", Robert Draper Ltd., Teddington, England, 1966, pp. 17-25
2. R. Dargis, "The hull cell: key to better electroplating: how to use it for planning, preventive maintenance and troubleshooting", Products Finishing, Contributing Editor from Products Finishing Editorial Advisory Panel, 11/2005

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT

They will be assessed:
- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

Topics 5 – Lab 5

1. The subject of the laboratory classes

Aluminum oxidation

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

The presented laboratory exercise aims to modify the aluminum surface by obtaining oxide coatings in the anodizing process in various acids, such as sulfuric, nitric, and phosphoric acid. The anodizing process carried out during classes enables the controlled formation of oxide layers, mainly $Al2O3$, on the aluminum surface. After obtaining the oxide layers, students will carry out the dyeing process. The presented dyeing process allows for a visual assessment of the quality of the obtained anodic $Al2O3$ coatings and control of the uniformity of their color. If leaks are detected in the layers, students will be familiarized with the process of sealing the coating, which aims to improve its durability and resistance. During the exercise, the quality of the obtained coating, its uniformity, and evenness of color will be assessed. Additionally, a scratch test will be carried out to determine the adhesion of the coating to the substrate, which is important for assessing its operational and mechanical durability. The laboratory exercise will allow students to gain practical knowledge of aluminum anodizing and coating coloring processes, as well as experience in assessing and improving the quality of the obtained oxide coatings.

3. Learning outcomes

- **Knowledge:** The student will be able to select appropriate parameters to protect metals in anodizing processes.
- **Comprehension:** The student will be able to select appropriate conditions for the anodizing process in order to obtain an oxide layer depending on the natural environment in which the material will work.
- **Application:** The student will be able to use the knowledge of metal protection methods to control its practical and visual properties.
- **Analysis:** The student will be able to select the appropriate bath and conditions in the anodizing process so that the resulting oxide layer minimizes the risk of degradation processes.
- **Synthesis:** The student will be able to determine the physical properties of the obtained coating and methods of electrochemical protection.
- **Evaluation:** The student will be able to practically apply the obtained results in places where it is necessary to protect metals against degradation.

4. Necessary equipment, materials, etc

- Lead electrode, sandpaper, aluminum, diamond knife
- Apparatus: power supply, thermostat, magnetic stirrer
- Laboratory glassware: glass beakers, glass rods
- Chemical reagents: NaOH, H_2SO_4, HNO_3, Na_2CO_3, anhydrous trisodium phosphate, methyl orange, $KMnO_4$

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Teaching methods used:

Group work: Students perform laboratory exercises in small groups of a maximum of 4 people in the laboratory. The exercises are conducted by the instructor.

Case method: Students use knowledge from the lecture to analyze the problem implemented during laboratory exercises. Students start a conversation about the analyzed problem.

Project-based learning: Students, individually or in groups, create a report on the completed laboratory exercise

Scheme of laboratory classes:

1. Introduction
    - Introduction to the subject of the laboratory exercise.
    - A short test checking students' preparation for the topic of a given exercise based on the content covered during the lecture. The questions will concern the theoretical part of a given laboratory exercise.
    - Presentation of the stages of the exercise, the goal and the expected results of the exercise.
    - Dividing students into groups and assigning workstations to each group, along with outlining the scope of work.

2. The course of the exercise
    - Presentation of the reagent sets and samples used during the exercises.
    - Perform the exercise in the order:
        - Clean aluminum sheet samples with sandpaper.
        - Measure the working surface of the aluminum sheet.
        - Etch the polished aluminum sheets in an aqueous NaOH solution at 40°C and 3 minutes.

- Brighten metal samples using the electrochemical method in a solution of Na_2CO_3, anhydrous trisodium phosphate at a temperature of 85°C under the current and time conditions specified by the Instructor.
- Carry out the oxidation process in sulfuric acid at room temperature and under the current and time conditions specified by the Instructor.
- Determine the thickness of the obtained oxide coating.
- Color the oxide coating with organic and inorganic dyes for 30 minutes and at 35°C
- Seal the obtained coating by keeping the samples in hot distilled water for 30 minutes.
- Carry out microscopic observations of the obtained coatings.
- Perform a scratch test on the obtained coatings to assess the adhesion of the coating to the substrate.

— The leader monitors the progress of student groups' work and provides necessary assistance. The leader serves as a mentor, supporting teams in developing a research plan and report and identifying any errors.

3. Data analysis and interpretation

— A group of students analyze and prepare charts and reports accordingly.

— The instructor leads a discussion about the results obtained and helps students interpret the results obtained during the laboratory exercise. The instructor tries to ensure interactivity in classes in order to acquire knowledge more effectively.

4. Summary and conclusions

— Group discussion about the results obtained and conclusions drawn from the laboratory exercise.

— Discussion of the significance of the results obtained.

5. Organization of work and completion

— The instructor gives tips on organizing the workstation for a given laboratory exercise and the correct use of chemical reagents.

— At the end of the laboratory exercise. The instructor reminds students about the next date of laboratory classes.

