MATERIALS SCIENCE MA(S)TERS

developing a new master's degree

IO2

Syllabuses

Part 1

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Co-funded by the European Union

ADDITIVE MANUFACTURING

Code: **AM**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Materials & Manufacturing

Form of tuition and number of hours*:

Lecture: 15 h

Laboratory: 30 h

ECTS

4

Prepared by:
Joanna Maszybrocka, PhD, Assoc. *Prof.*

www.freepik.com

COURSE DESCRIPTION

The goal of the course is to provide a comprehensive introduction to additive manufacturing technology, commonly known as 3D printing. Throughout a series of lectures, students will become familiar with additive manufacturing processes, their classification, characteristics, and the latest advancements in the field. The course will cover the diversity of materials used in 3D printing, such as plastics, metals, ceramics, and composites, which are widely applied in modern industry. Participants will gain knowledge on design principles tailored for 3D printing, exploring innovative methods for optimizing the geometry and properties of manufactured components. An integral part of the course is the laboratory exercises, where students will have the opportunity to apply the knowledge they have acquired. They will conduct independent research on the impact of printing parameters on the mechanical properties of parts produced using various additive technologies. Additionally, they will learn about quality control methods for printed items using advanced techniques like computed tomography. The course will culminate in an interdisciplinary debate where students will analyze the connections between 3D printing and the UN Sustainable Development Goals, thereby developing their critical thinking and discussion skills.

COURSE OBJECTIVES

The aim of the course is to provide students with advanced and comprehensive knowledge in the field of additive manufacturing technology, encompassing both theoretical foundations and practical applications. The course will equip students with specialized knowledge and advanced skills, enabling them to independently formulate and solve complex problems related to the practical use of additive manufacturing in various fields. As a result, they will be prepared to creatively and innovatively apply this technology in their future professional careers, critically evaluating its capabilities and limitations in the context of evolving socio-economic conditions and needs.

PREREQUISITES FOR TAKING THE COURSE

The course is open to all interested students; however, to fully benefit from the content offered, it is recommended to have a basic understanding of manufacturing processes and materials science. Proficiency in using computer-aided design (CAD) software will be a significant advantage. Additionally, familiarity with basic programming and data analysis will be beneficial. A general knowledge of engineering materials, their structure, properties, and applications will also aid in understanding the advanced concepts and principles of additive manufacturing presented during the course.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
MS_O_02	Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
MS_O_03	Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
MS_O_04	Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
MS_O_05	Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

METHODS OF CONDUCTING CLASSES

Code	Description	Kod modułu
Meth_01	**Lecture** Problem-based lecture; Active methods: discussion/debate; Presentation	MS_O_01 MS_O_02
Meth_02	**Laboratory** Explanation/clarification; Laboratory exercise/experiment; Active methods: discussion/debate; Demonstration	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	15	course work	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

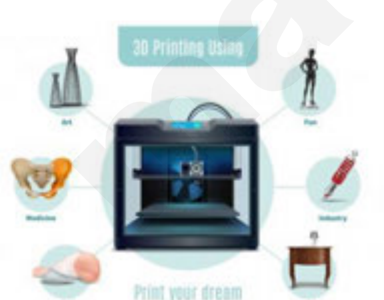
Co-funded by the European Union

Upon completion of the course, the student:

- Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
- Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
- Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
- Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
- Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

DO YOU KNOW

Charles Hull is the inventor of stereolithography, the first commercial rapid prototyping technology, commonly known as 3D printing.



www.freepik.com

COURSE CONTENT - LECTURE

Topic 1

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

The lecture serves as an introduction to a series of presentations dedicated to additive manufacturing technologies, also known as 3D printing. The goal is to provide a comprehensive overview of both the theoretical and practical aspects of this technology. The presentation will highlight the interdisciplinary nature of 3D printing and its wide range of applications across various sectors, from engineering to medicine. The current state of technological development and key stages of its evolution, from early experiments to modern industrial applications, will be discussed. The lecture will explore the impact of additive manufacturing on traditional production methods and highlight its advantages, such as customization, the creation of complex geometries, and cost optimization for small-scale production. A significant portion of the presentation will focus on the sustainability aspects of 3D printing compared to conventional manufacturing methods. Case studies from various industries will be presented. The lecture will conclude with an analysis of trends and forecasts regarding the future of additive manufacturing technologies and their potential to support the transformation of industry towards a circular economy.

Topic 2

Classification and Characteristics of Additive Manufacturing Processes

The aim of the lecture is to familiarize participants with the classification of additive manufacturing processes. The lecture will present a sysTopic ic categorization of additive methods based on the ISO/ASTM 52900 standard. Participants will learn about the different categories of additive manufacturing processes, with each category being briefly characterized. Special emphasis will be placed on the precise scientific terminology used in this field. Proper understanding and use of this terminology are crucial for effective communication in both research and industrial settings. Additionally, the lecture will include an introduction to industry standards related to additive technologies, covering aspects such as materials, testing, and quality control. This will provide attendees with a foundational, structured knowledge of additive manufacturing processes, serving as a solid introduction to more detailed lectures on the subject.

Topic 3

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

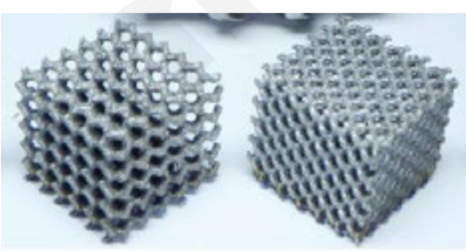
The lecture aims to provide a detailed overview of FDM (Fused Deposition Modeling) technology, covering its history, technical principles, applications, and future development prospects. The speaker will begin by highlighting key moments in the technology's evolution, including patents that have significantly influenced its development. Various applications of FDM, including in industry and medicine, will then be presented. The lecture will delve into the different

Upon completion of the course, the student:

- Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
- Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
- Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
- Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
- Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

DO YOU KNOW

One of the greatest advantages of 3D printing is the ability to create very complex shapes and geometries that would be difficult or even impossible to achieve using traditional manufacturing methods such as machining or casting.



Cellular structures manufactured using SLM technology

types of FDM printers, their design and kinematics, including Cartesian, Delta, CoreXY, H-Bot, polar, and those using robotic arms and SCARA kinematics. The mechanisms for filament feeding, with a particular focus on Bowden and Direct Drive systems, will be discussed in detail. An important element will be the analysis of print parameters and their impact on the quality and precision of prints, along with tips for optimizing settings. Common issues associated with FDM printing and methods for resolving them will be presented. Additionally, post-processing techniques will be covered. The speaker will also focus on the properties and applications of the most popular filaments, including ABS, PLA, and PETG. The lecture will also explore the future prospects of FDM technology, emphasizing innovations in devices and materials. A critical analysis of the impact of FDM technology development on achieving sustainable development goals will be conducted, identifying both opportunities and potential risks.

Topic 4

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

The lecture will begin with a historical overview, presenting the evolution of 3D printing technologies based on photopolymerization, from the pioneering work on stereolithography (SLA) in the 1980s to contemporary solutions. An introduction to fundamental concepts related to polymerization and photochemistry will follow. In the next section, the speaker will provide a detailed discussion of various 3D printing techniques that utilize photopolymerization, such as SLA, DLP, MSLA, and CLIP, comparing their advantages, disadvantages, and specific characteristics. Different types of resins and their properties will also be presented. The speaker will discuss current research trends and innovations in the development of 3D printing resins, with a focus on the advancement of biodegradable and environmentally friendly materials. A significant part of the lecture will be dedicated to a detailed discussion of print parameters and safety considerations when working with resins and 3D printing equipment. Attendees will gain the knowledge necessary to create a safe and effective working environment with photopolymerization-based 3D printing technologies.

Topic 5

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

The lecture will begin with a brief historical overview, showcasing the evolution of 3D printing technologies that utilize additive manufacturing techniques based on laser technology, from its initial experiments to modern solutions. Following this, an introduction will be presented to familiarize the audience with the classification of additive manufacturing techniques that employ laser technology. The speaker will discuss various technologies, with a particular focus on SLS (Selective Laser Sintering), SLM (Selective Laser Melting), DMLS (Direct Metal Laser Sintering), and LMS (Laser Metal Sintering), highlighting their differences and unique features. After the general introduction to laser technologies, the speaker will delve into a detailed discussion of the Selective Laser Melting (SLM) process. Topics will include the interaction of the laser beam with metallic powder, such as the absorption of laser energy and its penetration into the

Upon completion of the course, the student:

- Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
- Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
- Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
- Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
- Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

DO YOU KNOW

3D printing has the potential to revolutionize the manufacturing industry. This innovative technology not only reduces waste and enhances efficiency but also enables greater product customization. Additionally, 3D printing is more environmentally friendly than traditional manufacturing methods, using fewer resources and generating less waste. However, like any technology, it also has its drawbacks. You'll learn all about these aspects in the lectures and practical sessions!

material and substrate, material reflectivity, 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 liquid metal flow caused by stress gradients. The speaker will then discuss the key parameters of the SLM process, along with the properties of the metallic powders used in SLM technology. This part of the lecture will also cover the wide range of materials used in these technologies. Finally, the speaker will address the economic and environmental aspects associated with the use of SLM technology.

Topic 6

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

The aim of the lecture is to prompt participants to reflect on key questions regarding the application of AM technology in the production process, to avoid potential design and technical issues that could affect the success of the entire project. At the beginning of the lecture, participants will be encouraged to consider two crucial questions in production planning: (1) Should the part be made using AM? (2) Can it be produced using AM? To better illustrate the importance of these questions, participants will be introduced to a practical example, such as the use of conformal cooling channels in injection molds. In the next part of the lecture, the speaker will introduce the concept of Design for Additive Manufacturing (DFAM), a specialized approach to design that leverages the unique capabilities of additive technologies (AM). 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 carry out the entire design process, from concept to optimization, taking into account the specifics of additive technologies.

Topic 7

Sustainable Development and Additive Manufacturing Technologies

During the lecture, students will gain the knowledge necessary to understand the complex relationships between additive technologies and various aspects of sustainable development. The lecture will begin with a brief review of the definition and significance of sustainable development in the context of global challenges. Following this, key issues will be discussed, such as the environmental impact of 3D printing, the use of eco-friendly materials, the role of local supply chains, and the social, economic, ethical, and legal aspects associated with additive technology. The lecture will conclude by emphasizing the importance of an interdisciplinary approach to considering additive technologies (AM) in the context of achieving sustainable development goals.

MATERIALS SCIENCE MASTERS

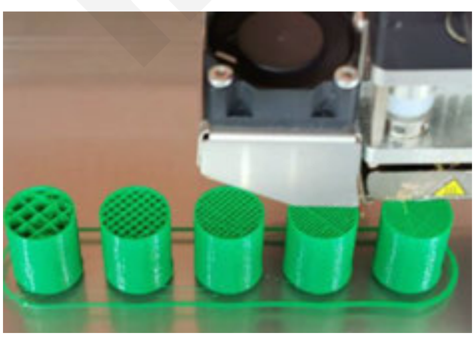
Co-funded by the European Union

Upon completion of the course, the student:

- Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
- Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
- Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
- Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
- Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

DO YOU KNOW

Thanks to the use of advanced materials and designs, 3D printed parts can achieve extremely high strength-to-weight ratios, making them ideal for the aerospace, automotive, and other industries where weight reduction is crucial.



Preparation of samples with varying infill densities for uniaxial compressive strength testing

COURSE CONTENT - LABORATORY

Topic 1

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

The objective of the course is to assess the impact of various 3D printing (FDM) 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 the prints. Through this hands-on approach, participants will deepen their understanding of the relationship between selected parameters and the characteristics of the final product, enabling them to more effectively optimize 3D printing processes in their future professional work. A key component of the lab will be familiarizing participants with ASTM and ISO standards that regulate the testing of 3D printed materials. The culmination of the course will involve solving an individual engineering problem. Each team will be presented with a unique challenge, such as designing a component with a specified strength while minimizing its weight, or optimizing print parameters to achieve maximum bending resistance.

Topic 2

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

The objective of the course is to assess the impact of various 3D printing (MSLA) parameters on the mechanical properties of the produced parts. The most critical aspect of the course will be solving an engineering problem. This task will allow students to apply the theoretical knowledge they have acquired in a practical context. For the given problem, students will need to independently propose a research plan, considering the impact of print parameters and post-processing techniques on the strength properties of the printed components. As part of the project, students will be required to demonstrate their ability to search for, interpret, and practically apply ASTM and ISO standards.

Topic 3

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

The objective of the laboratory is to investigate the impact of Selective Laser Melting (SLM) process parameters on the microstructure and hardness of various metals and their alloys. During the session, students will receive a set of pre-prepared samples made from different alloys (e.g., 316L, Ti6Al4V, H13, AlSi10Mg), which were previously produced using various SLM parameters. Students will begin by preparing metallographic specimens, followed by microscopic observations. A key task will be to identify the characteristic microstructural features of the assigned alloy and analyze the influence of SLM

Upon completion of the course, the student:

- Demonstrates advanced and in-depth knowledge of various additive manufacturing processes. Is capable of accurately selecting the appropriate technology for specific projects, understanding the key factors that influence the quality and reliability of the produced components.
- Effectively utilizes information from literature and other sources, critically evaluating and interpreting it. Based on this, formulates conclusions and solves complex problems related to additive manufacturing, considering the principles of sustainable development.
- Has the ability to plan and conduct experiments that investigate the impact of additive manufacturing technology parameters on the properties of the produced items. Skillfully selects research methods, analyzes results, and optimizes process parameters to achieve the desired material characteristics.
- Identifies problems and challenges associated with the application of additive manufacturing in production. Proposes innovative solutions to optimize processes, taking into account material specifics and the expected properties of the final product.
- Demonstrates the ability to prepare professional scientific reports and presentations, including critical analysis and synthesis of information. Works effectively both individually and in teams, conducting substantive discussions on additive manufacturing.

DO YOU KNOW

The technology of 3D printing is advancing at a rapid pace, with new materials being developed for the printing process, including metal powders, carbon fiber composites, and bio-based materials.

parameters on this microstructure. The next step will involve measuring hardness using the Vickers method. Students will perform a series of measurements for each sample, paying close attention to differences resulting from process parameters and the location of the measurement. Throughout the laboratory session, participants will be required to demonstrate their ability to search for, interpret, and practically apply information from literature and databases, ensuring that their research complies with international standards and allows for the comparison of results with literature data.

Topic 4

Quality Control of Components Manufactured by Additive Methods Using Computed Tomography

The laboratory will begin with a brief theoretical introduction, covering the principles of X-ray computed microtomography (X-ray CT) and its application in assessing the quality of components produced by additive manufacturing methods. Following this, students will participate in a demonstration of the measurement process, observing the scanning of a selected sample. After the demonstration, participants will be divided into working groups. Each group will receive a unique set of microCT measurement data, including scan results of samples produced using various 3D printing techniques such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM). 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 will include importing and visualizing 3D data, image segmentation to isolate material and voids, porosity analysis, pore distribution, and the identification and classification of defects such as cracks or discontinuities. Students will also learn to measure geometric accuracy by comparing results with the original CAD model, as well as analyze wall thickness and the uniformity of the structure in the printed components.

Topic 5

Additive Technologies - Threats, Challenges, and Perspectives

As part of the laboratory, an interdisciplinary debate is planned with the aim of placing issues related to 3D printing within the broader context of global challenges and the Sustainable Development Goals (SDGs). In preparation for the debate, participants will need 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 from a variety of information sources, such as scientific publications, industry reports, case studies, and expert opinions, to gain a comprehensive understanding of the impact of 3D printing on achieving the SDGs. Before the exercise, students will be divided into two groups: one supporting the thesis and the other opposing it. Both groups will be informed of the debate topic in advance, but they will not know whether they will need to defend or oppose it, which will require them to conduct an in-depth analysis of the issue from both perspectives.

TEXTBOOK / READINGS

www.fripik.com

1. Bian, L., Shamsaei, N., & Usher, J. M. (Eds.). (2017). Laser-based additive manufacturing of metal parts: Modeling, optimization, and control of mechanical properties. CRC Press.
2. Izdebska-Podsiadły, J. (Ed.). (2022). Polymers for 3D printing: Methods, properties, and characteristics. William Andrew.
3. Khan, M. A., & Jappes, J. W. (Eds.). (2022). Innovations in additive manufacturing. Springer.
4. Sandhu, K., et al. (Eds.). (2022). Sustainability for 3D printing. Springer.
5. Mwema, F. M., & Akinlabi, E. T. (2020). Fused deposition modeling: Strategies for quality enhancement. Springer Nature.
6. Narayan, R. (Ed.). (2019). Rapid prototyping of biomaterials: Techniques in additive manufacturing. Springer.
7. Manjaiah, M., et al. (Eds.). (2021). Additive manufacturing: A tool for industrial revolution 4.0. Woodhead Publishing.

ASSESMENT

Quiz:

At the beginning of each laboratory session, a brief quiz will be administered on the topics covered during that day's lab. This is intended to ensure that the recommended literature for the lab has been read, the material presented in the lecture has been understood, and that students are adequately prepared to conduct the exercises.
This approach will help make better use of the time during practical sessions and facilitate a deeper understanding of the experiments being carried out.

Raport:

Students, divided into teams, will prepare a written report on the laboratory exercises. The report should include theoretical background, a description of the experiments, analysis of the results, and conclusions. According to the instructor's guidelines, the report must be concise, use appropriate terminology, and include graphs, tables, and references to the literature. This task will help students deepen their knowledge of additive manufacturing and develop technical report writing skills and teamwork abilities.

Debate:

During the debate, the following will be assessed: the ability to present logical arguments and explain their relevance to the topic, the capability to respond to questions posed by other participants, and the skill of active listening and engaging in discussion with other debaters.

GRADING POLICY

The additive manufacturing course is graded using points. The final grade is based on the total points accumulated by the student throughout the semester (Quizzes, Reports, Debate). The maximum number of points that can be earned in laboratory exercises is 100. Students' grades will be assigned according to the criteria outlined in the table.