6. Preparation of the report

— The instructor discusses the requirements and rules for assessing the report created by students after completing the laboratory exercise

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts to prepare a theoretical introduction to the laboratory classes:

1. Totten G.E., MacKenzie D.S., *Handbook of aluminum*, Marcel Dekker Inc., New York, 2003
2. Eftekhari A., *Nanostructured materials in electrochemistry*, Wiley-VCH, Weinheim, 2008

7. Additional notes

- The topics will be covered in one laboratory classes
- ASSESSMENT

They will be assessed:

- substantive preparation (20%)
- the ability to properly plan and execute an experiment (20%)
- the ability to observe, analyze the results and draw appropriate conclusions (20%)
- activity (20%)
- ability to work in a group (20%)

Grading scale according to the table included in the Syllabus:

96 - 100 points = A
91 - 95 points = B+
86 - 90 points = B
80 - 85 points = C+
71 - 80 points = C
66 - 70 points = D+
61 - 65 points = D
0 - 60 points = F

8. Optional information

Exercise instruction will be available

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MASTER'S THESIS REALIZATION MODULE

Code: MTRM

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content

Topics 1

1. The subject of the laboratory classes

Selection of a research topic and creative approaches to its formulation

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

At the beginning of the course, students are introduced to the structure, objectives, and assessment criteria of the subject. The instructors present the schedule and main stages of implementing a research project, emphasizing students' independence and creativity. This course continues the process initiated during the first semester of the master's program, during which students preliminarily declared their areas of research interest. Based on these declarations, and with the support of mentors selected from among the academic staff, students developed an individual educational path by selecting courses that support the realization of their future projects.

The current stage focuses on refining these initial declarations and transforming them into specific research topics. Students participate in brainstorming sessions and group discussions, which help them identify precise areas of their academic interests. Individual consultations with supervisors are also a key component, aimed at refining research ideas and selecting the most promising topic. Each student is required to submit a preliminary research proposal, which includes a description of the chosen topic, initial research questions, and project objectives. These proposals will be assessed by supervisors, who will provide detailed feedback and potential recommendations for further project development.

The selection of an appropriate research topic is a crucial step that impacts the subsequent progress and quality of the final master's project. This approach ensures continuity and coherence in the educational process, enabling students to deeply engage with practical applications of their knowledge and smoothly transition from general interests to a specific research topic.

3. Learning outcomes

- The student is able to independently identify their academic interests and select an appropriate research topic using creative thinking techniques, such as brainstorming and individual reflection.
- The student can prepare a preliminary research proposal, including formulating initial research questions and project objectives, while adhering to formal and methodological requirements.
- The student demonstrates effective communication skills with supervisors, presenting their ideas clearly and incorporating received feedback into their work.
- The student possesses the ability to critically analyze and refine their research ideas using available literature sources.

- The student shows readiness for independent and responsible decision-making regarding the selection of a research topic, as well as the planning and execution of a research project.
- The student can collaborate effectively with other students and supervisors, actively participating in interactive group sessions and individual consultations.
- The student is capable of critically evaluating their own actions and implementing necessary adjustments based on received feedback.

4. Necessary equipment, materials, etc

- Software for managing and organizing literature (e.g., EndNote, Zotero, Mendeley).
- Access to digital libraries and databases (e.g., JSTOR, ScienceDirect, PubMed).
- Project management software (e.g., Trello, Asana) for planning and tracking research progress.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Introduction to the Course

Objective: Introduce students to the general framework of the course, objectives, schedule, and assessment criteria.

Content: Presentation covering the course structure, stages of project implementation, expected outcomes, and guidelines for collaboration with supervisors.

Methods: Lecture by the course coordinator, Q&A sessions, interactive discussion.

Selection of a Research Topic

Objective: Assist students in identifying their academic interests and making an initial selection of a research topic.

Content: Workshops and brainstorming sessions focused on generating research ideas. Presentation of sample topics and research areas.

Methods: Interactive group sessions, brainstorming, individual reflection, pair work.

Consultations with Supervisors

Objective: Refine research ideas and select the most promising topic.

Content: Individual meetings with potential supervisors to discuss initial ideas, receive **guidance**, and obtain recommendations.

Methods: Individual consultations, supervisor feedback, analysis of potential topics.

Preparation of a Preliminary Research Proposal

Objective: Develop a preliminary research proposal as a foundation for further actions.

Content: Individual work on preparing a document that includes a description of the chosen topic, initial research questions, and project objectives.

Methods: Independent work, support from supervisors, use of available literature sources.

Evaluation and Feedback

Objective: Assess preliminary research proposals and provide detailed guidance and recommendations.

Content: Student presentations of their preliminary research proposals, supervisor evaluation, discussion of strengths and areas for improvement.

Methods: Oral presentations, written feedback from supervisors, Q&A sessions.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Leedy, P. D., & Ormrod, J. E. (2019). *Practical Research: Planning and Design* (12th ed.). Pearson.
- Creswell, J. W., & Creswell, J. D. (2018). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications.
- Hart, C. (2018). Doing a Literature Review: Releasing the Research Imagination. SAGE Publications.

7. Additional notes

It is important for students to thoroughly document their meetings with supervisors and any feedback received. Maintaining a research journal can be helpful in tracking progress and organizing work effectively.

8. Optional information

The estimated time for completing this stage is approximately 2 weeks. Students should dedicate this time to thoroughly familiarize themselves with the course requirements, select a research topic, consult with supervisors, and prepare a preliminary research proposal.

Topics 2

1. The subject of the laboratory classes

Structure and Writing of a Master’s Thesis

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In this stage, students become familiar with the structure and principles of writing a master's thesis. The goal of this stage is to prepare students to create a cohesive and logical thesis that presents the results of their research in a clear and professional manner. Students will learn how to effectively organize content, apply the appropriate academic style, and avoid common mistakes. An important aspect of this stage is also learning how to properly format the thesis and use citations and references in accordance with accepted academic standards.

3. Learning outcomes

- The student possesses advanced knowledge about the structure and components of a master's thesis.
- The student understands the principles of writing and formatting academic texts.
- The student is capable of critically evaluating their own work and making necessary revisions based on received feedback.

4. Necessary equipment, materials, etc

- A computer with text editing software (e.g., Microsoft Word, LaTeX)
- Access to bibliography management tools (e.g., EndNote, Zotero)
- Guides on formatting and citation styles (e.g., APA, MLA, Chicago, etc.)
- Sample master's theses for analysis

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Introduction to the Structure of a Master's Thesis:

Objective: Familiarize students with the typical structure of a master's thesis and formal requirements.

Content: Discussion of elements such as the title page, table of contents, introduction, literature review, research methods, results, discussion, conclusions, and bibliography.

Methods: Lecture, presentation of examples, group discussion.

Writing the Introduction and Literature Review:

Objective: Teach students how to prepare an introduction and literature review, which form the foundation of a master's thesis.

Content: Techniques for writing an engaging introduction, conducting a literature review, structuring information, and critically analyzing sources.

Methods: Writing workshops, analysis of examples, practical exercises.

Research Methods and Results:

Objective: Assist students in presenting research methods and results clearly and transparently.

Content: Describing research procedures, presenting results using tables, charts, and diagrams, and interpreting data.

Methods: Lectures, workshops, practical exercises.

Discussion and Conclusions:

Objective: Teach students how to interpret research results and formulate conclusions.

Content: Techniques for analyzing and interpreting results, creating logical and coherent arguments, and drawing conclusions based on collected data.

Methods: Writing workshops, example analysis, group discussions.

Formatting and Citation:

Objective: Ensure students can properly format their master's thesis and apply citation principles.

Content: Rules for text formatting, creating tables of contents, tables, and graphs; citation styles (APA, MLA, Chicago); creating a bibliography.

Methods: Practical workshops, online tutorials, individual consultations.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Jones, M. P. (2022). *Master's/Ph.D. Thesis: A Step-by-Step Writing Guide*. Scientific Writing for Beginners. Mitchell P. Jones. ISBN: 9780645165470.

Reeves, S., & Buczkowski, B. (2023). *Mastering Your Dissertation: The Answers to Your Questions on Bachelor's, Master's and Project Theses*. Springer Cham. ISBN 978-3-031-41910-2.

7. Additional notes

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8. Optional information

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Topics 3

1.	**The subject of the laboratory classes**
	Literature Review and Research Plan

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

At this stage, students conduct a detailed literature review related to their chosen research topic. The purpose of the literature review is to identify existing studies, determine research gaps, and formulate clear research questions that will form the basis for further work. Students are required to critically analyze academic sources, identifying key theories, models, and research findings in the context of their topic.

Based on the gathered knowledge, they develop a preliminary research plan, which should include the research objective, research questions, hypotheses, and a general outline of the methodology. An important aspect of this stage is also creating a work schedule to facilitate effective time and resource management during the project's execution.

The literature review and research plan are key documents that must be approved by supervisors before progressing to the next stages. Final versions of both documents must be submitted, and their positive evaluation is a prerequisite for starting the actual research activities.

3. Learning outcomes

- The student possesses advanced knowledge of literature review techniques and critical analysis of academic sources.
- The student can independently conduct a literature review using available databases and library resources.
- The student is able to critically analyze academic literature, identifying key theories, models, and research findings.
- The student can develop a preliminary research plan, define objectives, formulate research questions, hypotheses, and outline a methodology.
- The student is capable of creating a research work schedule and effectively managing time.
- The student demonstrates readiness for independent and responsible scientific research.
- The student is capable of critically evaluating their work and making necessary revisions based on received feedback.

4. Necessary equipment, materials, etc

- Programs for managing and organizing literature (e.g., EndNote, Zotero, Mendeley).
- Access to digital libraries and databases (e.g., JSTOR, ScienceDirect, PubMed).
- Project management software (e.g., Trello, Asana) for planning and monitoring research progress.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Introduction to the Literature Review

Objective: To introduce students to literature review techniques and methods for searching and analyzing academic sources.

Content: A presentation covering the steps of conducting a literature review, using databases and library resources, critical reading, and evaluating literature.

Methods: Lecture, practical workshops, demonstrations of using search tools.

Critical Analysis of the Literature

Objective: To teach students the skills necessary for critically analyzing academic literature.

Content: Students learn to identify key theories, models, and research findings, as well as assess the quality and relevance of sources.

Methods: Analysis of sample articles, group discussions, individual work.

Identifying Research Gaps and Formulating Research Questions

Objective: To assist students in identifying areas requiring further research and formulating clear and precise research questions.

Content: Workshops focused on analyzing the collected literature, identifying gaps, and developing research questions.

Methods: Interactive group sessions, consultations with supervisors, individual work.

Developing a Preliminary Research Plan

Objective: To create a preliminary research plan that serves as a roadmap for subsequent research activities.

Content: Students define the research objectives, formulate research questions, hypotheses, and an outline of the methodology, including data collection and analysis methods.

Methods: Individual work, consultations with supervisors, peer feedback.

Creating a Work Schedule

Objective: To help students manage time and resources effectively during the research project.