Assignment Weights	**Percent**
4 Reports	50%
4 Quizes	40%
Debate	10%
Total	100%

Reports - max. 50 points
Quizes – max. 40 points
Debate – max. 10 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

ADVANCED TESTING METHODS IN MATERIALS SCIENCE

Code: ATMMS

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

1

Language

English

Thematic block

Advanced Methods for Materials Characterisation

Form of tuition and number of hours*:

Lecture: 30h

Laboratory: 30h

ECTS

4

COURSE DESCRIPTION

The dynamic development of engineering materials aimed at the miniaturization of devices or due to unconventional phenomena occurring at various size scales requires the use of methods characterizing structure from the macro scale to the nanoscale. The subject *Advanced Testing Methods in Materials Science* meets these expectations and introduces advanced techniques and methods for characterizing the structural state, phase composition, and chemical composition.

The *Advanced Testing Methods in Materials Science* course is dedicated to all paths, expanding students' knowledge of non-destructive methods of structure testing using microscopy techniqes (light and electron) as well as techniques based on X-ray diffraction..

The lectures will present the issues related to the phenomena used in advanced methods of characterizing the structure and properties of engineering materials, advanced measurement techniques, and the construction of research equipment. Practically, laboratories will approach the course participants to get practical knowledge of research equipment, carry out measurements and, above all, bring closer the interpretation of the results obtained in the context of measurement errors. Understanding the phenomena and principles of methods and techniques leads to the skillful application of the appropriate research technique to assess the structure and properties of materials.

COURSE OBJECTIVES

After completing the *Advanced Testing Methods in Materials Science* course, the student should understand the phenomena underlying the principles of operation of the apparatus used in advanced characterization methods. The course participant is prepared to use the appropriate research method to assess the structure, surface, and effectiveness of technological processes carried out on engineering materials..

PREREQUISITES FOR TAKING THE COURSE

To complete the course, it is recommended to implement learning outcomes related to the basics of physics, chemistry, and materials science.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extended and in-depth knowledge in the field of general knowledge, which is the basis for understanding complex relationships in the processes of testing of engineering materials.
MS_O_02	Has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in materials engineering.
MS_O_03	Can plan and carry out experiments, including measurements and computer simulations, interpret the results and draw conclusions.
MS_O_04	Can prepare a scientific study and present a presentation on the implementation of a research task, containing a critical analysis, synthesis and conclusions.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	30	exam	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

Co-funded by the European Union

LEARNING OUTCOMES

Student has extended and in-depth knowledge in the field of general knowledge, which is the basis for understanding complex relationships in the processes of testing of engineering materials. Also she/he has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in materials engineering.

COMMENTS

LECTURER

DO YOU KNOW

Nearly 80% of success in microscopic examinations depends on the quality of the sample.

www.freepik.com

COURSE CONTENT - lecture

Topics 1

Light microscopy

During the lecture, students will be familiarized with the properties of electromagnetic waves and light properties and phenomena in the visible spectrum range. The construction of a microscope for studying non-transparent materials, image formation, and observation techniques will be discussed..

Topics 2

X-rays and their interaction with matter

The lecture will discuss the formation and characteristics of X-rays, their interaction with matter, and the construction of an X-ray tube and X-ray apparatus devoted to testing engineering materials. In addition, students will be familiar with the impact of X-ray radiation on living organisms and the principles of the safe use of radiation in scientific research.

Topics 3

Qualitative phase analysis of multiphase materials

The lecture will be devoted to qualitative phase analysis - a method that allows us to identify the phases that form engineering materials. The phase composition is the basic information on the structure characterizing the technological process/processes carried out on engineering materials.

Topics 4

Advanced structure research techniques using X-ray diffraction

The lecture will familiarize students with the principles of the method of the constant angle of incidence of the primary beam and reflectometry used to study the structure of multilayer and gradient materials. In addition, techniques such as X-ray at elevated temperatures, determination of the average size of crystallites, and the preferred crystallographic orientation of grains will be discussed.

Topics 5

Scanning electron microscopy - SEM

During the lecture, the properties of the electron beam, its formation, and interaction with matter will be discussed. In addition, the construction of a scanning microscope, the principle of operation, the creation of images, and their interpretation will be shown.

Topics 6

Transmission electron microscopy -TEM

The construction of the transmission electron microscope, the formation of contrast, image formation, and methods of interpreting microscopic and diffraction images will be discussed during the lecture.

LEARNING OUTCOMES

Students can plan and carry out experiments, including measurements and computer simulations, interpret the results and draw conclusions. Also, she/he can prepare a scientific study and present a presentation on the implementation of a research task, containing a critical analysis, synthesis and conclusions.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Most engineering materials are transparent for X-rays, but some materials, such as lead, can stop them. Such materials are used to build shields that protect living organisms from X-rays.

www.freepik.com

COURSE CONTENT - laboratory classes

Topics 1

Light microscopy - quantitative analysis

The subject of laboratory exercises is related to the use of light microscopy in the study of opaque engineering materials. It includes the analysis of numerical parameters of the structure of engineering materials related to mechanical or technological properties.

Topics 2

X-ray tube radiation spectrum

Laboratory exercises are aimed at practical familiarizing the student with the X-ray apparatus and the production of the X-ray beam. In addition, the student will analyze the influence of the operating conditions of the X-ray tube on the generation of the real spectrum.

Topics 3

X-ray diffraction on a crystal lattice

Using the phenomenon of X-ray diffraction, the student will learn how to distinguish between amorphous and crystalline materials and will be able to determine the interplanar distances of polycrystalline materials.

Topics 4 .

X-ray qualitative phase analysis of multiphase materials

Using the acquired knowledge and practical skills from previous exercises, the student will practically acquire the ability to conduct a phase analysis, including multiphase materials.

Topics 5

Determination of layer sequences in multilayer materials

The phase identification methods already learned will be used to acquire the ability to study materials with a gradient or layered structure. Using the non-destructive method, the student can determine the sequence of layers of multilayer materials.

LEARNING OUTCOMES

Students can plan and carry out experiments, including measurements and computer simulations, interpret the results and draw conclusions. Also, she/he can prepare a scientific study and present a presentation on the implementation of a research task, containing a critical analysis, synthesis and conclusions.

COMMENTS

INSTRUCTOR

DO YOU KNOW
The lens that allowed the electron beam to be focused was the most challenging element to construct for electron microscopes.

www.freepik.com

Topics 6

Investigation of phase transitions initiated by temperature change.

An essential element of engineering materials is the phase changes occurring in them. During the laboratory, the student will learn how to modify the diffractometer using a temperature attachment that allows for the temperature change, thus inducing a phase change in the material. They will gain the ability to interpret structural development caused by temperature changes.

Topics 7

Sample preparation in electron microscopy

The laboratory will familiarize the student with the sample preparation methods dedicated to microscopic examination. The classes will guide students from obtaining the starting material to the final sample shape. The TEM and SEM microscopy techniques differ in the purpose of research, hence the different sample preparation methodologies.

Topics 8

Scanning electron microscopy - types of images and their interpretation

Laboratory classes will familiarize the student with the practical use of scanning microscopy to analyze the structure of engineering materials. The student will be able to apply the images obtained in backscattered electrons and secondary electrons. In addition, he/she will determine the chemical composition using EDS. Practical possibilities for in-situ testing of engineering materials will be presented.

Topics 9

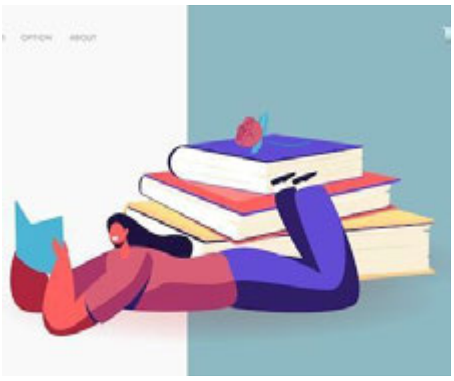
Imaging in transmission electron microscopy

Laboratory classes are aimed at practical familiarization with conducting microscopic observations of objects occurring on the nanoscale using various imaging techniques. The classes will enable the acquisition of practical skills in solving electron diffraction patterns.

Topics 10

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

The laboratory will enable the practical use of microscopic and electron diffraction images to analyze structural defects and determine the orientation of crystal grains.



www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing *Advanced Testing Methods in Materials Science:*
1. Douglas B. Murphy, Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, Wiley-Blackwell 2013
2. B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, Pearson Education Limited 2014
3. Peter J. Goodhew, John Humphreys, Richard Beanland, Electron microscopy and analysis, Taylor & Francis 2001
For extending and supplementing knowledge recommended are:
1. Anwar Ul-Hamid, A Beginners' Guide to Scanning Electron Microscopy, Springer Nature Switzerland AG 2018
2. Yoshio Waseda, Eiichiro Matsubara, Kozo Shinoda, X-Ray Diffraction Crystallography, Springer-Verlag Berlin Heidelberg 2011
ASSESMENT

ASSESMENT

Exam:

The oral exam verifies overall theoretical knowledge in the field of phenomena, principles of operation, and theoretical foundations of advanced research methods used to characterize engineering materials.

Report:

The reports result from the student's work during the laboratories; they refer to the in-depth theoretical and practical knowledge of performed exercises. They are developed in laboratories and consist of a theoretical introduction, a description of the exercise's purpose and scope, and a part reporting the obtained results. They end with a discussion and conclusions.

GRADING POLICY

The final evaluation is made based on the student achievement scoring system. The grade results from the sum of points obtained by the student during the semester from the laboratories and points received during the exam.
The exam is conducted in an oral form - 3 questions from the knowledge contained theoretical and practical aspects. The maximum number of points to be obtained in the exam is 100.
During the assessment of one laboratory, the following are taken into account: the initial test opening the exercise - passing the test is a condition for participation in the exercise (1 point), individual or team work on performing the exercise and developing a report in which:
- completeness of the report; (1 point)
- content included in the theoretical introduction (1 point)
- the correctness of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point)
and for which the student receives 10 points in total.
The student is obliged to perform the 10th exercise, which gives in maximum 100 points. The final grade is determined by 50% of the points obtained in the exam and 50% of the points obtained in the laboratories. According to the table on the left, the sum of the percentages will result in the final grade.

Assignment Weights and Points

Laboratories
90-100% = 90 – 100 points = A
80-89% = 80 – 89 points = B
70-79% = 70 – 79 points = C
60-69% = 60 – 69 points = D
Below 60% = 0 – 59 points = F

Grading Scale for Exam and final notes

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

Final score

Exam	50%
Laboratory	50%
Total	100%

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

SUSTAINABLE NANOMATERIALS

Code: **SN**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

3

Language

English

Thematic block

Applied Materials Science

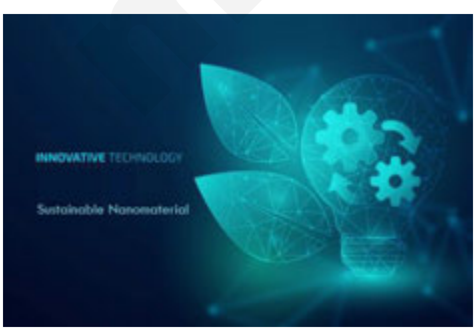
Form of tuition and number of hours*:

Lecture: 10h

Laboratory: 30h

ECTS

3



www.freepik.com

COURSE DESCRIPTION

The subject concerns sustainable nanotechnology; methods of production, characterization and use of green nanocrystalline materials for specific applications in material engineering.

Green nanotechnology is a technology that produces both innovative and environmentally friendly products, with the goal of developing and applying practical design principles to achieve greener nanomaterials and to find an effective synthetic approach to reproduce nanomaterials with expected structure and function in modern materials engineering.

The *Sustainable Nanomaterials* course, dedicated to the *IEMPS - Innovative Engineering Materials and Processes for Sustainability* path, broadens knowledge about the methods of production and the use of unconventional, modern engineering materials that are both innovative and environmentally friendly. Students pursuing the *IEMPS* path will deepen their knowledge of various aspects of sustainable development of modern materials engineering, while students pursuing different thematic paths will learn information about environmentally friendly technology.

Lectures are aimed at providing information on sustainable nanocrystalline materials, methods of their production, properties and applications. Laboratory exercises are intended for individual student work, independent performance of experiments and independent analysis leading to individual elaboration of the obtained results in the form of a report along with relevant studies and conclusions.

COURSE OBJECTIVES

By the end of the *Sustainable Nanomaterials* course, the student will be able to characterize sustainable nanotechnology, provide methods of producing green materials and their application; design more ecological nanomaterials with the expected structure used in modern materials engineering.

PREREQUISITES FOR TAKING THE COURSE

Before starting the study of subject *Sustainable Nanomaterial*, a student should have a general knowledge of the various types of engineering materials, their structure, properties and applications.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	He has extensive and in-depth substantive knowledge in the field of methods, processes of production of engineering sustainable nanomaterials
MS_O_02	Can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to the production and use of sustainable nanomaterials.
MS_O_03	**He can plan and carry out experiments, interpret the results and draw conclusions regarding the applications of sustainable engineering nanotechnology.**
MS_O_04	Can prepare a scientific paper and present a presentation on the possibilities of sustainable nanotechnology, including critical analysis, synthesis and conclusions. Able to work individually and in a team, and lead a debate.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04
Meth_03	**Team project**: critical analysis, synthesis and conclusions; individual and team work, communicate on specialist topics, leading a debate, SWOT analysis	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	10	exam	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

Co-funded by the European Union

LEARNING OUTCOMES

By the end of the *Sustainable Nanomaterials* course, the student will be able to characterize sustainable nanotechnology, provide methods of producing green materials and their application; design more ecological nanomaterials with the expected structure used in modern materials engineering.

COMMENTS:

LECTURER:

DO YOU KNOW

Reducing agents from natural sources like polysaccharides or plants extract or biological micro-organism like bacteria and fungus can be used to synthesize nanoparticles.

Free vector concept of green hydrogen energy molecule of h2 in hands shine on a backdrop with stars

www.freepik.com

COURSE CONTENT - LECTURE

Topics 1

Nanotechnology and green materials: introduction, fundamentals, and applications

During the lecture, as an introduction to the issue of sustainable nanotechnology, the most important features of nanotechnology will be presented. 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, and will learn about the negative impact of nanotechnology on our environment and human health.

Topics 2

Green synthesis of nanomaterials

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.

Topics 3

Modern applications of green nanotechnologies in the environmental industry

The lecture will present the applications of nanotechnology from the electronics and biomedical industry, through construction, where nanomaterials are used to improve the properties, from building materials, to the food industry, where new packaging films with good barrier, fire-resistant, mechanical and exfoliating properties are created, and many others applications.

Topics 4

Sustainable green nanomaterials for potential development in future

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.

Topics 5

Threats from the use of green nanomaterials

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 and resolving threats.

LEARNING OUTCOMES

Student will be able to prepare a report containing a critical analysis, synthesis and conclusions. He will be able to work individually and in a team as well as communicate on specialist topics, including leading a debate.

COMMENTS:

LECTURER:

DO YOU KNOW

Green synthesis employs a clean, safe, cost effective and environmentally friendly process of constructing nanomaterials. Microorganisms such as bacteria, yeast, fungi, algal species and certain plants act as substrates for the green synthesis of nanomaterials.

www.fripik.com

COURSE CONTENT – LABORATORY CLASSES

Topics 1

Nanomaterial structure characterization

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 classes. The completed experiment will be the basis for developing a report on the exercises.

Topics 2

Green synthesis of nanomaterials

During laboratory classes, students will choose the 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.

Topics 3

Green nanomaterials characterization - properties

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. The completed experiment will be the basis for developing a report on the exercises.

Topics 4

Conventional and sustainable nanomaterials

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*.

Topics 5

Threats from the use of green nanomaterials

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.

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Co-funded by the European Union

www.fripik.com

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Sustainable Nanomaterial*:

1. *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.
2. *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

To deepen the course topics, optional recommended texts include:

1. *Green Synthesis of Nanomaterials*. Huston, M.; DeBella, M.; DiBella, M.; Gupta, A., Nanomaterials, 2021, 11, 2130. https://doi.org/10.3390 /nano11082130
2. *Sustainable nanomaterials by design. A new material selection tool offers a proactive perspective on nanotechnology research and development,* Callie W. Babbitt and Elizabeth A. Moore. ENVIRONMENTAL NANOTECHNOLOGY, Nature Nanotechnology VOL 13, 2018, 621–629, www.nature.com/naturenanotechnology

ASSESMENT

Reports:

The reports relate to experimental laboratory exercises; contribute to deepening theoretical and practical knowledge in the field of sustainable nanocrystalline materials. The reports contain theoretical background, description of performed experiments and analyses, together with discussion and conclusions.

Team project (during the semester)**:**

Team project verifying knowledge of issues in the field of sustainable nanocrystalline materials and ability to team work.

Exam (after the semester):

The oral exam verifying overall knowledge in the field of sustainable nanocrystalline materials.

GRADING POLICY

The *Sustainable Nanomaterial* course is scored with points. The grade results from the sum of points obtained by the student during the semester (laboratory exercises) and points obtained during the exam. During laboratory exercises, the following are assessed on an ongoing basis: theoretical preparation (discussion at the beginning of laboratory exercises as an introduction to conducting the experiment and preparing the report), submitted reports (max. 10 points, i.e. 3 reports x 10 points = 30 points are assessed), Team project (1 x 10 pts = 10 pts) and Debate (1 x 10 points). The maximum number of points obtained in the laboratory exercises is 50. The exam is conducted in an oral form - 3 questions from the previously given range of topics are to be selected. The maximum number of points to be obtained in the exam is 50. Student grades will be assessed as follows in the box on the left.