Content: Students create a detailed work schedule covering all stages of the research project.

Methods: Planning workshops, individual work, consultations with supervisors.

Evaluation and Approval of Literature Review and Research Plan

Objective: To evaluate the prepared documents by supervisors and gain approval before proceeding to subsequent research stages.

Content: Presentation of the prepared literature reviews and research plans, evaluation by supervisors, discussions, and incorporation of any necessary revisions.

Methods: Oral presentations, written evaluation, Q&A sessions, individual consultations.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Leedy, P. D., & Ormrod, J. E. (2019). *Practical Research: Planning and Design* (12th ed.). Pearson.
- Creswell, J. W., & Creswell, J. D. (2018). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications.
- Hart, C. (2018). Doing a Literature Review: Releasing the Research Imagination. SAGE Publications.

7. Additional notes

The estimated time for completing this stage is approximately 3-4 weeks. Students should allocate this time to thoroughly review the literature, develop a preliminary research plan, and prepare a work schedule.

8. Optional information

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Topics 4

1. The subject of the laboratory classes

Research Methodology

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

In this part of the module, students will explore various research methodologies that can be applied to their projects. The theoretical sessions include an overview of qualitative and quantitative methods, data collection techniques, and statistical analysis. The aim of this stage is to equip students with the necessary knowledge and skills to conduct independent research.

Students are required to select the most appropriate research methods and analytical tools to address their research questions. To ensure their chosen approach is suitable and feasible, they conduct detailed consultations with their supervisors. Additionally, students prepare a detailed methodological plan, which includes a description of the selected methods, data collection procedures, and a data analysis plan. This document is crucial for the progress of their research and must be approved by their supervisor.

The final version of the methodology should be submitted by the end of the sixth week of the course. During this time, students also begin organizing materials and tools necessary for conducting empirical research.

3. Learning outcomes

- The student possesses advanced knowledge of research methodology and various data collection and analysis techniques.
- The student understands the importance of selecting appropriate research methods in the context of executing a research project.
- The student can independently select suitable research methods for their project.
- The student demonstrates readiness for independent and responsible scientific research.
- The student is capable of creating a research schedule and effectively managing time and resources during the project execution.
- The student is capable of critically evaluating their work and making necessary revisions based on received feedback.

4. Necessary equipment, materials, etc

- A computer or laptop with internet access
- Programs for managing and organizing literature (e.g., EndNote, Zotero, Mendeley)
- Tools for quantitative data analysis (e.g., Excel)
- Software for statistical analysis (e.g., Statistica)

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Introduction to Research Methodology:

Objective: To introduce students to various research methodologies and their application in technical sciences.

Content: Overview of qualitative methods (interviews, observations, content analysis), quantitative methods (surveys, experiments, statistical analysis), and mixed methods.

Methods: Lectures, presentations, case studies.

Data Collection Techniques:

Objective: To teach students various data collection techniques appropriate for their research projects.

Content: Practical aspects of data collection, such as preparing questionnaires, conducting interviews, and gathering experimental data.

Methods: Practical workshops, demonstrations, group exercises.

Statistical Analysis and Analytical Tools:

Objective: To equip students with data analysis skills using statistical tools.

Content: Introduction to statistical software (e.g., SPSS, R), data analysis techniques (regression, analysis of variance, statistical tests).

Methods: Computer-based workshops, practical exercises, data analysis tasks.

Consultations with Supervisors:

Objective: To refine selected research methods and analytical tools and ensure the methodological plan aligns with project objectives.

Content: Individual meetings with supervisors to discuss selected methods, receive feedback, and obtain recommendations.

Methods: Individual consultations, supervisor feedback, analysis, and discussions.

Developing a Detailed Methodological Plan:

Objective: To formulate a detailed methodological plan that will serve as the foundation for conducting research.

Content: Description of selected methods, data collection procedures, data analysis plan, and research timeline.

Methods: Individual work, consultations with supervisors, peer reviews.

Approval of the Methodological Plan:

Objective: To obtain supervisor approval for the detailed methodological plan.

Content: Presentation of the prepared methodological plan, evaluation by supervisors, and implementation of any necessary revisions.

Methods: Oral presentations, written evaluations, Q&A sessions, individual consultations.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- Leedy, P. D., & Ormrod, J. E. (2019). *Practical Research: Planning and Design* (12th ed.). Pearson.
- Creswell, J. W., & Creswell, J. D. (2018). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications.
- Hart, C. (2018). Doing a Literature Review: Releasing the Research Imagination. SAGE Publications.

7. Additional notes

Studenci powinni dokładnie przestrzegać ustalonego harmonogramu i terminów. Wczesne rozpoczęcie pracy nad wyborem metod badawczych i przygotowaniem planu metodologicznego jest kluczowe dla uniknięcia opóźnień w dalszych etapach projektu.

8. Optional information

Topics 5

1. The subject of the laboratory classes

Training in Laboratory Equipment Operation and Safety

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

At this stage, students undergo practical training in laboratory equipment operation and safety protocols. The goal of this training is to ensure that students are fully prepared to conduct research in the laboratory safely and efficiently. The sessions include demonstrations and hands-on exercises where students learn to use various laboratory devices and tools. Additionally, they participate in sessions covering health and safety regulations (HSE) to minimize risks associated with working in a laboratory environment.

This training is mandatory before beginning any research activities in the laboratory and is tailored to the equipment students will use in their research. Upon completion of the training, students are required to pass a test demonstrating their skills and knowledge of safety rules. Only after achieving a satisfactory result can they proceed with independent laboratory work.

This training ensures that students can conduct their research professionally and safely, which is crucial for the quality and reliability of their results.

3. Learning outcomes

- The student knows and understands health and safety regulations in the laboratory.
- The student possesses knowledge of operating basic and advanced laboratory equipment.
- The student can apply health and safety rules in laboratory practice.
- The student is able to carry out emergency procedures and use personal protective equipment.
- The student demonstrates responsibility for their actions in the laboratory and adheres to safety regulations.
- The student can collaborate with other members of the laboratory team, ensuring collective safety and work efficiency.

4. Necessary equipment, materials, etc

Equipment and materials may vary depending on the research project being conducted. Students should consult with their supervisors to ensure they have access to all the resources necessary for their specific research.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Course Outline

Introduction to Safety Principles:

Objective: To familiarize students with fundamental safety principles in the laboratory.

Content: Overview of general safety rules, emergency procedures, use of personal protective equipment (PPE), and protocols for handling accidents and equipment malfunctions.

Methods: Lecture, multimedia presentations, case studies.

Operation of Laboratory Equipment:

Objective: To teach students the safe and efficient use of basic laboratory equipment.

Content: Demonstrations and practical exercises in using devices such as microscopes, automatic pipettes, spectrometers, chromatographs, centrifuges, and other specialized equipment.

Methods: Practical workshops, demonstrations, individual and group exercises.

Health and Safety Training:

Objective: To ensure students understand and adhere to health and safety regulations in the laboratory.

Content: Overview of safety procedures, proper use of personal protective equipment, handling hazardous substances, and maintaining cleanliness and order in the laboratory.

Methods: Lectures, workshops, demonstrations, practical exercises.

Tests and Certification:

Objective: To assess students' knowledge and skills in laboratory equipment operation and safety principles.

Content: Theoretical and practical tests, evaluation of practical skills, certification of completion of health and safety and equipment operation training.

Methods: Written tests, practical tests, instructor evaluations.

Preparation for Research Work:

Objective: To ensure students are fully prepared to begin independent research work in the laboratory.

Content: Discussion of specific requirements for equipment and procedures for individual research projects, consultations with supervisors and instructors.

Methods: Individual and group meetings, consultations, Q&A sessions.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

- It is recommended that students begin by familiarizing themselves with the general health and safety regulations.

- Next, students should review equipment manuals, safety procedures, and laboratory protocols.
- Regular meetings with instructors and laboratory technicians can help improve understanding of procedures and equipment operation guidelines.

7. Additional notes

Students should maintain a journal or notes documenting their progress and feedback received, which will facilitate subsequent stages of their research work.

8. Optional information

The estimated time for completing this stage is approximately 2 weeks. Students should dedicate this time to thoroughly familiarize themselves with safety regulations and the operation of laboratory equipment.

Topics 6

1. The subject of the laboratory classes

Conducting Experimental Research

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

At this stage, students begin conducting their research projects by performing experimental studies in accordance with the previously developed methodological plan. The goal of this stage is to collect data that will serve as the basis for analysis and conclusions in the subsequent phases of their work. Students are required to strictly adhere to the established procedures and safety regulations.

While conducting experiments, students must demonstrate technical skills and the ability to solve problems that may arise during the research. Data collection is carried out using various methods and tools that were previously selected and described in the methodological plan. All activities must be thoroughly documented to ensure that experiments can be replicated and results verified by other researchers.

During this stage, students are also responsible for analyzing preliminary results, allowing them to evaluate progress and make necessary adjustments to the research procedures. Regular consultations with supervisors provide valuable guidance and advice that can be crucial for the research's further progress. Supervisors can also assist in interpreting preliminary data and suggest additional experiments or modifications to existing procedures.

The ultimate goal of this stage is to gather complete, reliable, and credible data that will serve as a solid foundation for further analysis and conclusions in the final phase of the research project.

3. Learning outcomes

- The student possesses advanced knowledge of conducting experimental research.
- The student understands the importance of accurately documenting the research process.
- The student can conduct experiments in accordance with the developed plan.
- The student is capable of monitoring research progress and making necessary adjustments.
- The student can accurately document the research process, maintain a laboratory journal, and prepare research reports.
- The student demonstrates responsibility for their actions in the laboratory and adheres to safety regulations.
- The student can collaborate with supervisors and research team members, effectively participating in group sessions and individual consultations.
- The student is capable of critically evaluating their work and implementing necessary improvements based on received feedback.

4. Necessary equipment, materials, etc

Equipment and materials may vary depending on the research project being conducted.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Course Progression:

Introduction to Experimental Research:

Objective: Ensure students are prepared to conduct research in accordance with the methodological plan.

Content: Review of key methodological elements, data collection principles, and the importance of accurately documenting the research process.

Methods: Lecture, discussion, case analysis.

Conducting Experiments in the Laboratory:

Objective: Collect empirical data according to the developed plan.

Content: Conducting experiments under laboratory conditions, monitoring research progress, and recording observations.

Methods: Individual and group work, practical exercises, experiments.

Documenting the Research Process:

Objective: Ensure all activities are accurately documented to allow for analysis and reproduction of results.

Content: Maintaining a laboratory journal, recording results, documenting procedures, and noting deviations from the plan.

Methods: Detailed note-taking, photographic documentation, video recording.