Assignment Weights	**Percent**
3 Reports	30%
Team project	10%
Debata	10%
Exam	50%
Total	100%

3 reports (max. 10 points each) – max. 30 points
Team project– max. 10 points
Debata – max. 10 points
Final exam – max. 50 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

SUSTAINABLE COMPOSITE MATERIALS

Code: SCM

Field of study
Materials Science and Engineering

Level of study
Master Study

Semester
1

Language
English

Thematic block
Advanced Engineering Materials

Form of tuition and number of hours*:
Lecture: 15h
Laboratory: 30h

ECTS
3

COURSE DESCRIPTION

Since sustainability is a global priority with a massive drive for change, the student will be familiar with the concept of sustainable materials management during this course. The student will gain a solid background in the field of sustainable composite materials. The properties, production methods, and environmental implications of sustainable composite materials based on polymers, metals, and ceramics will be introduced to the students. The course will connect composites' structure and mechanical properties with the technology used for their production from renewable or bio- materials. The lecture will discuss environmental impacts, e.g., carbon emissions, and water and air pollutants, connected with production and the use of composite materials. It will also cover the waste hierarchy and the problem of composite materials recycling. During laboratory classes, based on the knowledge gained from lectures and literature suggested by the teacher, students will have the opportunity to design and produce a composite material that meets sustainable development's assumptions. By using the appropriate material testing methods, students will also characterize the structure and properties of the obtained composite materials.

COURSE OBJECTIVES

The course aims to enable students to understand modern sustainable composite materials' role in the economy. The acquired knowledge allows the student to classify composite materials, indicate the basic criteria for their selection, and become aware of the degradation processes. These skills will enable the student to understand the relationship between composite materials' chemical structure, phase structure and surface condition, and the material's performance properties. After the course, the student will be able to critically evaluate the use of sustainability in composites manufacturing, industrial growth, and economic development.

PREREQUISITES FOR TAKING THE COURSE

Prerequisites include basic knowledge of engineering materials, such as polymers, metals and ceramics. The student is familiar with the material's structure and processing methods and their impact on the materials properties. The student should also know and be able to apply the basic materials testing methods.

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Student will have extensive and in-depth substantive knowledge about composite materials classification and properties based on the type of matrix, reinforcement and their structure. Knows and is able to apply the appropriate materials testing methods to characterize composite materials.
MS_O_02	Student will gain the knowledge necessary to understand the ethical, economic and ecological aspects of the design of new engineering materials and their production technology.
MS_O_03	Student will be aware of the responsibility for their work and take responsibility for the tasks carried out in the team. Students will be able to lead a team and follow teamwork rules. Student will be able to communicate on topics related to sustainable composite materials with diverse audiences, including presentation of the results of their work/study or leading a debate.
MS_O_04	Student will be able to integrate, interpret and critically evaluate information obtained from literature, databases and other available sources. Student will be able to draw conclusions and formulate and solve problems related to sustainable composite materials. Students will also manage to plan and carry out experiments, including measurements, interpret the results and draw conclusions.
MS_O_05	Student will be able to select the appropriate raw and renewable materials, technologies and techniques for the production, processing and testing of sustainable composite materials.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lecture:** informative and problem-based lecture, multimedia presentation.	MS_O_01, MS_O_02
Meth_02	**Laboratory classes:** research project, presentation, discussion, multimedia presentation	MS_O_03, MS_O_04, MS_O_05

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	course work	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03, MS_O_04, MS_O_05	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of project reports.	NO
a_02	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_03	Preparation of project reports	Preparation and development of project reports. Consultation.	YES

LEARNING OUTCOMES

Please list the essential learning outcomes. (Max 500 characters with space)

COMMENTS

LECTURER

DO YOU KNOW

Please provide some interesting information related to a course topic. (Max 500 characters with space)

e.g.

Additive manufacturing is used to produce lighter, stronger parts and systems, with greater efficiency. It has uses across a variety of industries, including aerospace, automotive and medical.

COURSE CONTENT - LECTURE

Topics 1

Introduction to sustainability in composites

This lecture defines sustainability and the thermodynamics of sustainable development. During the lecture, the three pillars of sustainability will be discussed. Topics such as materials supply and planetary resource, planetary limitations, life-cycle analysis (LCA) and environmental product declarations (EPDs) will also be considered.

Topics 2

Composites

The lecture will cover the basic definitions of composite materials. During the lecture, the dependencies resulting from the type of matrix and infill will be explained. Composite manufacturing technologies in terms of sustainable development will also be discussed.

Topics 3

Sustainable polymer matrix composites

Polymer-based composites are the largest group of composite materials. The subject of the lecture will focus mainly on polymers and composites from natural and renewable resources. 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.

Topics 4

Sustainable metal matrix composites

This lecture provides information on metal matrix composites' chemical composition and physical and mechanical properties. The topic of the lecture will cover the different green reinforcement and matrix materials within. The primary fabrication techniques, together with the application of this kind of materials, will also be discussed in this lecture.

Topics 5

Sustainable ceramics matrix composites

The lecture will discuss ceramic matrix composite materials. The properties and application of these materials will be discussed. The lecture will focus on materials and their production technologies that are part of the sustainable development trend.

Topics 6

Cradle to cradle

Lecture on the life cycle of a composite material. Issues regarding the hierarchy of waste and the possibility of recycling composite materials will be presented.

LEARNING OUTCOMES

Please list the essential learning outcomes. (Max 500 characters with space)

COMMENTS

INSTRUCTOR

DO YOU KNOW

Please provide some interesting information related to a course topic. (Max 500 characters with space)

e.g.

Additive manufacturing is used to produce lighter, stronger parts and systems, with greater efficiency. It has uses across a variety of industries, including aerospace, automotive and medical.

COURSE CONTENT - LABORATORY CLASSES

Topic of the project:

Designing and obtaining a sustainable composite material, determining its properties and specifying the potential application areas.

The aim of education is for the student to acquire the ability to independently conduct scientific research, including planning research works, their implementation, development and interpretation of results, proposing conclusions and research hypotheses, as well as preparing a report and presenting the results. The primary goal of the course is to develop the competence of an individual approach to solving complex research problems.

Laboratory classes are related to the implementation of individual research projects by students. Students carry out research projects that combine the ability to select composite materials, determine their potential properties and then test them using appropriate materials testing methods. The implementation of the project includes the preparation of research procedures by the student based on literature studies. After their approval by the scientific supervisor, students perform research work in scientific laboratories under scientific supervision. The obtained research procedures, a description of their implementation, and the results and conclusions will be presented in research reports and a multimedia presentation subject to discussion and evaluation.

[Kliknij tutaj, aby dodać podpis]

TEXTBOOK/READINGS

1. Publications from this thematic area detailed during the classes

2. Daniel Gay et al., “Composite Materials: Design and Applications,” CRC Press, 2002, ISBN 9781420031683.

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

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

5. Deepak Verma et al., “Sustainable Biopolymer Composites”, Woodhead Publishing, 2020, ISBN 9780128222911

ASSESMENT

Final exam: Written examination of the knowledge presented during the lecture and recommended literature.

Report of the project: The report should include a theoretical background, a description of the conducted project, an analysis of the results, and its discussion and conclusions section.

Presentation of results: The graphic form of the multimedia presentation and the way the team presents the results of their research will be assessed.

GRADING POLICY

The *Sustainable composite materials* course is scored with points. The grade results from the sum of points obtained by the student during the semester (Class Participation, Report of the project, Presentation of results, Final Exam). Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
Class Participation	10%
Report of the project	25%
Presentation of results	15%
Final exam	50%
Total	100%

Grading Scale

96% - 100% = A
91% - 95% = B+
86% - 90% = B
81% - 85% = C+
71% - 80% = C
66% - 70% = D+
61% - 65% = D
0% - 60% = F

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

CERAMICS MATERIALS FOR THE ENERGY HARVESTING

Code: **CMEH**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

1

Language

English

Thematic block

Advanced Engineering Materials

Form of tuition and number of hours*:

Lecture: 15 h

Laboratory: 30 h

ECTS

3

Lecturer: Małgorzata Adamczyk-Habrajska, PhD, DSc, Assoc. Prof.

https://onlinelibrary.wiley.com/doi/10.1002/ese3.63#

COURSE DESCRIPTION

The course is a bridge between solid-state theory and the processing and application of ceramic materials. Its main idea is to understand the roles and interactions between crystal structure, defect chemistry, microstructure and electrical, magnetic, piezoelectric and pyroelectric properties, which underlies the functionalisation of ceramics for specific applications. Particular emphasis will be placed on those ceramic properties that make them suitable for energy conversion. The student will be familiarised with the basic principles of designing new ceramic materials for the market's needs. The main directions of application of ceramic materials will be discussed, with a strong emphasis on the idea of energy harvesting, which is associated with a gradual increase in the use of ceramic materials in systems transforming ambient energy into electricity. Such systems reduce the dependence of the energy market on fossil fuels and increase the overall energy efficiency of the systems; thus they are a response to the growing and prospective needs of sustainable energy related to decarbonisation and climate protection. Until recently, the concept of energy harvesting was associated with powering small electronic gadgets. Now the idea has expanded to larger devices such as electric vehicles. In addition, during the course, the students will be familiarised with the issues of harvesting energy sources, including radio (RF), solar, thermal, flow and vibration energy.

COURSE OBJECTIVES

The main objective of the MHE course is to provide in-depth knowledge about the fundamentals of various ceramic materials in energy harvesting applications. After ending the course, Students should be well-versed in the processing and fabricating of advanced ceramic materials. They should know the broad spectrum of properties of ceramics material that predispose them to applications in the field of energy harvesting. Students should also see the possibility of influencing the properties of materials by changing technological conditions or doping. In effect, after the course, they should be prepared to be future materials scientists and engineers who can conduct investigations for relevant scientific breakthroughs in the harvesting and storage of energy.

PREREQUISITES FOR TAKING THE COURSE

Prerequisites for taking the MHE course include a basic knowledge of engineering

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Students will have understand the exploitation of the process-microstructure-properties relationship in the design of ceramics materials with an appropriate combination of properties.
MS_O_02	Understand the processes and issues in the manufacture of powder ceramic products
MS_O_03	Students will be able to relate the chemical composition, crystal structure and microstructure of functional ceramics to the particular conductive, dielectric, ferroelectric, piezoelectric, pyroelectric and magnetic properties
MS_O_04	Students will be equipped with the skills to identify the latest technological developments in functional ceramic materials and innovatively use the above knowledge for applications in energy harvesting.
MS_O_05	Students will acquire the skill of surveying and critically evaluating relevant scientific literature, and they will be able to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work and leading discussions on materials for energy harvesting.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	10	course work	MS_O_01 MS_O_02	
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

By the end of the Ceramics Materials for Energy Harvesting course student:

- will have in-depth knowledge about the fundamentals of various ceramic materials in energy harvesting applications.
- understand the processes and issues in the manufacture of powder ceramic products.
- will be able to relate the chemical composition, crystal structure and microstructure of functional ceramics to the particular conductive, dielectric, ferroelectric, piezoelectric, pyroelectric and magnetic properties
- will be equipped with the skills to identify the latest technological developments in functional ceramic materials and innovatively use the above knowledge for applications in energy harvesting.
- will acquire the skill of surveying and critically evaluating relevant scientific literature and will be able to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work and leading discussions on materials for energy harvesting.

www.freepik.com

COURSE CONTENT - LECTURE

Topics 1

Introduction to the Ceramics Materials – method of obtaining

The first part of the lecture includes an introduction to ceramic materials. The audience will be acquainted with the history of ceramics, starting from the utility ceramics of the early Iron Age and the functional electroceramics of today. Next, the classification of ceramic materials will be made. We will briefly discuss fine ceramics, bioceramics and technical ceramics, with particular emphasis on electroceramics. The final part of the lecture will be devoted to the technology and method of obtaining ceramic materials. The solid phase synthesis method, the sol-gel method, and the Pechini method will be discussed in detail. Students will learn about the structure of ceramic powders and how to characterize them. Concepts such as average grain size, grain shape, and pore distribution will be discussed. The will has knowledge about the methods of presenting the grain analysis of powders. In the next part of the lectures, students will learn in detail about the ways of forming powders by pressing. Other forming methods will also be briefly discussed. The lecture will end with a discussion on the processes occurring during the sintering of powders.

Topics 2

Microstructure and it influence on properties of ceramics properties

Students will learn about the microstructure of ceramic materials. The basic elements of the microstructure will be discussed, i.e., grains, grain boundaries, pores, and their types. The students will also learn about the methods of microstructure observation, focusing on the use of the scanning electron microscope. During the lecture, there will be time to explain the principle of operation of SEM. The lecture will also pay attention to X-ray microanalysis as a method of confirming the achievement of the assumed theoretical stoichiometry of ceramic materials. At the end of the lecture, the influence of the microstructure, i.e. the shape and size of grains, their orientation and the number of pores on the functional properties of ceramic materials, with particular emphasis on electroceramics, will be discussed.

By the end of the Ceramics Materials for Energy Harvesting course student:

- will have in-depth knowledge about the fundamentals of various ceramic materials in energy harvesting applications.
- understand the processes and issues in the manufacture of powder ceramic products.
- will be able to relate the chemical composition, crystal structure and microstructure of functional ceramics to the particular conductive, dielectric, ferroelectric, piezoelectric, pyroelectric and magnetic properties
- will be equipped with the skills to identify the latest technological developments in functional ceramic materials and innovatively use the above knowledge for applications in energy harvesting.
- will acquire the skill of surveying and critically evaluating relevant scientific literature and will be able to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work and leading discussions on materials for energy harvesting.

https://www.researchgate.net/figure/Examples-of-piezoelectric-nanowires-incorporated-into-nanogenerators-under-different_fig2_280630530

COURSE CONTENT - LECTURE

Topics 3

Crystal structure, defects and electrical conduction of ceramics

This lecture focuses on crystal structure, defects and connects them with electrical conductivity. A number of different point defects can form in all ceramics but their concentration and distributions are interrelated. In the event of the production of a vacancy, for example, by the displacement of a lattice atom, this released atom can be either contained within the crystal lattice as an interstitial species (forming a Frenkel pair) or migrate to the surface to form part of a new crystal layer (resulting in a Schottky reaction). In ceramic materials, both the vacancy and interstitial defects are usually charged but the overall reaction is charge neutral. The energy necessary for this reaction to proceed is the energy to create one vacancy by removing an ion from the crystal to infinity plus the energy to create one interstitial ion by taking an ion from infinity and placing it into the crystal. Students together with the teacher will discuss the problem of defect structure in Non-stoichiometric and stoichiometric oxides. The next part of the lecture will be a discussion on the role of the discussed defects in the process of electrical conductivity. Students will learn about charge transport parameters. The lecture ends with a discussion of the applications of the acquired knowledge in the design of fuel cells and solid oxide fuel cells (SOFC). We will especially focus on ceramic-based membranes for fuel cells: processing and properties.

Topics 4

Pyroelectric and piezoelectric properties of ceramics

The first part of this lecture provides the basic and latest information on piezoelectric materials, which are capable of converting mechanical stress to electrical charge and vice versa. These piezoelectric effects have made them useful for a long time for sensors and actuators as well as in the control of structural vibration. Students will be introduced to the background of the theory of piezoelectricity, the definition of piezoelectric coefficients and their measurement methods. Listeners will be presented with general characteristics and differences between lead and lead-free-based piezoelectric materials. The ways to enhance piezoelectric properties will also be discussed during the lecture. The audience will learn the details of the use of piezoelectric materials to obtain energy from:

- human activity (human body motion, human joint motion),
- civil infrastructure and transportation,
- natural sources (such as wind energy and energy from rain).

The second part of the lecture is devoted to explaining pyroelectric effects principles. The definition of pyroelectric coefficients and methods of its measurements will be presented. The principle of pyroelectric energy harvesting using the Olsen cycle will be discussed in detail as well as other applications of pyroelectric materials to thermal and infrared detection.

By the end of the Ceramics Materials for Energy Harvesting course student:

- will have in-depth knowledge about the fundamentals of various ceramic materials in energy harvesting applications.
- understand the processes and issues in the manufacture of powder ceramic products.
- will be able to relate the chemical composition, crystal structure and microstructure of functional ceramics to the particular conductive, dielectric, ferroelectric, piezoelectric, pyroelectric and magnetic properties
- will be equipped with the skills to identify the latest technological developments in functional ceramic materials and innovatively use the above knowledge for applications in energy harvesting.
- will acquire the skill of surveying and critically evaluating relevant scientific literature and will be able to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work and leading discussions on materials for energy harvesting.

www.freepik.com

COURSE CONTENT - LECTURE

Topics 5

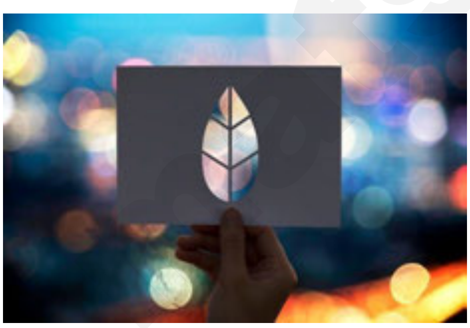
Dielectric and ferroelectric properties of ceramics

The first section of the lecture is an introduction to the large group of ceramics, namely dielectric materials. Dielectrics are insulating or nonconducting ceramics materials used in many applications such as capacitors, memories, sensors and actuators. First, Students will look at the simple properties of dielectric materials, such as dipole moment, polarization, permittivity, and polarization mechanisms. Subsequently, a detailed analysis of dielectric properties for each of the polarization mechanisms under the influence of alternating fields will be done, which is essential from the point of understanding the behaviour of these materials in real conditions. Various measurement techniques of dielectric properties, especially impedance spectroscopy, will be introduced. Finally, the breakdown mechanisms leading to dielectric materials' failure will be discussed.

In the second section of the lecture, ferroelectricity and ferroelasticity will be discussed with a particular focus on the effect of crystal structure and compositional phase boundaries, the role of domain wall motion and defects, and the influence of stress-induced structural phase transformations. Measurement techniques for characterizing the behaviour of discussed materials in the large field, such as the Sawyer-Tower circuit, will also be introduced. Students will be introduced to another class of materials, namely the ferroelectric relaxor ferroelectrics. Relaxor ferroelectrics are ferroelectric materials that exhibit high electrostriction. Relaxor Ferroelectric materials find application in high-efficiency energy storage and conversion as they are characterized by high dielectric constants, orders of magnitude higher than those of conventional ferroelectric materials. Like conventional ferroelectrics, relaxor ferroelectrics show permanent dipole moments in domains. However, these domains are on the nano-length size, whereas the classic ferroelectrics domains are generally on the micro-length size and take less energy to order. Consequently, relaxor ferroelectrics are marked by high capacitance and have thus generated interest in energy storage.

By the end of the Ceramics Materials for Energy Harvesting course student:

- will have in-depth knowledge about the fundamentals of various ceramic materials in energy harvesting applications.
- understand the processes and issues in the manufacture of powder ceramic products.
- will be able to relate the chemical composition, crystal structure and microstructure of functional ceramics to the particular conductive, dielectric, ferroelectric, piezoelectric, pyroelectric and magnetic properties
- will be equipped with the skills to identify the latest technological developments in functional ceramic materials and innovatively use the above knowledge for applications in energy harvesting.
- will acquire the skill of surveying and critically evaluating relevant scientific literature and will be able to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work and leading discussions on materials for energy harvesting.



www.freepik.com

COURSE CONTENT - LECTURE

Topics 6

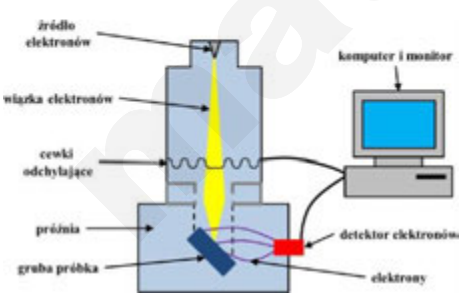
Introduction to energy harvesting

The advances in sensors, embedded processing, and wireless connectivity have fueled modern, small, autonomous electronic devices. Daily living depends on ubiquitous, miniature electronic systems, from implanted and portable biomedical devices, sensor-assisted control in cars, aeroplanes and industrial manufacturing, portable and mobile communication devices, and distributed sensor networks, to portable entertainment gadgets. Since users are always looking for seamless operation of this class of devices, which does not require their intervention to change or charge the battery, energy harvesting from the environment has emerged as a key solution for such systems. This is how the idea of energy harvesting was born

Harvesting of small amounts of energy available in the environment and converting it to electrical power. The power levels required for typical applications may range from microwatts to a few watts, and the energy scavenged from the environment may be able to recharge or even eliminate the battery by powering up autonomous devices perpetually. This lecture gives students a solid foundation to design energy harvesting circuits for autonomous systems. The harvesting system consists of three main components (a) an energy transducer that converters the energy from its free form in the environment into electrical energy, (b) interface circuits (power converters) that extract energy efficiently from the harvester and deliver it to the load, (c) control circuits for output voltage regulation, maximum power tracking, etc. In the final part of the lecture, examples of specific solutions will be given, among others multifunctional nanogenerators.

Students will be enabled to:

- measure the density and porosity of ceramics materials
- present difference between backscattered electrons (BSEs) and secondary electrons (SEs) images,
- calculate piezoelectric coefficients based on model of a forced harmonic oscillator,
- calculate the pyroelectric coefficient,
- know the origin of thermally stimulated depolarization current,
- use ZView program to obtain the value of equivalent circuit parameters.



Schematic form of SEM (M.Rerak)

COURSE CONTENT - LABORATORY

Topics 1

Testing the density and porosity and microstructure of ceramic materials.

The aim of the laboratory is to familiarize with the methods of measuring the density and porosity of ceramic materials. In addition, students learn the principles of sample preparation for research using a scanning electron microscope.

Topics 2

Microstructure images

The aim of the laboratory is to investigate the effect of various sintering conditions on the microstructure of perovskite ceramics. Students will be familiar with the based function of scanning electron microscopy. Different signals result from the interaction between electrons and matter, each carrying useful information about the sample. In the case of a scanning electron microscope (SEM), two types of electrons are typically detected: backscattered electrons (BSEs) and secondary electrons (SEs). BSEs come from deeper regions of the sample, whereas SE originates from surface regions. Thus, the two 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 surface information.

Topics 3

Determination of piezoelectric coefficients

The laboratory aims to familiarize 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 by this method. The model of a forced harmonic oscillator will be applied to find the characteristic piezoelectric frequencies and complex elastic compliances.

Students will be enabled to:

- measure the density and porosity of ceramics materials
- present difference between backscattered electrons (BSEs) and secondary electrons (SEs) images,
- calculate piezoelectric coefficients based on model of a forced harmonic oscillator,
- calculate the pyroelectric coefficient,
- know the origin of thermally stimulated depolarization current,
- use ZView program to obtain the value of equivalent circuit parameters.

www.freepik.com

COURSE CONTENT - LABORATORY

Topics 4

Measurements of pyroelectric current and calculation of the pyroelectric coefficient

The first part of the laboratory will be sacrificed for sample polarization. The process of polarization can take place in several different ways. Students will discuss the method and conditions of sample polarization. The process of polarization 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 polarized 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.

Topics 5

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

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.

www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Ceramics materials for the energy harvesting:*

1. A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, 2003
2. R. K. Pandey, Fundamentals of Electroceramics: Materials, Devices, and Applications, John Wiley & Sons, 2019
3. Ling Bing Kong, Tao Li, Huey Hoon Hng, Freddy Boey, Tianshu Zhang, Sean Li, Waste Energy Harvesting, Mechanical and Thermal Energies, Springer, 2014

To deepen the course topics, optional recommended texts include:

1. Narottam P. Bansal, Handbook of Ceramic Composites, Springer-Verlag, 2010.

ASSESMENT

Quiz:

At the start of each laboratory, a brief quiz will be given regarding the lab's subject matter that will be performed that day. This is done to ensure that the necessary literature recommended for the laboratory (and the concepts presented during the lecture) have been read beforehand, and that the students are ready to conduct the lab.

Reports:

Students will be grouped into teams and tasked with producing a written report on their experimental laboratory exercises. The report should include a theoretical background, a description of the experiments conducted, an analysis of the results, and a discussion and conclusions section. Through these reports, students will deepen their theoretical and practical knowledge in the field of materials for hydrogen energy.

Debate:

During the debate, the ability to present logical arguments and explain their relevance to the topic, the ability to respond to questions posed by other participants, and the ability to actively listen and participate in the discussion with other debate participants will be subject to evaluation.

GRADING POLICY

The *Ceramics materials for the energy harvesting* course is scored with points. The grade results from the sum of points obtained by the student during the semester (Quizes, Raports, Debate). The maximum number of points obtained in the laboratory exercises is 100. Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
4 Reports	50%
4 Quizes	40%
Debate	10%
Total	100%

Reports - max. 50 points
Quizes – max. 40 points
Debate – max. 10 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

MATERIALS FOR HYDROGEN ENERGY

Code: **MHE**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Materials & Manufacturing

Form of tuition and number of hours*:

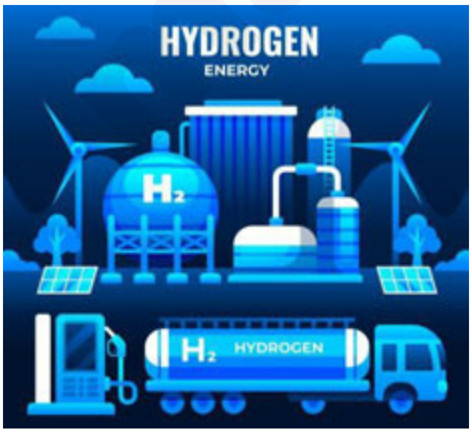
Lecture: 15 h

Laboratory: 30 h

ECTS

4

Lecturer:
Bożena Łosiewicz, PhD, DSc, Assoc. Prof.



www.freepik.com

COURSE DESCRIPTION

The Materials for Hydrogen Energy (MHE) course is to enable the student to acquire knowledge in the field of technological requirements, production and properties of new electrode materials for the production of green hydrogen, which is seen as the fuel of the future. The content of the module will present the latest trends in the development of innovative materials for hydrogen energy, capable of catalytically reducing the energy consumption of the water electrolysis process. The student will be familiarized with the basic principles of designing new engineering materials for the needs of high-efficiency fuel cells, taking into account their impact on the environment and methods of material analysis for hydrogen energy. The tasks of hydrogen economy will be discussed, including methods of hydrogen production, methods of hydrogen storage, infrastructure for hydrogen use and principles of safe hydrogen use. Prospects for the practical use of hydrogen as the most environmentally friendly energy carrier and the role of hydrogen in balancing greenhouse gas emissions and their absorption will be presented. The MHE module meets the growing and prospective needs of a sustainable hydrogen energy, whose basic assumptions and goals are in line with the national and European strategy for clean energy, decarbonisation and climate protection.

COURSE OBJECTIVES

The main objective of the MHE course is to comprehensively prepare students for work in the energy sector related to the production, storage, transmission and use of hydrogen as well as the design and operation of energy equipment and technological processes in which hydrogen is used. Students have the knowledge and skills to solve material problems that occur in the field of responsibility of enterprises, institutions or local government units and, in accordance with the assumed learning outcomes, are prepared to take up professional work in the field of hydrogen energy, industry and transport, as well as related fields.

PREREQUISITES FOR TAKING THE COURSE

Prerequisites for taking the MHE course include a basic knowledge of engineering materials, especially understanding the correlation between the nature of chemical bonds, crystallographic structure, electronic structure and transport properties, reactivity and stability of solids. Understanding the concepts and principles related to the electrochemical production of hydrogen and characterizing the properties of materials for hydrogen energy, and the principles of operation of electrochemical devices, including batteries, accumulators and fuel cells, is helpful.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Students will have extensive and in-depth knowledge about the construction and operation of various types of fuel cells. They will be able to experimentally determine the operating parameters of the fuel cell and select materials for the construction of the fuel cell, and design a laboratory model of the fuel cell.
MS_O_02	Students will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to materials for hydrogen energy with consideration of sustainable development principles.
MS_O_03	Students will be equipped with the skills to plan and conduct experiments to evaluate the impact of water electrolysis parameters on the corrosion resistance of electrode materials. In addition, they will have developed the ability to select appropriate testing methods, analyze the results, and optimize electrodeposition parameters in order to achieve the desired material properties.
MS_O_04	Students will be able to identify problems and challenges related to the safe use of hydrogen in the energy sector and prepare guidelines and issues relevant to the certification process for specialized entities. They will distinguish the issue of admitting a technology or product on special terms for the pilot or demonstration phase, as opposed to commercial solutions.
MS_O_05	Students will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on materials for hydrogen energy.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	10	course work	MS_O_01 MS_O_02	
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

By the end of the Materials for Hydrogen Energy course student:

- will have extensive and in-depth knowledge about the construction and operation of various types of fuel cells. They will be able to experimentally determine the operating parameters of the fuel cell and select materials for the construction of the fuel cell, and design a laboratory model of the fuel cell.
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to materials for hydrogen energy with consideration of sustainable development principles.
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of water electrolysis parameters on the corrosion resistance of electrode materials. In addition, they will have developed the ability to select appropriate testing methods, analyze the results, and optimize electrodeposition parameters in order to achieve the desired material properties.
- will be able to identify problems and challenges related to the safe use of hydrogen in the energy sector and prepare guidelines and issues relevant to the certification process for specialized entities. They will distinguish the issue of admitting a technology or product on special terms for the pilot or demonstration phase, as opposed to commercial solutions.
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on materials for hydrogen energy.

DO YOU KNOW

Hydrogen is the most common element in the universe. 88% of all atoms are hydrogen atoms so there is more hydrogen than any other substance. The name comes from the two Greek words hydro and genes, which together mean 'water-forming'. Hydrogen atoms were made in the Big Bang, when the universe is believed to have started.

www.freepik.com

COURSE CONTENT - LECTURE

Topics 1

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

This lecture combines theory with latest scientific results and practical approaches to design and engineering of materials for hydrogen energy. The lecture serves as an introduction to the carbon neutral hydrogen technologies playing a role in preventing climate change and ensuring sustainable development. This lecture deals with the maximizing production of hydrogen in a clean efficient manner, which is critical to the hydrogen economy. The state-of the-art and future developments of modern hydrogen technologies are presented. Attention is given to the renewable energy, including the role of renewable hydrogen and hydrocarbon fuels, and possible renewable energy sources. The criteria for selecting the fuel of the future are discussed. The lecture describes hydrogen as an alternative and environment-friendly energy carrier, which is the missing link to a successful green energy transition. The main advantages of hydrogen as a fuel are presented. The lecture focuses on the tasks of the hydrogen economy including methods of hydrogen production, hydrogen purification and transfer, hydrogen storage, and conversion of hydrogen chemical energy into electricity using fuel cells. The challenges facing hydrogen technologies and the barriers to their use are outlined. Additionally, the lecture highlights the fundamental importance of scientific research for the development of the hydrogen economy.

Topics 2

Materials used in the hydrogen production

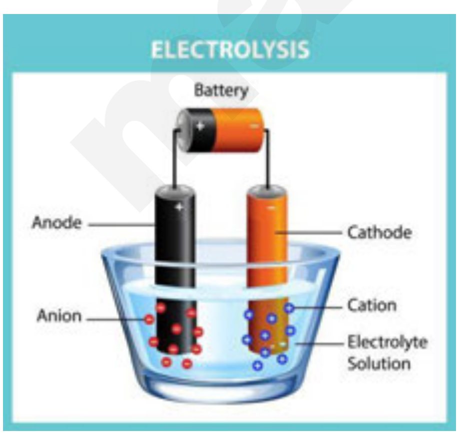
This lecture provides an in-depth treatment of the hydrogen production by exploring the fundamentals required for the selection of the materials, their synthesis methods, and possible ways to modify them for higher efficiency and enhanced stability. The lecture discusses various technical challenges to making the hydrogen production into a reality and provides an understanding of these challenges. The lecture focuses on hydrogen production methods with particular emphasis on low- or zero-emission methods. The lecture introduces a classification of hydrogen depending on the extraction/production technology as black, brown, grey, blue, green or pink, where brown hydrogen is obtained as a result of coal gasification, grey hydrogen is produced from fossil fuels, blue hydrogen is generated in steam reforming, and green hydrogen is produced by the water splitting. Pink hydrogen involving the electrolysis of water using electricity, but with nuclear energy as the source is also provided. The lecture highlights the importance of green hydrogen obtained by water electrolysis using electricity generated by renewable electricity as solar energy, wind energy and others. The lecture explains how to solve the problems of water electrolysis by better construction of the hydrogen generator and decreasing hydrogen and oxygen overpotentials using catalytic electrodes. Different ways to produce, characterize kinetics and mechanism of hydrogen evolution, and improve activity of electrodes, are also discussed.

By the end of the Materials for Hydrogen Energy course student :

- will have extensive and in-depth knowledge about the construction and operation of various types of fuel cells. They will be able to experimentally determine the operating parameters of the fuel cell and select materials for the construction of the fuel cell, and design a laboratory model of the fuel cell.
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to materials for hydrogen energy with consideration of sustainable development principles.
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of water electrolysis parameters on the corrosion resistance of electrode materials. In addition, they will have developed the ability to select appropriate testing methods, analyze the results, and optimize electrodeposition parameters in order to achieve the desired material properties.
- will be able to identify problems and challenges related to the safe use of hydrogen in the energy sector and prepare guidelines and issues relevant to the certification process for specialized entities. They will distinguish the issue of admitting a technology or product on special terms for the pilot or demonstration phase, as opposed to commercial solutions.
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on materials for hydrogen energy.

DO YOU KNOW

8.92 liters of demineralized water are needed to produce 1 kg of green hydrogen and 8 kg of oxygen by water electrolysis.



www.freepik.com

COURSE CONTENT - LECTURE

Topics 3

Materials used in the hydrogen storage and transport

This lecture focuses on new developments of hydrogen storage technologies and deals with an overview of the materials and science necessary for storing hydrogen with great attention to the synthesis, kinetics, and thermodynamics of new advanced materials including nanomaterials produced using top-down and bottom-up approach. The lecture introduces students to the problems of hydrogen storage and transport, especially for mobile applications. Limitations of current methods of storing renewable hydrogen including geological hydrogen storage, liquified hydrogen, compressed and cold/cryo compressed hydrogen storage, and materials-based storage, are described. This lecture explains physically bound hydrogen storage in zeolites, carbon nanostructures, and metal-organic framework materials. The lecture emphasizes the storage of hydrogen in lightweight solids as emerging technology for hydrogen storage and transport. This lecture enables knowledge of solid-state hydrogen storage system design. It provides chemically bound hydrogen storage in intermetallics, magnesium hydrides, alanates, borohydrides, imides, amides, and multicomponent hydrogen storage systems. Organic liquid carriers for hydrogen storage and indirect hydrogen storage in metal ammines is also the subject of the lecture. During the lecture, methods for determining the content of stored hydrogen and new concepts of hydrogen storage are explained.

Topics 4

Fundamentals and principles of water electrolysis

This lecture aims with hydrogen as an opportunity to balance the unstable energy system, which is still renewable energy sources. Special emphasis is given to the water electrolysis method for green hydrogen production in a net-zero future. The lecture explains fundamentals and principles of water electrolysis including water electrolysis cell, thermodynamics, non-equilibrium thermodynamics, and cell efficiencies. The brief history of water electrolysis from its beginnings to the present with focus on new markets for renewables energies is presented. The subject of the lecture is alkaline electrolysis, its status and prospects, physical and chemical principles of alkaline electrolysis, principle of operation of an alkaline electrolyzer, technical concepts of alkaline electrolysis, materials, degradation effects in alkaline electrolyzers, anion exchange membrane electrolysis, description of technical plants, and future prospects of alkaline electrolysis. This lecture explains proton exchange membrane (PEM) water electrolysis, its general principle, cell and stack materials, performance, degradation mechanisms and lifetime, cost breakdown, highlights of recent years and new concepts. General principles of high temperature steam electrolysis, chlor–alkali electrolysis, seawater electrolysis, and regenerative fuel cells based on PEM technology, are provided. The lecture contains economic considerations for hydrogen production with a focus on PEM electrolysis. New electrolyzer principles of decoupled photoelectrochemical and photocatalytic water splitting are discussed.