Consultations with Supervisors:

Objective: Obtain feedback and introduce any necessary corrections to the research process.

Content: Regular meetings with supervisors to discuss research progress, analyze problems, and implement required changes.

Methods: Individual consultations, group meetings, Q&A sessions.

Monitoring Progress:

Objective: Track research progress and evaluate adherence to the schedule.

Content: Regular evaluation of progress, identification of potential delays and issues, and implementation of corrective measures.

Methods: Laboratory journal analysis, progress reporting, control meetings.

Preparing a Laboratory Progress Report:

Objective: Present collected data, initial conclusions, and an analysis of data quality.

Content: Descriptions of conducted experiments, applied methods, obtained results, encountered challenges, and their resolutions, along with critical data analysis.

Methods: Individual work, consultations with supervisors, peer reviews.

Evaluation of the Report by Supervisors:

Objective: Receive detailed feedback and recommendations for further actions.

Content: Evaluation of the report, supervisors' comments and recommendations, and planning the next stages of research.

Methods: Written evaluation, Q&A sessions, individual consultations.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

The selection of literature should be tailored to the specificity and requirements of the students' individual research projects. During the earlier literature review, students identified key academic sources, books, and articles related to their research topics. At this stage, they should continue using these materials while also consulting with their supervisors to identify additional sources that may be essential for a deeper understanding and successful execution of their experiments. Supervisors may suggest new publications, studies, or textbooks that are particularly relevant to the specific research project.

7. Additional notes

Experimental research may require adjustments to the methodology in response to unforeseen results or challenges. Students should be prepared to make changes to their research plans, always in consultation with their supervisors.

8. Optional information

Students should regularly consult with their supervisors to receive support and guidance on the next steps. Openness to feedback and readiness to implement necessary corrections are key to the project's success. At the conclusion of the experimental research stage, students should conduct a critical assessment of the collected data and the research process. Reflecting on the conducted studies will aid in preparing for data analysis and writing the final report.

Topics 7

1. The subject of the laboratory classes

Preparing a Laboratory Progress Report

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

Students prepare a detailed laboratory progress report, presenting the collected data and initial conclusions. This report should include precise descriptions of the experiments conducted, the methods applied, and the results obtained. Students should also address any challenges encountered and the solutions implemented to overcome them.

A critical analysis of the quality of the collected data and an assessment of its relevance for further research are essential components of the report. The laboratory progress report is evaluated by supervisors, who provide detailed feedback and recommendations for future actions.

This is a key moment for students to gain valuable insights and improve their research approach. The final progress report must be submitted by the deadline specified by the supervisor. The evaluation of the report serves as the basis for continuing the research and progressing to subsequent stages of the project.

3. Learning outcomes

- The student can prepare a detailed laboratory progress report.
- The student is able to critically analyze collected data and assess its relevance for further research.
- The student can incorporate supervisors' feedback and recommendations.
- The student demonstrates responsibility for the quality of their work and attention to detail in research documentation.
- The student can prepare and deliver a presentation of research findings in a clear and understandable manner.
- The student is capable of critically evaluating their work and implementing necessary improvements based on received feedback.

4. Necessary equipment, materials, etc

A computer with appropriate software

- Software for managing literature
- Access to scientific databases
- Programs for data analysis and statistical computations
- Software for data visualization
- Tools for creating presentations

Equipment and materials may vary depending on the specifics of the research project. Students should consult with their supervisors to ensure they have access to all necessary resources and tools required for conducting the statistical analysis of their research.

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Course Progression:

Preparing the Progress Report:

Objective: To present the research findings and experiments conducted so far.

Content: Detailed descriptions of experiments, applied methods, obtained results, and encountered challenges with solutions.

Methods: Report writing, data analysis, documenting processes.

Critical Data Analysis:

Objective: To assess the quality of collected data and its relevance for further research.

Content: Critical analysis of results, evaluation of data accuracy and reliability, identification of potential errors and deviations.

Methods: Statistical analysis, data verification, discussion of findings.

Consultations with Supervisors:

Objective: To receive feedback and recommendations on the report and further research activities.

Content: Presentation of the report to supervisors, discussion of feedback, and consideration of possible revisions and changes.

Methods: Individual consultations, Q&A sessions, group meetings.

Introducing Revisions and Finalizing the Report:

Objective: To incorporate supervisors' feedback and finalize the progress report.

Content: Updating the report based on feedback, finalizing the document, and preparing it for submission.

Methods: Writing, editing, consultations with supervisors.

Evaluation of the Progress Report:

Objective: Formal evaluation of the report by supervisors, serving as a basis for continuing the research.

Content: Assessment of the report's content, quality of data analysis, precision of experiment descriptions, and applied methods.

Methods: Written evaluation, feedback from supervisors, individual meetings.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students should acquire basic principles of data analysis, including statistical methods and data visualization techniques.
It is recommended that students familiarize themselves with guides on writing scientific reports and documenting research findings.

7. Additional notes

It is recommended that students regularly consult with instructors and supervisors to receive guidance on the structure and content of the report.

8. Optional information

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Topics 8

1. The subject of the laboratory classes

Preparing a Master's Thesis

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

At this stage, students focus on preparing the complete draft of their master's thesis. The goal is to compile all sections of the thesis into a cohesive and logical document that effectively presents the research findings and analyses. Students will work on editing and organizing the content, ensuring appropriate structure and clarity of argumentation.