By the end of the Materials for Hydrogen Energy course student:

- will have extensive and in-depth knowledge about the construction and operation of various types of fuel cells. They will be able to experimentally determine the operating parameters of the fuel cell and select materials for the construction of the fuel cell, and design a laboratory model of the fuel cell.
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to materials for hydrogen energy with consideration of sustainable development principles.
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of water electrolysis parameters on the corrosion resistance of electrode materials. In addition, they will have developed the ability to select appropriate testing methods, analyze the results, and optimize electrodeposition parameters in order to achieve the desired material properties.
- will be able to identify problems and challenges related to the safe use of hydrogen in the energy sector and prepare guidelines and issues relevant to the certification process for specialized entities. They will distinguish the issue of admitting a technology or product on special terms for the pilot or demonstration phase, as opposed to commercial solutions.
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on materials for hydrogen energy.

DO YOU KNOW

NASA is developing a light-weight fuel cell technology to meet the expected energy demands for surface exploration vehicles and energy storage on the surface of the Moon or Mars. Fuel cells are not only a source of electricity, but also drinking water in the Space.

www.freepik.com

COURSE CONTENT - LECTURE

Topics 5

Fuel cells: From fundamentals to applications

This lecture presents the most important information about the use of hydrogen to power fuel cells producing electricity and heat in an emission-free way. The lecture provides the issues related to the construction and methods of development and testing fuel cells, the evaluation of the performance and lifetime of fuel cells and the concepts of hydrogen production. The lecture begins with a brief history of fuel cells. The fundamentals and principles of the fuel cell including thermodynamic and electrochemical basics of fuel cell operation and the chemical reactions that take place in a fuel cell, are discussed. Fuel cell efficiency and factors its limiting is explained. The lecture presents the classification of fuel cells due to operating temperature, electrolytes and fuels. It explores the advantages and disadvantages of fuel cell technologies. The lecture discusses the technological requirements, preparation and properties of new electrode materials for the construction of 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 other types of fuel cells like redox flow cells, biological fuel cells, semi-fuel cells, and direct carbon fuel cells. The perspectives of fuel cell applications as well as impact of fuel cells on the environment are outlined.

Topics 6

Use of hydrogen in industry, energy and transport

This lecture presents the current state and latest development trends of hydrogen economy with the focus on applications. It gives an overview of the hydrogen utilization as it relates to the transport technology, such as automobiles, heavy-duty vehicles, trains, ships, air, and space transport and industry. This lecture describes the materials used in the utilization of hydrogen for transportation and energy production. Large attention is given to structural and functional materials science, technologies and innovations with focus on the development of new materials and electrolytes for specific applications. Strictly related to mobility is the relation between vehicles and refuel stations, the safety analysis, risk assessment for both infrastructures and transport. The content of the lecture deals with the commercialization of fuel cells for large stationary power plants, small stationary power, transport, portables, military applications, and handicaps preventing a broader commercialization of fuel cells. The main applications of PEFCs for transport, but also space technology vehicles are discussed. The lecture explores AFCs in the context of applications in transport, vehicle and boat power. PAFCs are characterized as an example of already commercialized types of fuel cells that are used as a source of electricity and heat in public facilities (hospitals, offices, small housing estates). This lecture introduces plans to use SOFCs in large, high-power installations. It presents limitations in the use of MCFCs for the production of large amounts of heat, which is used for heating purposes and in technological processes.

By the end of the Materials for Hydrogen Energy course student:

- will have extensive and in-depth knowledge about the construction and operation of various types of fuel cells. They will be able to experimentally determine the operating parameters of the fuel cell and select materials for the construction of the fuel cell, and design a laboratory model of the fuel cell.
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to materials for hydrogen energy with consideration of sustainable development principles.
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of water electrolysis parameters on the corrosion resistance of electrode materials. In addition, they will have developed the ability to select appropriate testing methods, analyze the results, and optimize electrodeposition parameters in order to achieve the desired material properties.
- will be able to identify problems and challenges related to the safe use of hydrogen in the energy sector and prepare guidelines and issues relevant to the certification process for specialized entities. They will distinguish the issue of admitting a technology or product on special terms for the pilot or demonstration phase, as opposed to commercial solutions.
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on materials for hydrogen energy.

DO YOU KNOW

Hydrogen can be produced from diverse, domestic resources including fossil fuels, biomass, and water electrolysis with wind, solar, or grid electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced.

www.freepik.com

COURSE CONTENT - LECTURE

Topics 7

Safety of hydrogen use

The lecture discusses the risks associated with the use of hydrogen that pose a threat to the safety of hydrogen use, such as flammability, susceptibility of materials to hydrogen embrittlement, permeability, hydrogen leakage, low temperatures during transport, high pressure for hydrogen transport in the form of compressed gas, mixture of hydrogen with other gases and explosiveness of hydrogen. Hydrogen safety covering the safe production, handling and use of hydrogen, particularly hydrogen gas fuel and liquid hydrogen is described. The lecture presents the general characteristics of activities aimed at creating a secure chain of technical links in the entire logistics process, including the production, storage and delivery of hydrogen to recipients. The lecture includes a description of fire hazards, prevention of fires and hydrogen explosions. It provides a risk analysis of hydrogen systems. Certification and law regulations for hydrogen energy are discussed. The lecture presents in detail the certification of hydrogen technologies, the certification of the source of hydrogen, the certification of transport and storage equipment and systems in land and water transport applications, and the certification of electrolysers. The lecture explores hydrogen codes and standards for hydrogen fuel cell vehicles, stationary fuel cell applications and portable fuel cell applications.

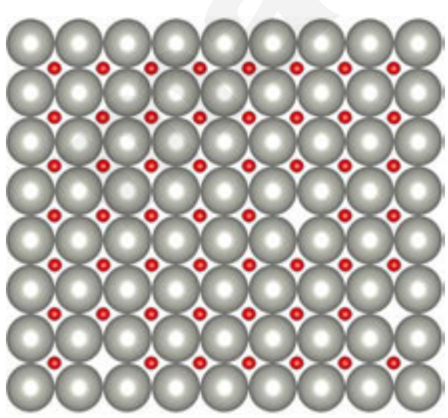
Co-funded by the European Union

Students will be enable to:

- Electrodeposit nickel electrocatalysts
- Produce green hydrogen by electrolysis of water
- Store hydrogen in metals by electrochemical methods
- Construct and test electrochemical properties of a polymer electrolyte membrane fuel cell
- Determine destructive effect of hydrogen electroevolution on metallic electrodes
- Evaluate the potential of materials for hydrogen energy in achieving sustainable development goals and devise strategies for its implementation in industry

DO YOU KNOW

Hydrogen offers a promising alternative for supplying clean and sustainable energy to meet increasing demands worldwide. However, materials are key to transforming the technology into a viable industry.



Palladium hydride structure

COURSE CONTENT - LABORATORY

Topics 1

Electrodeposition of nickel electrocatalysts

The aim of the laboratory is to investigate the effect of various electrodeposition conditions on the quality of nickel electrocatalysts using the Hull cell. By varying the operating parameters as electrolyte composition, current and time, and analyzing their effects on the quality of electrodeposited coatings, students will gain a better understanding of how to optimize electrodeposition parameters in a new electrolyte, how the electrodeposition of metallic coatings using the Hull cell can be performed, and how the current efficiency in the process of cathodic deposition of metallic coatings can be determined.

Topics 2

Production of green hydrogen by electrolysis of water

The aim of the laboratory is to investigate the effect of various electrolytes on the electrocatalytic properties of nickel electrocoatings towards hydrogen evolution using the method of water electrolysis. The effects of operating parameters such as electrolyte composition and overpotential of hydrogen electroevolution will be examined. The electrocatalytic properties of nickel electrodes will be evaluated using electrochemical methods. By varying the water electrolysis parameters and analyzing their effects on the hydrogen production, students will gain a better understanding of how to produce green hydrogen and how to determine electrocatalytic activity of metallic electrodes in the reaction of hydrogen evolution in water electrolytes.

Topics 3

Hydrogen storage in metals by electrochemical methods

The aim of the laboratory is to investigate the effect of various electrosorption parameters on the hydrogen storage in metals. The effects of operating parameters as electrolyte composition, potential and time of hydrogen electrosorption will be examined. The storage in metallic electrodes will be evaluated using electrochemical methods. By varying the electrosorption parameters and analyzing their effects on the hydrogen storage, students will gain a better understanding of how to accumulate hydrogen in an electrochemical way, and how to determine amount of hydrogen accumulated in metallic electrodes and the hydrogen diffusion and desorption rate.

Students will be enable to:

- Electrodeposit nickel electrocatalysts
- Produce green hydrogen by electrolysis of water
- Store hydrogen in metals by electrochemical methods
- Construct and test electrochemical properties of a polymer electrolyte membrane fuel cell
- Determine destructive effect of hydrogen electroevolution on metallic electrodes
- Evaluate the potential of materials for hydrogen energy in achieving sustainable development goals and devise strategies for its implementation in industry

DO YOU KNOW

Compared to conventional gasoline vehicles, hydrogen fuel cell vehicles can even reduce carbon dioxide by up to half if the hydrogen is produced by natural gas and by 90%, if the hydrogen is produced by renewable energy, such as wind and solar. There are also no pollutants emitted from the tailpipe — just water!

www.freepik.com

COURSE CONTENT - LABORATORY

Topics 4

Construction and testing of electrochemical properties of a polymer electrolyte membrane fuel cell

The aim of the laboratory is to acquire the skills of practical use of hydrogen as the most environmentally friendly energy carrier on the example of a car model in which traditional fuels (gasoline, diesel oil, petroleum) have been replaced with hydrogen. The launch of a car model powered by hydrogen as fuel in a reversible fuel cell will be preceded by electrolysis of distilled water in the electrolyser using an external power source or solar panel, separate storage of gaseous hydrogen and oxygen in fuel cell tanks with a polymer membrane, and flammability test of the accumulated hydrogen. The next stage will be the assembly of the PEM fuel cell with gas tanks on the car chassis, and then starting the vehicle as a result of hydrogen combustion in the presence of oxygen with the simultaneous release of heat and water as a combustion product. The combustion product (water) will be used for re-electrolysis and obtaining gaseous hydrogen and oxygen.

Topics 5

Destructive effect of hydrogen electroevolution on metallic electrodes

The aim of the laboratory is to investigate the effect of hydrogen evolution reaction on micromechanical properties and corrosion resistance of metallic electrodes in water electrolytes. The effects of operating parameters such as electrolyte composition, overpotential and time of hydrogen electroevolution will be examined. The evaluation of the micromechanical properties of the tested metallic electrodes before and after hydrogen evolution will be carried out on the basis of Vickers microhardness tests. The corrosion resistance of metallic electrodes before and after hydrogen evolution will be evaluated using electrochemical methods. By varying the water electrolysis parameters and analyzing their effects on the microhardness and corrosion resistance, students will gain a better understanding of how to determine micromechanical properties and corrosion performance of metallic electrodes in water electrolytes.

www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Materials for Hydrogen Energy*:

1. Van de Voorde, Marcel, Volume 1, Hydrogen Production and Energy Transition, De Gruyter, 2021.
2. Van de Voorde, Marcel, Volume 2, Hydrogen Storage for Sustainability, De Gruyter, 2021.
3. Van de Voorde, Marcel, Volume 3, Utilization of Hydrogen for Sustainable Energy and Fuels, De Gruyter, 2021.
4. Pooja Devi, Green Energy Harvesting: Materials for Hydrogen Generation and Carbon Dioxide Reduction, Willey, 2020.

To deepen the course topics, optional recommended texts include:

1. Dengwei Jing, Handbook of Hydrogen Energy: The Entire Hydrogen Systems, Wiley-VCH; 1st edition, 2023.
2. Duncan Seddon, Hydrogen Economy, The Hydrogen Economy: Fundamentals, Technology, Economics, World Scientific Publishing Co Pte Ltd, 2022.
3. Marco Alverà, The Hydrogen Revolution: A Blueprint for the Future of Clean Energy, Basic Books, 2021.

ASSESMENT

Quiz:

At the start of each laboratory, a brief quiz will be given regarding the lab's subject matter that will be performed that day. This is done to ensure that the necessary literature recommended for the laboratory (and the concepts presented during the lecture) have been read beforehand, and that the students are ready to conduct the lab.

Reports:

Students will be grouped into teams and tasked with producing a written report on their experimental laboratory exercises. The report should include a theoretical background, a description of the experiments conducted, an analysis of the results, and a discussion and conclusions section. Through these reports, students will deepen their theoretical and practical knowledge in the field of materials for hydrogen energy.

Debate:

During the debate, the ability to present logical arguments and explain their relevance to the topic, the ability to respond to questions posed by other participants, and the ability to actively listen and participate in the discussion with other debate participants will be subject to evaluation.

GRADING POLICY

The *Materials for Hydrogen Energy* course is scored with points. The grade results from the sum of points obtained by the student during the semester (Quizes, Raports, Debate). The maximum number of points obtained in the laboratory exercises is 100. Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
4 Reports	50%
4 Quizes	40%
Debate	10%
Total	100%

Reports - max. 50 points
Quizes – max. 40 points
Debate – max. 10 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

POWDER METALLURGY

Code: **PM**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Materials & Manufacturing

Form of tuition and number of hours*:

Lecture: 15 h

Laboratory: 30 h

ECTS

4

https://www.pickpm.com/

COURSE DESCRIPTION

The lecture will cover various concepts of powder metallurgy and introduce powder metallurgy technology, from the beginnings of experiments in this field to current industrial applications. Students will be able to learn about different processes and technologies related to powder metallurgy methods. The powder production, compaction, shaping, and sintering components for industrial applications by powder metallurgical will be explained. In addition, participants will gain knowledge of powder analysis methods and the structure, defects, and microstructure of products prepared by powder metallurgy technologies, and their different variants of manufacturing processing will be discussed. The microstructure, density, porosity, and other properties of powder metallurgical components will be investigated with an emphasis on their design and applications. At the end of the lecture, issues related to sustainable industrial development and strategies to achieve sustainable development goals using powder metallurgy technologies will be discussed.

During the laboratory, students can apply the knowledge gained in lectures and develop practical skills in powder metallurgy technology. In addition, they will enhance their abilities to evaluate the quality of powders and final components prepared by powder metallurgy technologies. They will be able to identify problems and challenges related to the use of powder metallurgy technology for the production of products and propose solutions aimed at optimiiing ones, depending on the types and properties of the materials and the desired properties of the final product.

Furthermore, students will be proficient in selecting appropriate testing methods, analyiing the results, and optimiiing process parameters to achieve desired material properties using powder metallurgy techniques.

COURSE OBJECTIVES

The main objective of this course is to provide students with a comprehensive understanding of the powder metallurgy method. By the end of the course, students will have gained a thorough understanding of the principles and concepts that underlie the powder metallurgy method and be equipped with the knowledge and skills necessary to make informed decisions about its use in practical applications.

PREREQUISITES FOR TAKING THE COURSE

Prerequisites for taking the course include a basic understanding of manufacturing processes and materials science. Additionally, a prior knowledge of various engineering materials, their structure, properties, and applications may help understand the concepts and principles related to the powder metallurgy method.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Students will have extensive and in-depth knowledge of the powder metallurgy method. They will be able to accurately select the appropriate technology for a given project and understand the key factors that influence the quality and reliability of the manufactured parts.
MS_O_02	Students will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to powder metallurgy method with consideration of sustainable development principles.
MS_O_03	Students will acquire the necessary skills to plan and conduct experiments to evaluate the impact of powder metallurgy method parameters and types on the resulting materials. In addition, they will have developed the ability to select appropriate testing methods, analyie the results, and optimiie process parameters to achieve the desired material properties.
MS_O_04	Students will be able to identify problems and challenges related to using the powder metallurgy method for producing products and propose solutions aimed at optimiiing the powder metallurgy method, depending on the properties of the materials and the desired properties of the final product.
MS_O_05	Students will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and conclusion. They will acquire skills in individual and team-based work and leading discussions on additive manufacturing.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: Lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate; brainstorm	MS_O_03 MS_O_04
Meth_03	**Team project:** Critical analysis, synthesis, and conclusions; individual and teamwork; communication on specialist topics, leading a debate; SWOT analysis	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of Conducting Classes
FT_01	lecture	15	course work	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

By the end of the powder metallurgy course student:

- will have extensive and in-depth knowledge about the various powder metallurgy technologies,
- appreciate the importance of powder metallurgy technology for production of materials and components in comparison with other fabrication techniques,
- will know the advantages, limitations and applications of powder metallurgy technique,
- will be able to develop and design powder metallurgical components for specific applications and needs of various industries,
- will be able to choose the production method to get the required siie and shape of the powders,
- will gain the knowledge of various characteriiation methods to control the properties of the powders and components prepared by the powder metallurgy method,
- will be able to accurately select the appropriate technology for a given project and understand the key factors that influence the quality and reliability of the manufactured parts,
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to the powder metallurgy method with consideration of sustainable development principles,
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of powder metallurgy technology parameters and types on the resulting materials,
- will have developed the ability to select appropriate testing methods, analyie the results, and optimiie process parameters in order to achieve the desired material properties,
- will be able to identify problems and challenges related to the use of powder metallurgy technologies for the production of products and propose solutions aimed at optimiiing powder metallurgy technologies, depending on the properties of the materials and the desired properties of the final product,
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on powder metallurgy technologies,

COURSE CONTENT - LECTURE

Topics 1

Introduction to Powder Metallurgy: history; advantages and limitations of powder metallurgy; applications of powder metallurgy

During the lecture, Students will be introduced to powder metallurgy technology and learn the basic terms and concepts of powder metallurgy. In addition, the lecture will provide an opportunity to learn about the history of this method from its beginning to current industrial applications. In addition, the most important properties of various powder metallurgy technologies, including their advantages and disadvantages, will also be presented.

Topics 2

Powder production methods and their characteristics.

During this lecture, participants will also learn about the preparation methods of powders and some compounds: mechanical, physical-mechanical, physical-chemical, and physical-chemical methods. During this lecture, students will learn about the properties of powders and selected methods of their study: siie, shape, and structure of powder particles, specific surface area of powders, and technological properties.

Topics 3

Compaction of powders

During the lecture, Students will 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 will also be presented, including the phenomena occurring during compacting, the mechanism of powder compaction, the role of friction, ejection pressure, and the expansion of green compacts. In addition, pressure and non-pressure powder compaction techniques will be discussed: matrix compaction, cold isostatic pressing, powder rolling, powder forging, and explosive forming. The lecture will also review high-temperature compaction methods: hot pressing, hot extrusion, spark plasma sintering, and HIP.
In addition, the lecture will 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.

By the end of the powder metallurgy course student:

- will have extensive and in-depth knowledge about the various powder metallurgy technologies,
- appreciate the importance of powder metallurgy technology for production of materials and components in comparison with other fabrication techniques,
- will knowledge the advantages, limitations and applications of powder metallurgy technique,
- will can develop and design powder metallurgical components for specific applications and needs of various industries,
- able to choose the production method to get the required siie and shape of the powders,
- will knowledge of various characteriiation methods to control the properties of the powders and components prepared by the powder metallurgy method,
- will be able to accurately select the appropriate technology for a given project and understand the key factors that influence the quality and reliability of the manufactured parts,
- will be able to use information from literature and other available sources, interpret and critically evaluate them, draw conclusions, and formulate and solve problems related to the powder metallurgy method with consideration of sustainable development principles,
- will be equipped with the skills to plan and conduct experiments to evaluate the impact of powder metallurgy technology parameters and types on the resulting materials,
- will have developed the ability to select appropriate testing methods, analyie the results, and optimiie process parameters in order to achieve the desired material properties,
- will be able to identify problems and challenges related to the use of powder metallurgy technologies for the production of products and propose solutions aimed at optimiiing powder metallurgy technologies, depending on the properties of the materials and the desired properties of the final product,
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on powder metallurgy technologies,
- will develop the ability to prepare scientific reports and presentations, including critical analysis, synthesis, and drawing conclusions. They will acquire skills in both individual and team-based work, as well as leading discussions on powder metallurgy technologies.

COURSE CONTENT - LECTURE

Topics 4

Principles and practice of sintering

During the lecture, Students will be introduced to the issues of sintering methods for powders and green compacts. Definitions of sintering, mechanisms of sintering, stages of sintering, driving forces of the process, and mechanisms of matter transport will be presented. In addition, the lecture will also discuss the principles of sintering single and multi-component materials, and the Lecturer will explain the phenomena occurring during sintering.
During this lecture, students will learn about the possibilities and limitations of sintering in the presence of a liquid phase. In addition, at the end of the lecture, the rules of sintering furnaces in air and protective atmospheres will be explained, including a discussion of the different types of protective atmospheres used in sintering green compacts.

Topics 5

Finishing treatment and application of components prepared by powder metallurgy technology

During the lecture, Students will be introduced to finishing topics, including a detailed presentation of the heat and thermochemical treatment of sintering.
In addition, the lecture will also discuss the principles of sinter property testing, including porosity, microstructure, phase composition, and mechanical properties.
At the end of the lecture, the concept of obtaining composites by powder metallurgy will be explained, as well as the definition of composites and their classification.
In addition, in this part of the lecture, the Lecturer will present examples of properties, structures, and applications of various composite components produced by powder metallurgy technology.

Students will be:

- enable to develop and design powder metallurgical components for specific applications and needs of various industries
- able to choose the production method to get the required siie and shape of the powders,
- able to use of various characteriiation methods to control the properties of the powders,
- able to understand the key factors influencing the quality and reliability of manufactured parts,
- able to conduct a comprehensive analysis of the microstructure and properties of components produced by various powder metallurgy methods,
- able to evaluate the potential of powder metallurgy in achieving sustainable development goals and devise strategies for its implementation in industry,

COURSE CONTENT - LABORATORY

Topics 1

Project overview, technological analysis, technological allowances, and green compact technology selection.

The Laboratory aims to present the assumptions of the project. In addition, the student will develop an analysis of the phase diagram's producibility, so he will develop a set of design features of a specific item that allows it to be easily made in given production conditions.
During laboratory classes, students will work alone or in a group, sharing tasks and working together to establish a work plan, analyie results, and draw conclusions. The completed experiment will be the basis for preparing the exercise report.

Topics 2

Research of physical and technological properties of powders. Powder properties: Determination of bulk density and flowability of metal powders. Preparation of powder samples.

The laboratory aims to present methods of testing powders' physical and technological properties. In addition, the students will prepare powder samples. The completed experiment will be the basis for preparing the exercise report.

Topics 3

Powder homogenization (mixing in a planetary mill, mechanical synthesis)

The Laboratory aims to present the student with the practical basics of powder homogeniiation methods. In addition, the student will be able to learn about mixing or mechanical synthesis in a ball mill. The completed experiment will be the basis for preparing the exercise report.

Topics 4

Pressing powders: Pressing powders with (or without) porogen's at various pressing forces

The Laboratory aims to present the student with the practical basics of pressing powders. 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 porogens, and powder compaction.
Also, the Laboratory aims to present the student with the practical basics of pressing powders with (or without) the addition of porogens at various pressing forces to obtain uniform compacts. The completed experiment will be the basis for preparing the exercise report.

Students will be enable to:

- develop and design powder metallurgical components for specific applications and needs of various industries
- able to choose the production method to get the required siie and shape of the powders,
- able to use of various characteriiation methods to control the properties of the powders,
- able to understand the key factors influencing the quality and reliability of manufactured parts,
- able to conduct a comprehensive analysis of the microstructure and properties of components produced by various powder metallurgy methods,
- able to evaluate the potential of powder metallurgy in achieving sustainable development goals and devise strategies for its implementation in industry,

COURSE CONTENT - LABORATORY

Topics 5

Sintering of powders: Parameters of the sintering process of metal powder green compacts. Determination of linear and volumetric shrinkage after the sintering process

The Laboratory aims to present the student with the practical basics of sintering green compacts. The student will select the sintering time and temperature, taking into account the properties of the used powders. The completed experiment will be the basis for preparing the exercise report.
Also, the Laboratory aims to present the student with the practical basics of sintering in air or protective gases. In addition, the student will prepare the charge for the furnace and carry out the sintering process.

Topics 6

Properties of sintered products: Effect of sintering and pressing pressure on the properties and dimensions of sintered products

The Laboratory aims to present the student with a practical basis for assessing the quality and properties of the obtained sinters. The student will analyie the effect of sintering and pressing pressure on the properties and dimensions of sinters by measuring the mass, volume, and dimensions of the obtained sinters. The completed experiment will be the basis for preparing the exercise report.

Topics 7

Metallographic preparation of sintered materials

The Laboratory aims to present the student with the practical basics of preparing the materials for further characteristics and analysis. Using the university infrastructure, the student will prepare a metallographic microsection and etch the sinters. The completed experiment will be the basis for preparing the exercise report.

Students will be enable to:

- develop and design powder metallurgical components for specific applications and needs of various industries
- able to choose the production method to get the required siie and shape of the powders,
- able to use of various characteriiation methods to control the properties of the powders,
- able to understand the key factors influencing the quality and reliability of manufactured parts,
- able to conduct a comprehensive analysis of the microstructure and properties of components produced by various powder metallurgy methods,
- able to evaluate the potential of powder metallurgy in achieving sustainable development goals and devise strategies for its implementation in industry,

COURSE CONTENT - LABORATORY

Topics 8

Testing of sintered materials - SEM and OM microscopic examinations

The Laboratory aims to present the student with the practical basics of microscopic study. To analyie the microstructure, the student will perform selected experiments with OM and SEM methods as part of laboratory classes. The completed experiment will be the basis for preparing the exercise report.

Topics 9

Testing of sintered materials - XRD, porosimeter, microhardness

The laboratory will present the student with the practical basics of studying physical and mechanical properties. The student will perform selected XRD experiments to carry out the structural analysis of nanomaterials. To analyie the basic mechanical properties, the student will conduct microhardness tests. However, to assess the porosity, the Student will perform an analysis based on the results from stereometrics and experiment on a porosimeter. The completed experiment will be the basis for preparing the exercise report.

Topics 10

Final exercises: presentation of results, debate, test.

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 pass the Student written test of knowledge from the Powder Metallurgy laboratory.

Co-funded by the European Union

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Additive Manufacturing*:

1. Powder Metallurgy Science, Technology and Applications – P.C. Angelo & R. Subramanian
2. Powder Metallurgy – J.S. Hirschhorn
3. Treatise on Powder Metallurgy – C. Goetiel, 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.

ASSESSMENT

Quiz:

At the start of each laboratory, a brief quii will be given regarding the lab's subject matter that will be performed that day. This is done to ensure that the necessary literature recommended for the laboratory (and the concepts presented during the lecture) have been read beforehand and that the students are ready to conduct the lab.

Reports:

Students will be grouped into teams and tasked with producing a written report on their experimental laboratory exercises. The report should include a theoretical background, a description of the experiments conducted, an analysis of the results, and a discussion and conclusions section. Students will deepen their theoretical and practical knowledge in powder metallurgy technology through these reports.

Debate:

During the debate, the ability to present logical arguments and explain their relevance to the topic, respond to questions posed by other participants, and actively listen and participate in the discussion with other debate participants will be subject to evaluation.

GRADING POLICY

The Powder Metallurgy course is scored with points. The grade results from the sum of points obtained by the student during the semester (Quiies, Raports, Debate). The maximum number of points obtained in the laboratory exercises is 100. Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
4 Reports	50%
4 Quiies	40%
Debate	10%
Total	100%

Reports - max. 50 points
Quiies – max. 40 points
Debate – max. 10 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information on the didactic form in which the course is implemented (e.g., lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (e.g., lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organiied for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

MODERN METALLIC MATERIALS FOR SUSTAINABLE INDUSTRY

Code: **MMMSI**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

1

Language

English

Thematic block

Advanced Engineering Materials

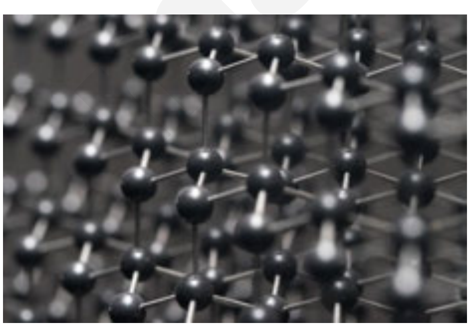
Form of tuition and number of hours*:

Lecture: 10h

Laboratory: 30h

ECTS

3



www.freepik.com

COURSE DESCRIPTION

The proposed *Modern Metallic Materials for Sustainable Industry* course is focused on introducing students to the topic of modern metallic materials used in a sustainable industry. During the course students will gain knowledge about the structure, manufacturing and processing methods of the metallic materials and how they influence selected properties of the metallic materials. An important aspect of the proposed course will be the application of selected metallic materials in modern industry with a specific emphasis on their contribution to sustainable practices and environmental preservation.

The sustainable industry refers to the implementation of environmentally friendly practices, resource optimization, and responsible manufacturing methods within industrial sectors. It involves minimizing negative environmental impacts, reducing carbon emissions, conserving resources, and promoting long-term ecological balance. The course explores how metallic materials can play a crucial role in achieving these sustainability goals across diverse industry sectors, such as automotive, aerospace, energy, construction, and electronics.

Lectures are aimed at providing information on sustainable nanocrystalline materials, methods of their production, properties and applications. Laboratory exercises are intended for individual student work, independent performance of experiments and independent analysis leading to the individual elaboration of the obtained results in the form of a report, along with relevant studies and conclusions.

COURSE OBJECTIVES

By the end of the *Modern Metallic Materials for Sustainable Industry* course, the students will be able to describe the structure of metallic materials and how it is related to the basic mechanical and transport properties. Students will be able to identify selected groups of metallic materials and indicate potential applications. Students should be able to propose basic manufacturing and processing methods for materials preparation and modification of their properties.

PREREQUISITES FOR TAKING THE COURSE

Before starting the study of the subject *Modern Metallic Materials for Sustainable Industry,* students should have a general knowledge of the basics of materials science, crystallography and materials testing methods.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MMMSI_O_01	The student person has extensive and in-depth knowledge in the field of structure and selected properties as well as can propose the production process and processing of metallic materials
MMMSI_O_02	The student person can use information from literature and other available sources, interpret and critically evaluate them, draw conclusions and formulate and solve problems related to the structure, selected properties and manufacturing and processing of the metallic materials for application in the sustainable industry.
MMMSI_O_03	**The student person can distinguish selected metallic materials based on the performed experiments or data provided by the manufacturer and draw conclusions regarding the applications of the metallic materials in the sustainable industry.**
MMMSI_O_04	The student person can prepare a scientific report and present a presentation on the properties and applications of selected metallic material, including critical analysis, synthesis and conclusions. The student person is able to work individually and in a team and lead a debate.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: Lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MMMSI_O_01 MMMSI_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MMMSI_O_03 MMMSI_O_04
Meth_03	**Team project**: Critical analysis, synthesis and conclusions; individual and teamwork, communication on specialist topics, leading a debate, SWOT analysis	MMMSI_O_03 MMMSI_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	10	exam	MMMSI_O_01 MMMSI_O_02	
FT_02	laboratory	30	course work	MMMSI_O_03 MMMSI_O_04	Meth_02 Meth_03

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

LEARNING OUTCOMES

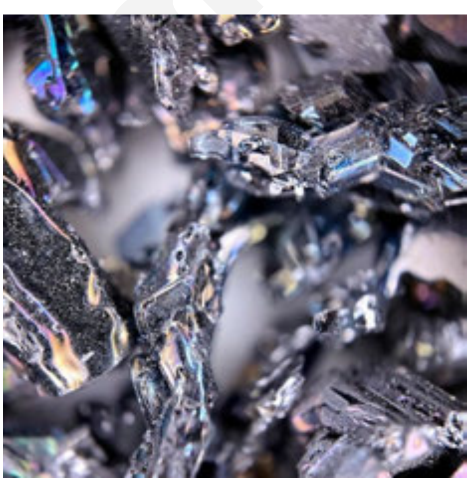
By the end of the *Modern Metallic Materials for Sustainable Industry* course, the students will be able to describe the structure of metallic materials and how it is related to the basic mechanical and transport properties. Students will be able to identify selected groups of metallic materials and indicate potential applications. Students should be able to propose basic manufacturing and processing methods for materials preparation and modification of their properties.

COMMENTS

LECTURER

DO YOU KNOW

Metals make up the largest group of elements in the periodic table, and there are as many as 92 of them. Alloys are made by combining at least two metallic elements, so think how many binary, ternary, quaternary, etc. alloys can be made...



www.freepik.com

COURSE CONTENT - LECTURE

Topic 1

Metallic materials: introduction and fundamentals

During the lecture an introduction to the structure and properties of metallic materials will be given. The lecture will be focused on the properties of metallic bonds and how do it influences the basic properties of metallic materials. Basic crystal structure types will be discussed and how they influence the mechanical properties of the most common groups of metals. Basic alloy types will be discussed and the condition for its creation will be provided.

Topics 2

Steel and its various types for advanced applications

This lecture is focused on providing the students with a comprehensive understanding of steel and its diverse types, specifically focusing on their applications in advanced industries and their contributions to sustainable practices. Steel, as an alloy composed of iron-carbon and various alloying elements, is known for its strength, versatility, and recyclability. Despite being known for centuries still plays a crucial role in sustainable industry sectors such as construction, transportation, energy, and manufacturing. This lecture aims to explore the various types of steel and the influence of alloying elements on the specific properties, highlighting their importance in achieving sustainability goals

Topics 3

Aluminium alloys for automotive and aerospace applications

This lecture is focused on providing students with knowledge regarding aluminium alloys and their critical role in both the automotive and aerospace sectors, with a special focus on sustainable industry practices. Aluminium alloys have revolutionized these industries due to their exceptional properties, lightweight nature, and their potential for promoting sustainability in manufacturing processes. The application of alloying elements such as Si, Mg or Li greatly extended the possible application of aluminium alloys.

Topics 4

High-entropy alloys as a new concept for the production of novel alloys for various applications

The lecture will be focused on the concept of high-entropy alloys (HEA), which are multicomponent alloys composed of five or more elements in nearly equimolar proportions. This unique composition leads to the formation of solid solutions with extraordinary properties. HEAs represent a new paradigm in alloy design, offering exciting possibilities for achieving superior mechanical, physical, and functional properties while reducing the environmental impact associated with traditional alloy production.

Topics 5

Shape memory metals for various applications

This lecture will be focused on providing students with a comprehensive understanding of shape memory metals and their versatile applications in the context of the sustainable industry. Shape memory metals are a class of materials that exhibit unique properties, allowing them to "remember" and recover their original shape after being deformed. These materials have gained significant attention due to their potential to contribute to sustainable practices across various industrial sectors.

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

LEARNING OUTCOMES

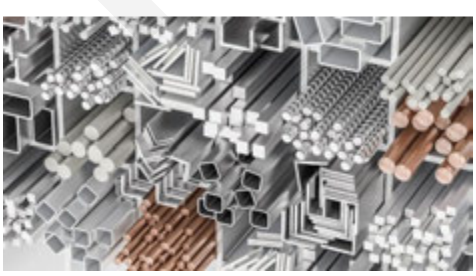
The student person can prepare a scientific report and present a presentation on the properties and applications of selected metallic material, including critical analysis, synthesis and conclusions.
The student person is able to work individually and in a team, and lead a debate.

COMMENTS

INSTRUCTOR

DO YOU KNOW

The diversity of melting temperatures among metals is quite remarkable. Did you know that the melting points of metals can range from as low -39 degrees Celsius (for mercury) to as high as 3422 degrees Celsius (for Tungsten)?



https://www.freepik.com

COURSE CONTENT – LABORATORY CLASSES

Topics 1

Metallic materials: introduction and fundamentals

During laboratory classes, students will analyse the basic crystal structures of the selected metallic materials. Students will also analyse the selected phase diagram and discus what are the proposed properties of the various alloys phases. The last part ot the classes will be focused on the application of TEM to analyse the structure of alloys with precipitates and its defect structure.