An essential part of this process includes proper formatting, using appropriate citation styles, and preparing the final version of the bibliography. During this stage, students must compile all previously written sections of the thesis, such as the introduction, literature review, methodology, results, discussion, and conclusions, into a unified document.

Editing the content involves improving the coherence of the text, eliminating redundancies, and filling in any missing information. Students should also focus on the clarity and logical arrangement of the thesis to ensure it is understandable for the reader.

Formatting the thesis according to the university’s guidelines and academic standards is crucial. This includes correctly formatting title pages, tables of contents, tables, graphs, footnotes, and the bibliography. Students must also ensure that all citations and references adhere to the chosen citation style, such as APA, MLA, or Chicago.

During this phase, students will regularly consult with their supervisors to receive feedback and make necessary revisions. Supervisors can assist in evaluating the structure of the thesis, the clarity of argumentation, and the quality of the analyses. Final reviews and revisions are critical to ensuring that the thesis meets all formal and academic requirements.

The ultimate goal of this stage is to produce a complete, professionally edited, and formatted master's thesis, ready for submission and defense.

3. Learning outcomes

- The student understands the principles of writing and formatting academic texts.
- The student is able to conduct a critical analysis of the literature and present research findings in a clear and logical manner.
- The student can apply citation rules and create a bibliography in accordance with accepted academic standards.
- The student is capable of critically evaluating their work and making necessary revisions based on received feedback.

4. Necessary equipment, materials, etc

- Reliable computer with text editing and formatting software
- Citation software (e.g., EndNote, Zotero, Mendeley).
- University library access and databases (e.g., JSTOR, ScienceDirect).

- Thesis formatting guidelines and citation style manuals
- Cloud storage or external drives for backups and platforms for feedback (e.g., Google Docs, OneDrive).

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Course Progression:

Compilation of Thesis Sections:

Objective: To gather and organize all parts of the master's thesis into a cohesive document.

Content: Compilation of the introduction, literature review, methodology, results, discussion, and conclusions.

Methods: Individual work, analysis, and integration of text fragments.

Content Editing and Organization:

Objective: To ensure a logical and clear structure of the master's thesis.

Content: Editing the text, improving argument coherence, eliminating redundancies, and filling in missing information.

Methods: Individual work, consultations with supervisors, and editorial workshops.

Thesis Formatting:

Objective: To format the text correctly in line with university and academic standards.

Content: Formatting title pages, tables of contents, tables, graphs, footnotes, and the bibliography.

Methods: Individual work, consultations with supervisors.

Applying Citation Styles:

Objective: To ensure all citations and references comply with the chosen style (APA, MLA, Chicago, etc.).

Content: Reviewing and correcting citations, formatting the bibliography, verifying compliance with the selected style.

Methods: Individual work, use of reference management tools (e.g., EndNote, Zotero), consultations with supervisors.

Final Review and Revisions:

Objective: To conduct a final review of the thesis and implement any necessary corrections before submission.

Content: Verifying compliance with formal requirements, correcting language and content errors, final editing.

Methods: Individual work, consultations with supervisors, Q&A sessions.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Turabian, K. L. (2018). *A Manual for Writers of Research Papers, Theses, and Dissertations.* University of Chicago Press.

7. Additional notes

It is recommended that students regularly consult with their supervisors and academic advisors to receive guidance on writing and organizing their thesis.

8. Optional information

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Topics 9

1. The subject of the laboratory classes

Preparing for the Master's Thesis Defense

2. Thematic scope of the laboratory classes (abstract, maximum 500 words)

During the workshop, participants learn how to present the key aspects of their master's thesis in a clear, concise, and convincing manner. This includes not only showcasing research findings and analyses but also effectively explaining the applied research methods and the significance of the conclusions within the context of existing knowledge in the field. An essential element of the workshop is also learning effective communication with the examination committee.

Students practice how to respond to questions and address concerns, as well as how to defend their arguments based on reliable evidence and logical reasoning. These activities build confidence and enhance students' argumentative skills.

The workshop places significant emphasis on practical exercises, such as defense simulations and Q&A sessions. These activities allow participants to experience realistic conditions of presenting under pressure, providing invaluable preparation for the actual defense. These simulations teach students how to remain calm and focused, even in stressful situations.

3. Learning outcomes

- The student has an in-depth understanding of advanced techniques for presenting scientific research results, including strategies for effective oral and written communication.
- The student possesses knowledge of methods for coping with stress and pressure during presentations and the defense of a master's thesis.
- The student can clearly, coherently, and convincingly present key aspects of their master's thesis, adapting the form and content of the presentation.
- The student is able to communicate effectively with the examination committee, responding to questions and concerns and defending arguments based on reliable evidence and logical reasoning.
- The student can critically assess their strengths and weaknesses in the context of presentations and thesis defense and identify areas requiring further development.
- The student is open to receiving constructive criticism and using it to improve presentation and communication skills.
- The student is committed to further developing their competencies in presenting and defending scientific work, recognizing the importance of these skills for their future academic or professional career.