Topics 2

Steel and its various types for advanced applications

During laboratory classes, students will characterize the microstructure of selected steel types after selected thermomechanical processing. Students will prepare metallographic specimens themselves from various steels types and observe the microstructure using light microscopy. Further during the classes students will discuss the microstructures within themselves and discus the predicted materials properties.

Topics 3

Aluminum alloys - microstructure and selected mechanical properties

During the laboratory classes students will have the task to analyze the microstructure of the proposed aluminum alloys (for example Al-Si alloys) using light microscopy and scanning electron microscopy. Based on the performed observations students will determine the size distribution and amount of silicon phase hardening precipitates. Further during the classes students will determine the alloys hardness using Vickers hardness tests and compere the results with the observed microstructure.

Topics 4

High-entropy alloys - production and characterization

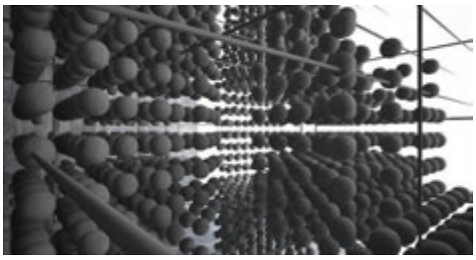
During the laboratory classes students will have the task to prepare selected high-entropy alloy and characterize its microstructure. This task will be conducted in the form of teamwork project. Each group of students will choose its own chemical composition of the alloy. Students will prepare weightings of the selected alloy from elemental powders and will prepare green compacts using laboratory press. The next step will the alloy manufacturing by means of vacuum arc melting technique. The last part of the assignment will be microstructure characterization using light microscopy and scanning electron microscopy. Students will prepare report based on their work and present it to other groups and discus the obtained results and compare them to results of other groups.

Topics 5

Shape memory metals

During the laboratory classes students will have the task to analyze the microstructure of the proposed shape memory material (for example Nitinol) and to determine the characteristic temperatures of the martensitic transformation using DSC (Differential Scanning Calorimetry) method. Additional task will be the observation of the crystal structure transformation using a temperature X-ray diffraction experiment. Students will be also involved in the induction of a two-way shape memory effect by thermos-mechanical cycling.

Co-funded by the European Union



https://www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Modern Metallic Materials for Sustainable Industry*:

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;

To deepen the course topics, optional recommended texts include:

1. *Basic Concepts of Iron and Steel Making* by S. K. Dutta and Y. B. Chokshi, Springer Nature Singapore, 2020, ISBN: 9789811524363;
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. *Shape Memory Alloys: Manufacture, Properties and Applications* by H. R. Chen, Nova Science Publishers, 2010, ISBN: 9781607417897;
4. *Shape Memory Alloys* by M. Fremond and S. Miyazaki, Springer Vienna, 2014, ISBN: 9783709143483;
5. *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;

ASSESMENT

Reports:

The reports relate to experimental laboratory exercises; contribute to deepening theoretical and practical knowledge in the field of studied metallic materials. The reports contain theoretical background, description of performed experiments and analyses, together with discussion and conclusions.

Team project (during the semester)**:**

Team project verifying knowledge of issues in the field of *Metallic Materials for Sustainable Industry* and ability to teamwork. Students will select chemical composition of high-entropy alloy and will manufacture it and characterize its microstructure with accessible experimental methods.

Exam (after the semester):

The oral exam verifies overall knowledge in the field of *Metallic Materials for Sustainable Industry*.

GRADING POLICY

The *Metallic Materials for Sustainable Industry* course is scored with points. The grade results from the sum of points obtained by the student during the semester (laboratory exercises) and points obtained during the exam. During laboratory exercises, the following are assessed on an ongoing basis: theoretical preparation (discussion at the beginning of laboratory exercises as an introduction to conducting the experiment and preparing the report), submitted reports (max. 10 points, i.e. 3 reports x 10 points = 30 points are assessed), Team project (1 x 10 pts = 10 pts) and Debate (1 x 10 points). The maximum number of points obtained in the laboratory exercises is 50. The exam is conducted in an oral form - 3 questions from the previously given range of topics are to be selected. The maximum number of points to be obtained in the exam is 50. Student grades will be assessed as follows in the box on the left.

Assignment Weights	**Percent**
3 Reports	30%
Team project	10%
Debata	10%
Exam	50%
Total	100%

3 reports (max. 10 points each) – max. 30 points
Team project– max. 10 points
Debata – max. 10 points
Final exam – max. 50 points

Total points – max. 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

MODERN KNOWLEDGE ABOUT POLYMERS

Code: **MKP**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

1

Language

English

Thematic block

Advanced Engineering Materials

Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 30h

ECTS

3

Lecturer: Sylwia Golba, PhD

COURSE DESCRIPTION

The course focus on the characteristic of polymers with broad outlook spanning from planning, producing, processing and recycling of these materials. Currently, we are dealing with a situation in which the high usability of plastic products is struggling with the awareness of the threats resulting from their long-term impact on the environment. Hence, it is highly recommended to acquire knowledge leading to understanding the structure-property relationship. This gives a further opportunity to design the life cycle of the material on the path from synthesis to decomposition in a balanced manner.

The lecture aims to present the basic characteristics of polymers divided into basic groups, such as thermosets, thermoplastics and elastomers. Basic methods specific to these groups will be presented and described to sketch the relationship between structure and mechanical-physical behavior. For each group, the recycling strategy will be discussed in terms of technological requirements along with its social and economic aspects.

The exercises are designed to broaden the students' perspective on the usefulness, but also the degradability of plastics. The activities aim to gain a broad perspective on aspects of characterization and (re)processing by understanding the phenomena and states typical of large molecular weight materials.

COURSE OBJECTIVES

After completing the Modern Knowledge about Polymers course, the student should describe the basic properties of polymeric materials with a proper description of the basic subtypes. The course participant is aware of the usefulness and threats of the use of polymers in vast areas of the economy.

PREREQUISITES FOR TAKING THE COURSE

To complete the course, it is recommended to implement learning outcomes related to the basics of physics, chemistry, and materials science.

www.freepik.com

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extended and in-depth understanding in the field of general knowledge, which is the basis for understanding relationships in the processes of designing, manufacturing, testing and application of polymeric material.
MS_O_02	Has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in polymer materials processing.
MS_O_03	Can use information from literature, databases and other available sources to predefine the properties of polymeric materials. Can solve practical engineering tasks that require the use of engineering standards and norms in the field of polymeric materials.
MS_O_04	He understands the need for an interdisciplinary approach to solving problems and the need for a comprehensive, scientific analysis of problems in the field of polymer materials engineering.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation;	MS_O_03
Meth_03	**Laboratory exercises**: problem learning; debate	MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	Exam	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials, review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials, familiarization to work instruction and review of activities necessary to participate in classes	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

Co-funded by the European Union

LEARNING OUTCOMES

Student has broad and in-depth understanding in the field of general knowledge, which is the basis for understanding relationships in the processes of designing, manufacturing, testing and application of polymeric material.

COMMENTS

LECTURER

DO YOU KNOW

Many people still have problems separating waste into five fractions. Meanwhile, the inhabitants of the Japanese town of Kamikatsu separate it into 45 types and thus recycle more than 80 per cent of their waste. After arriving to the town, one must know a massive dose of rules about the principles of waste separation. The rules must be strictly adhered to. Otherwise, the waste may not be collected by the municipal services and, in addition, it will bring shame to the host of the facility which, in the mentality of a typical Japanese, is an important aspect.

www.freepik.com

COURSE CONTENT - lecture

Topics 1

General characteristics of polymer materials

The lecture will provide introductory information on the basic characteristic properties and basic types of polymers. Common materials will be used as examples to familiarise students with the common features of this group, but also with its diversity. (2 h)

Topics 2

Structure of polymer materials

The topic will deliver the information starting at the basic level of ordering which is the macromolecule structure, along with higher stages leading to either amorphous or crystal-like phases. Also supramolecular interactions provoking nanostructural organization will be discussed. (2 h)

Topics 3

The thermo-mechanical behavior aspect

In the lecture the information about thermal character of the polymers and their changes will be presented. Also modifications induced by the influence of temperature in short and long term exposure will be discussed in relation to the stability and degradation processes. (2 h)

Topics 4

Ageing and stabilisation

In this section the aspect of the stability and aging process of polymers will be considered. The impact of multiple factors like temperature, light, stress, environmental factors ect. will be discussed as they influence markedly on their (re)usage opportunities. (3 h)

Topics 5

Degradation and recycling opportunities

In the following lecture, several degradation mechanisms will be discussed, including a controlled mechanism for biodegradable materials. The main recycling pathways will be presented with a discussion of their advantages and disadvantages in terms of material, social and economic aspects. (3 h)

Topics 6

Market assessment - technical developments and new developments in plastics

The final lecture will summarise the economic outlook and discuss the current image of plastics. Examples of successful strategies for reusing plastics will be presented, but also risks and unresolved issues will be discussed. (3 h)

LEARNING OUTCOMES

Has an in-depth, theoretically underpinned and structured knowledge of modern techniques and testing methods used in the processing of polymeric materials. He/she will be able to select an appropriate technique for characterising a material in terms of identification, degree of crystallinity, thermal properties or strength.

COMMENTS

INSTRUCTOR

DO YOU KNOW
The first chewing gum was resin from the bark of the gum tree, that was already used to freshen breath by the ancient Greeks. Many cultures reached for chewing gum that was extracted from plants, e.g. the Aztecs reached for tzictli, the milk from the stem of the sap tree. On an industrial scale, production was attempted in the mid-19th century. The method of making gum was patented in 1869 in Ohio. From the Second World War onwards, it was added, for example, to the provisions of American soldiers as an alertness and tension-reducing agent.

www.freepik.com

COURSE CONTENT - laboratory classes

Topics 1

Characteristic of polymers by flame analysis

In the experiment several type of polymer granules will be subjected flame analysis which is the fundamental method for their identification. The behavior of various material under the temperature influence will be discussed (e.g. self-extinguishing vs non extinguishing one or the risk of flammable materials on landfill sites). (3 h)

Topics 2

Testing of polymers from natural products (thermoplastic starch material)

Within the classes the material of natural origin namely starch will be utilized for production of thermoplastic usable material. The process leads to film forming material applicable as protective packaging material. This open the discussion about thin polymer packaging materials.

Topics 3

Specific surface area determination for polymer by BET method

In the laboratory classes the student will perform studies of nitrogen adsorption on the surface of chosen polymer materials. Based on collected data the BET isotherm will be constructed and specific surface area will be calculated. This parameter is useful for assessing the surface area available for heterogeneous processes.

Topics 4

Study on the swelling phenomenon of gelatine in water

The experiment involves determining the degree of swelling of a biomaterial such as gelatine. This parameter is inversely proportional to the degree of spatial cross-linking of the polymer structure. The results provide an opportunity to discuss the swelling and solubility of polymeric materials.

Topics 5

Analysis of optical properties of polymeric materials

The aim of the study is to determine the UV attenuation properties of transparent hydrogel and silicone hydrogel materials. Quantitative information on the degree of protection is to be provided by calculating the protective factor on the basis of the transmittance value recorded in the UV vis spectrophotometric analysis.

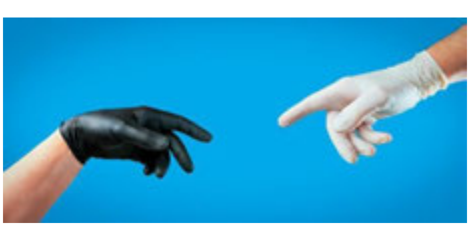
LEARNING OUTCOMES

The student is aware of the economic, social and environmental impact of polymeric materials. Is able to identify the advantages and disadvantages of using and producing polymeric materials. Is aware of the life cycle of the material and is able to propose a sustainable system including the stages of production, use and recycling of polymeric materials.

COMMENTS

INSTRUCTOR

DO YOU KNOW
A polymer can be trully intelligent (such material are also called smart polymers) as they react to small physical or chemical stimuli surrounding them, that cause them to transform. Such polymeric materials exist in multiple forms - they can be deposited on surfaces, be dissolved in solutions, or be a part on construction as a source of mediation. Commonly, intelligent polymers are merged with biomolecules in order to create a substantial family of polymers that answer intelligently to physical, biological, or chemical stimuli. They can be used as sensors for cancer marker detection, vehicles for drug transport to prescribed location, indicators for (bio)molecules imaging, sorbents for water purification.



www.freepik.com

Topics 6

Elastic recovery of the polymer sample

In the work the polymer samples cylindrical in shape will be squeezed with mechanical force and then the load will be released. Along the loading – unloading cycle 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. (3 h)

Topics 7

Abrasive wear of polymeric materials - toothbrush fibre

The aim of this research is to trace the abrasive wear process of polymer fibres. The subject of analysis will be polyamide fibres in two states: a virgin, unused material of the toothbrush and a used toothbrush elements. The imaging technique will be the SEM, followed by an analysis of the morphology in terms of the degree of wear. (3 h)

Topics 8

Analysis of the permeability of polymer membrane

In the experiment, students will analyse polymeric membrane materials of known pore size for permeability to both H_3O^+ and OH^- ions. A system with a suitable receiver will provide the ability to control the pH, allowing the movement of ions to be tracked throughout the experiment. (3 h)

Topics 9

Determination of crystallinity degree of the polymer

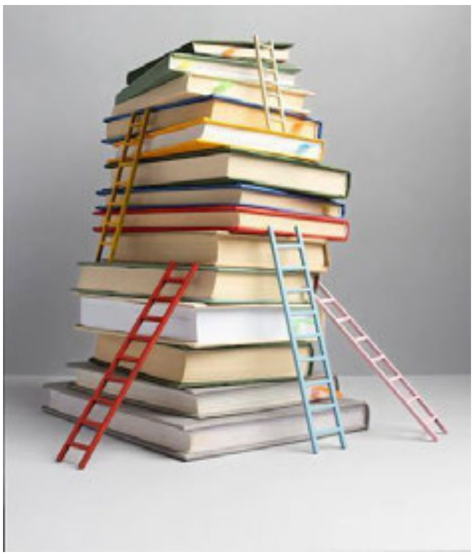
The experiment is planned to determine the crystallinity degree of the polymer, which is a parameter that influences dramatically on the mechanical and optical properties of the sample. The analytical technique utilised in the study is FTIR spectrophotometry delivering spectra containing peaks characteristic for vibration present in both amorphous and crystalline phase. (3 h)

Topics 10

Scanning Kelvin Probe (SKP) analysis of coating polymer layer

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 material will be deposited electrochemically on the surface of the polished stainless steel electrode in a form of homogenous layer. (3 h)

Co-funded by the European Union



www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing *Modern Knowledge about Polymers*:

1. Charles E. Carraher, "Polymer chemistry", CRC Press, Taylor & Francis (Londyn), 2018, ISBN: 9781498737388
2. Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, "Polymer chemistry" Springer-Verlag (Berlin), 2017, ISBN: 9783662492772
3. Harry R. Allcock, Frederick, Contemporary polymer chemistry", Upper Saddle River : Pearson Education, 2003, ISBN: 0130650560

For more profound understanding of the course subject matter, optional recommended texts include:

1. David I. Bower, "An introduction to polymer physics", Cambridge University Press, 2004, ISBN: 0521631378
2. Joel R. Fried, "Polymer science and technology", Upper Saddle River : Prentice Hall Professional Technical Reference, 2008, ISBN: 9780130181688

ASSESMENT

Exam:

The written exam verifies overall theoretical knowledge in the field of phenomena-related to polymer materials, their composition and its impact on physico- mechanical properties. Also knowledge of the stability and degradation – related process will be verified.

Report:

The reports involve results of the student's work during the laboratories; they refer to the pristine theoretical and practical knowledge of performed exercises. They are developed in laboratories and consist of a theoretical introduction, a description of the exercise's purpose and scope, and a part reporting the obtained results. They end with a discussion and conclusions.

GRADING POLICY

The final evaluation reflects the student achievement scoring system. The grade results from the sum of points obtained by the student during the semester from the laboratories and points received during the exam.
The written form of the exam includes 3 questions based on the scope of information presented and contains both theoretical and practical aspects. The maximum number of points to be obtained in the exam is 100.
During the assessment of one laboratory, the following rules points are granted: the initial test prior to the exercise - passing the test is a condition for participation in the exercise (1 point),
individual or team work on performing the exercise and developing a report in which:
- 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)

and for this part the student receives 10 points in total.
The student is obliged to perform the 10th exercise, which gives in maximum 100 points.
The final grade is determined by 50% of the points obtained in the exam and 50% of the points obtained in the laboratories. According to the table, the sum of the percentages will result in the final grade

Assignment Weights and points | **Percent**

Laboratories
90-100% = 90 – 100 points = A
80-89% = 80 – 89 points = B
70-79% = 70 – 79 points = C
60-69% = 60 – 69 points = D
Below 60% = 0 – 59 points = F

Grading Scale for Exam and final notes

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

Final score	
Exam	50%
Laboratory	50%
Total	100%

Grading Scale

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

COURSE SCHEDULE?

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

GREEN TRIBOLOGY

GT

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

english

Thematic block

Materials Testing Methods and Failure Analysis

Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 30h

ECTS

4

Lecturer: Adrian Barylski,PhD

https://www.bearing-news.com/europes-largest-international-conference-tribology-lubrication/

COURSE DESCRIPTION

The lecture is a broad approach to the subject of green tribology from its history, challenges, principles, and main concepts related to friction and wear to the life cycle of products and their applications. Students learn, among others, the concept of material consumption, abrasion processes, and adhesion. The processes of fatigue, thermal wear, erosion, and corrosion will also be discussed. Topics related to the use of lubricants will be discussed. Next, phenomena occurring during the wear of ceramic and polymer materials will be discussed. The next block of classes will be lecturing on surface engineering for green tribology. During these lectures, students will learn about the surface properties of solids, processes of surface engineering for green tribology, the effects of self-organization, and topics related to green and sustainable tribology in the context of challenges for humanity. At the end of the lecture, they will learn about the product life cycle and applications for green tribology.