4. Necessary equipment, materials, etc

- A computer with presentation software (e.g., Microsoft PowerPoint, Prezi, Google Slides)
- Multimedia projector and screen for displaying presentations
- Laser pointer or remote control for slide navigation
- Flipchart or whiteboard for noting key points during discussions and brainstorming
- Video camera for recording simulated presentations for later analysis and evaluation
- Printed materials with key tips and exercises for participants
- A room with appropriate lighting, sound system, and seating arrangement conducive to interaction and collaboration

5. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

- Workshops on presentation skills focusing on speech structure, body language, voice modulation, and eye contact.
- Thesis defense simulations where peers and instructors act as the committee, allowing realistic practice of the defense.
- Q&A sessions where students practice answering challenging questions in a safe environment.
- Presentation reviews with detailed feedback to iteratively improve and refine the presentation.

Part 1: Introduction and Preparation

Content:

Brief introduction by the facilitator, explaining the goals and structure of the workshop.

Discussion of strategies for effective time management during presentations.

Introduction to stress management techniques to help maintain composure during presentations and Q&A sessions.

Methods:

Presentation skills workshops focusing on speech structure, body language, voice modulation, and eye contact.

Interactive lecture by the facilitator presenting stress management techniques.

Part 2: Simulations and Practice

Content:

Each student delivers a simulated presentation of their thesis excerpt before a "committee" consisting of peers and the facilitator.

Thesis defense simulations where peers and instructors act as the committee, providing a realistic defense rehearsal.

Methods:

Each presentation is timed to ensure adherence to the time limit.

Students receive immediate feedback after each simulation, focusing on improving presentation skills and handling challenging questions.

Part 3: Feedback and Skill Development

Content:

Presentation reviews with detailed feedback to iteratively improve and refine presentations.

Practical exercises for managing stress that students can apply during the defense.

Methods:

Group discussion where participants share insights and strategies for overcoming difficulties encountered during simulations.

Summary and Conclusion

Content:

Summary of key lessons from the workshop, emphasizing stress management techniques and effectively answering challenging questions.

Motivational conclusion encouraging students to continue refining their presentations.

Methods:

A short closing speech by the facilitator, highlighting participants' progress and their readiness for upcoming challenges.

6. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Knapek, E. (2020). The Art of Presentation in Science: How to Effectively Present Research. Publishing PWN.

Alley, M. (2018). The Craft of Scientific Presentations: Critical Steps to Succeed and Critical Errors to Avoid. Springer.

7. Additional notes

Students should prepare visual presentations that support their oral delivery while ensuring the content focuses on the key points of their work.

8. Optional information

The presentation should not exceed 30 minutes to allow sufficient time for the Q&A session. The defense should also include a segment where students can share their thoughts on future research directions or potential applications of their work's results.

Course Topics and Details

Weeks / Topics	Scope	Activities	Notes
1-2: Introduction and Topic Selection	Familiarizing students with the structure, goals, and evaluation criteria of the course. Brainstorming and group discussions to identify research interests. Individual consultations with supervisors to refine the topic. Preparing and submitting a preliminary research proposal.	- Introductory lecture - Brainstorming and group discussions - Individual consultations with supervisors - Independent work on research proposal	This stage may overlap with subsequent stages as topic selection may require a preliminary literature review.
2: Literature Review and Research Plan	Conducting a detailed literature review on the selected topic. Identifying research gaps and formulating research questions. Developing a preliminary research plan, including objectives, hypotheses, and methodological outline. Preparing a research schedule. Submitting and obtaining approval for the literature review and research plan from supervisors.	- Literature review workshops - Independent work on literature review - Consultations with supervisors - Developing research plan - Presenting and defending research plan	The literature review may lead to modifications or refinements of the research topic.
6: Research Methodology	Learning about various research methodologies. Selecting appropriate methods and tools for the project. Developing a detailed methodological plan. Consultations with supervisors and approval of the methodology.	- Research methodology lectures - Exercises in selecting research methods - Consultations with supervisors - Developing methodological plan	Methodology selection may require revisiting the literature review to identify best practices and research approaches.
3: Training on Laboratory Equipment and Safety	Practical training on the operation of necessary laboratory equipment. Familiarizing with safety procedures and protocols. Testing and certification in equipment operation and safety protocols.	- Safety lectures - Practical exercises on equipment use - Testing and certification	-

7-12: Conducting Experimental Research	Carrying out experiments as per the methodological plan. Collecting and documenting empirical data. Ongoing analysis of results and making adjustments if necessary. Regular consultations with supervisors and reporting progress.	- Laboratory work - Data collection and analysis - Consultations with supervisors - Progress reporting	During experimental research, it may be necessary to adjust the methodology in response to unforeseen results or challenges.
4: Preparing a Laboratory Progress Report	Preparing a detailed report on conducted experiments. Critically analyzing collected data and evaluating its quality. Submitting the report and receiving supervisors' evaluation.	- Independent work on the report - Consultations with supervisors - Presenting and evaluating the report	-
13-14: Preparing the Master's Thesis	Compiling all parts of the thesis into a cohesive document. Editing and organizing content, ensuring logical structure. Formatting the thesis according to academic standards. Applying appropriate citation styles and creating a bibliography. Consulting with supervisors and making final revisions.	- Independent work on thesis editing - Consultations with supervisors - Formatting and citation workshops - Final revisions and edits	At this stage, it may be necessary to revisit earlier parts of the thesis, such as the literature review or methodology, to ensure consistency and integrity of the entire text.
15: Preparing for the Master's Thesis Defense	Workshops on presentation and communication skills. Simulations of thesis defense and Q&A sessions. Refining the presentation and visual materials. Strategies for managing stress and pressure during the defense.	- Presentation workshops - Thesis defense simulations - Stress management exercises - Individual consultations	-

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