During laboratory exercises, students will have the opportunity to apply the knowledge gained in lectures and develop practical skills in the field of green tribology. They will be able to prepare and measure a surface for tribological tests using profilographometry. They will also get acquainted with the measurements of micromechanical properties and conduct tribological tests by selecting the appropriate conditions, friction node, and lubricant for the test material - respecting the assumptions of green tribology. Students will also develop the ability to analyze test surfaces after tribological tests, identify wear mechanisms and analyze the results and possibilities of reducing friction and wear.

COURSE OBJECTIVES

The course aims to familiarize students with the issues of green tribology. The course will provide them with knowledge of the main concepts, types, and mechanisms of wear, but also the possibilities of preventing and limiting friction processes. After laboratory exercises, they will also gain the ability to examine and select appropriate conditions for specific friction nodes for applications in accordance with the assumptions of green tribology.

PREREQUISITES FOR TAKING THE COURSE

Participation in the course should be conditioned by a basic knowledge of materials science and materials testing methods. Knowledge of data analysis software is also necessary. The student should have a general knowledge of the properties and applications of engineering materials.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	The student will have knowledge and skills in the field of green tribology. He will be able to design and select the appropriate friction node based on the assumptions of green tribology, using various material combinations or lubricating media - which is of great importance in extending the service life and reducing the wear processes of engineering materials.
MS_O_02	The student can efficiently use information from various bibliographic sources. He can interpret, assess and, based on his knowledge, solve the given problems of green tribology.
MS_O_03	The student will be able to carry out a complete tribological experiment - from surface preparation, selection of operating conditions and lubricant to developing test results and evaluation of wear mechanisms.
MS_O_04	After the tests, the student will identify the problems of green tribology and propose solutions to optimize the friction processes depending on the material or counter-sample used and the type of motion in which the friction node works.
MS_O_05	The student will be able to prepare reports and present the results in a graphical form. Students will work on their own, in groups, and by conducting joint discussions and brainstorming.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures:** lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises:** experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04 MS_O_05

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	course work	MS_O_01 MS_O_02	
FT_02	laboratory	15	course work	MS_O_03 MS_O_04 MS_O_05	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

By the end of the Green Tribology course student:

- Will have extensive knowledge of green tribology from its history through challenges and development prospects. Understand the causes of enormous energy costs and losses generated by wear and friction.
- Will have consolidated and extended knowledge about the basics of tribology and basic concepts, will be familiarized with the most commonly used standards in tribological tests, and will expand the importance of knowledge about the identification of wear processes, the impact of green lubricants on wear and engineering processes of surfaces for Green Tribology, the cycle life of products and applications.
- Will be able to use information from various bibliographic sources, interpret them, evaluate them, draw correct conclusions, and on their basis, solve the problems of green tribology.
- Will be able to carry out tribological experiments both for different types of friction pairs and for different types of motion, as well as the use of green lubricants. In addition, they will develop the ability to select appropriate research methods, analyze results and optimize test parameters to obtain the most repeatable results.
- Will be able to prepare a report and presentation of the results obtained during tribological tests, including analysis and formulating conclusions. In addition, students will learn how to work individually and in a team, as well as how to conduct discussions on topics related to green tribology.

DO YOU KNOW

The term tribology appeared for the first time in a United Kingdom Government Report published on March 9, 1966, now commonly known as the Peter Jost report.

Anton Paar Tribometer – TRB in Surface Layer Laboratory (University of Silesia, Institute of Materials Engineering, Chorzów, Poland)

COURSE CONTENT - LECTURE

Topics 1

History of Tribology and Green Tribology, challenges and perspectives. Global warming processes and prevention options

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.

Topics 2

Wear of materials for Green Tribology. Basic equations and types of wear

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.

By the end of the Green Tribology course student:

- Will have extensive knowledge of green tribology from its history through challenges and development prospects. Understand the causes of enormous energy costs and losses generated by wear and friction.
- Will have consolidated and extended knowledge about the basics of tribology and basic concepts, will be familiarized with the most commonly used standards in tribological tests, and will expand the importance of knowledge about the identification of wear processes, the impact of green lubricants on wear and engineering processes of surfaces for Green Tribology, the cycle life of products and applications.
- Will be able to use information from various bibliographic sources, interpret them, evaluate them, draw correct conclusions, and on their basis, solve the problems of green tribology.
- Will be able to carry out tribological experiments both for different types of friction pairs and for different types of motion, as well as the use of green lubricants. In addition, they will develop the ability to select appropriate research methods, analyze results and optimize test parameters to obtain the most repeatable results.
- Will be able to prepare a report and presentation of the results obtained during tribological tests, including analysis and formulating conclusions. In addition, students will learn how to work individually and in a team, as well as how to conduct discussions on topics related to green tribology.

DO YOU KNOW

Professor Si-Wei Zhang of China launched (green tribology) as a tribology policy in London on June 8, 2009, which date can be regarded as the acknowledged birthday of green tribology as an international concept.

www.freepik.com

Topics 3

Wear of Ceramic Materials, Wear of Polymers, and a summary of lectures on friction, wear and wear mechanisms

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 (K_{Ic} 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.

Topics 4

Effect of lubricants. Water lubricated bearings. Green and natural oil lubricants

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

By the end of the Green Tribology course student:

- Will have extensive knowledge of green tribology from its history through challenges and development prospects. Understand the causes of enormous energy costs and losses generated by wear and friction.
- Will have consolidated and extended knowledge about the basics of tribology and basic concepts, will be familiarized with the most commonly used standards in tribological tests, and will expand the importance of knowledge about the identification of wear processes, the impact of green lubricants on wear and engineering processes of surfaces for Green Tribology, the cycle life of products and applications.
- Will be able to use information from various bibliographic sources, interpret them, evaluate them, draw correct conclusions, and on their basis, solve the problems of green tribology.
- Will be able to carry out tribological experiments both for different types of friction pairs and for different types of motion, as well as the use of green lubricants. In addition, they will develop the ability to select appropriate research methods, analyze results and optimize test parameters to obtain the most repeatable results.
- Will be able to prepare a report and presentation of the results obtained during tribological tests, including analysis and formulating conclusions. In addition, students will learn how to work individually and in a team, as well as how to conduct discussions on topics related to green tribology.

DO YOU KNOW

Green tribology is also known as ecotribology. Since its inception, green tribology has been a key subject in major international and world tribology conferences

Anton Paar Micro Combi Tester (MCT^3) in Surface Layer Laboratory (University of Silesia, Institute of Materials Engineering, Chorzów, Poland)

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.

Topics 5

Solid surfaces and properties, engineering processes of surfaces for Green Tribology

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 engineering processes as Strain-Hardening Processes, Electrochemical Processes, Chemical, Thermally Assisted Processes, Vapor-Phase Deposition, Thick-Film Overlays.

Topics 6

Green and Sustainable Nanotribology in the frame of the global challenges for humankind

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

By the end of the Green Tribology course student:

- Will have extensive knowledge of green tribology from its history through challenges and development prospects. Understand the causes of enormous energy costs and losses generated by wear and friction.
- Will have consolidated and extended knowledge about the basics of tribology and basic concepts, will be familiarized with the most commonly used standards in tribological tests, and will expand the importance of knowledge about the identification of wear processes, the impact of green lubricants on wear and engineering processes of surfaces for Green Tribology, the cycle life of products and applications.
- Will be able to use information from various bibliographic sources, interpret them, evaluate them, draw correct conclusions, and on their basis, solve the problems of green tribology.
- Will be able to carry out tribological experiments both for different types of friction pairs and for different types of motion, as well as the use of green lubricants. In addition, they will develop the ability to select appropriate research methods, analyze results and optimize test parameters to obtain the most repeatable results.
- Will be able to prepare a report and presentation of the results obtained during tribological tests, including analysis and formulating conclusions. In addition, students will learn how to work individually and in a team, as well as how to conduct discussions on topics related to green tribology.

DO YOU KNOW

Main principles of green tribology:
• Reduction of material and energy loss due to wear
• Reduction in energy loss due to friction
• Conservation of energy and nonrenewable resources by extending life cycles of the components
• Reduction or elimination of lubricants by proper selection of low friction mating surfaces

https://www.ifas.rwth-aachen.de/cms/IFAS/Forschung/~qgdv/Tribologie/?lidx=1

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.

Topics 7

Life-Cycle Assessment and applications in Green Tribology

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.

Co-funded by the European Union
UNIVERSITY OF SILESIA IN KATOWICE
UNIVERSITY OF ŽILINA

LEARNING OUTCOMES

Students will be enable to:

- Understanding the importance of green tribology for reducing wear, and friction, reducing heat loss, and reducing the consumption of natural resources
- Learn to select the appropriate surface preparation method for testing different materials for green tribology
- They learn about the influence of surface roughness on tribological properties
- Performing tribological tests of light alloys, polymeric materials, and green lubricants
- Conducting tests on the surface of solids using the microindentation method
- Analysis and interpretation of the obtained test results
- Identification of signs of wear
- Group work
- Presentation of results

DO YOU KNOW

Friction is the primary source of energy dissipation, one-third of the energy consumption in the US is spent to overcome friction. The control of friction and friction minimization, which leads to both energy conservation and the prevention of damage to the environment due to the heat pollution, is a primary task of tribology.

Mitutoyo Surftest SJ - 500 Profilometer in Surface Layer Laboratory (University of Silesia, Institute of Materials Engineering, Chorzów, Poland)

COURSE CONTENT - FORM OF TUITION (e.g. laboratory classes)

Topics 1

The technology of surface preparation for green tribology

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.

Topics 2

Tribological tests of light alloys - influence of surface roughness on tribological wear in friction pair ball-on-disc

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.

Topics 3

Tribological studies of polymers - polymer wear micromechanism

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

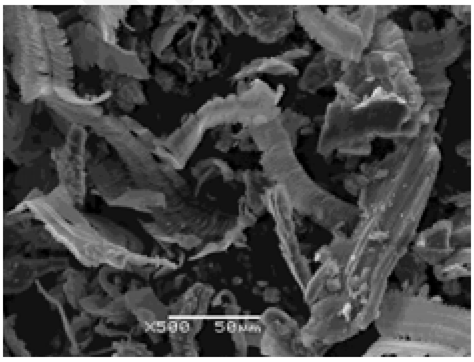
LEARNING OUTCOMES

Students will be enable to:

- Understanding the importance of green tribology for reducing wear, and friction, reducing heat loss, and reducing the consumption of natural resources
- Learn to select the appropriate surface preparation method for testing different materials for green tribology
- They learn about the influence of surface roughness on tribological properties
- Performing tribological tests of light alloys, polymeric materials, and green lubricants
- Conducting tests on the surface of solids using the microindentation method
- Analysis and interpretation of the obtained test results
- Identification of signs of wear
- Group work
- Presentation of results

DO YOU KNOW

Minimization of wear is the second most important task of tribology which has relevance to green tribology. Wear limits the lifetime of components and therefore creates the problem of their recycling. Wear can lead also to catastrophic failure. In addition, wear creates debris and particles which contaminate the environment and can be hazardous for humans in certain situations. For example, wear debris generated after human joint replacement surgery is the primary source of long-term complications in patients.



Wear debris morphology of magnesium alloy WE43

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.

Topics 4

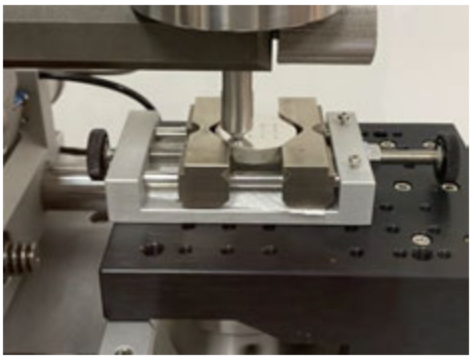
Tribological tests of friction pairs lubricated with green lubricants

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.

Topics 5

The properties of the surface phase and their influence on friction and wear

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 (MCT^3). Using microindentation, students will examine such properties as instrumental hardness H_{IT}, Young's modulus instrumental E_{IT}, total indentation work W_{tot} (and its components W_{plast}, W_{elast}), material stiffness S, percentage of elastic strain work η_{IT}, 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.



Linear reciprocating Tribology test

TEXTBOOK/READINGS

The mandatory reading for completing the subject Green Tribology:

- 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.
- Zum Gahr, K.H. Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987

To deepen the course topics, optional recommended texts include:

- 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
- ASTM and ISO standards.

ASSESMENT

Test/Quiz:

At the beginning of each laboratory exercise, students will write a short test/quiz on the laboratory topic that will be performed on that day. This ensures that the necessary literature recommended for the laboratory (and the concepts presented in the lecture) are familiarized in advance and that students are ready to participate in laboratory classes.

Reports:

Students will be divided into teams, and their task will be to prepare a written report on the conducted experiments. The report should contain theoretical background, research description, analysis of results, Discussion, and conclusions. Thanks to these reports, students will deepen their theoretical and practical knowledge in green tribology.

Debate:

Debate is designed to assess students' ability to present logical arguments and explain them. It will also develop the ability to listen, answer questions, and participate in the Discussion both actively and passively

GRADING POLICY

The Green Tribology course is scored with points. The grade results from the sum of points obtained by the student during the semester (Test/Quizes, Reports, Debate). The maximum number of points obtained in the laboratory exercises is 100. Student grades will be assessed as follows in the box on the left.. Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
5 Reports	50%
4 Quizes	40%
Debate	10%

Reports max. 50 points
Quizes max. 40 points
Debate max. 10 points

Total Points - 100 points

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

DESIGN FOR SUSTAINABILITY USING CAD/CAM SOFTWARE

Code: **DFSUCCS**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Computational Methods and Their Applications in Materials Science:

Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 30h

ECTS

3

Prepared by: Michal Dworak, PhD

COURSE DESCRIPTION

The industrial production sector is undergoing a digital metamorphosis, enabling businesses to tailor their production processes due to advancements in machine learning, eco-friendly design, generative design, and collaboration, with unified design and manufacturing processes.

Eco-conscious design (also known as "green design," "eco-design," or "environmental design") represents the artistry involved in crafting physical items by the principles of economic, social, and ecological sustainability. Its scope extends from creating small, everyday-use things to conceiving buildings, cities, and the physical surface of our planet.

Sustainable product development primarily emphasizes incorporating ethical considerations in the design process. Both manufacturers and product designers must scrutinize how a product is created and evaluate whether each step in this process adversely impacts the longevity of our environment. In terms of sustainable product design, a preemptive (rather than reactive) strategy proves most effective in mitigating the environmental impact of human activities.

COURSE OBJECTIVES

The main objective of this course is to introduce students to advanced computer-aided design and manufacturing techniques and the use of CAD/CAM systems, focusing on subtractive and additive manufacturing processes and sustainable design principles in manufacturing.

PREREQUISITES FOR TAKING THE COURSE

Prerequisites for the course include proficiency in computer-aided design (CAD) software and basic knowledge of materials science and manufacturing and processing.

www.freepik.com

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Students will have an in-depth knowledge of CAD/CAM methods and a well-established and in-depth knowledge of engineering graphics and design and the creation of technical documentation.
MS_O_02	Students will have extensive and in-depth subject knowledge of design methods, manufacturing processes, and processing of engineering materials, as well as development trends and the latest developments in sustainability.
MS_O_03	Students will know the necessary to understand the ethical, economic, and environmental aspects of the design of new engineering materials and their manufacturing technologies and the impact of materials engineering development on sustainable development and the progress of civilization.
MS_O_04	Students can use information from literature, databases, and other available sources. They can integrate the information obtained, interpret and critically evaluate it, draw conclusions, and formulate and solve complex, innovative problems. They will be able to solve practical engineering tasks requiring the application of engineering standards and norms.
MS_O_05	Students can plan and carry out computer simulations, interpret the results, and draw conclusions.
MS_O_06	Students can select appropriate raw materials, technologies, and techniques for producing, processing, and testing engineering materials. They can select and apply appropriate methods and tools, including sustainable design.
MS_O_07	Students will be able to work individually and as part of a team and to interact with others in teamwork. They can independently identify directions for further learning and carry out self-learning.
MS_O_08	Students will be aware of and know the opportunities for further training and enhancement of professional, personal, and social competencies. They will understand the need for an interdisciplinary approach to problem-solving and the need for a comprehensive, scientific analysis of problems in materials engineering.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation; problem learning; debate	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	lecture	15	exam	MS_O_01 MS_O_02	Meth_01
FT_02	laboratory	30	course work	MS_O_03 MS_O_04	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

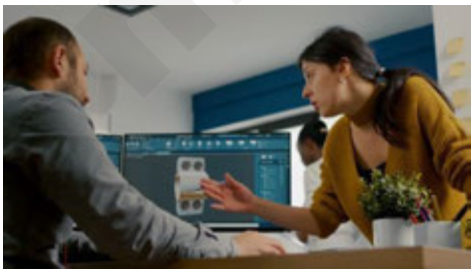
Code	Category	Name	Work with teacher
a_01	Reading literature	A query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	A query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

By the end of this course students:

- will have an in-depth knowledge of CAD/CAM methods, as well as a well-established and in-depth knowledge of engineering graphics and design and the creation of technical documentation;
- will have an extensive and in-depth subject knowledge of design methods, manufacturing processes and processing of engineering materials, as well as development trends and the latest developments in sustainability;
- will have the knowledge necessary to understand the ethical, economic and environmental aspects of the design of new engineering materials and their manufacturing technologies, and the impact of materials engineering development on sustainable development and the progress of civilization;
- will be able to use information from literature, databases and other available sources. They will be able to integrate the information obtained, interpret and critically evaluate it, and draw conclusions and formulate and solve complex innovative problems. They will be able to solve practical engineering tasks requiring the application of engineering standards and norms.

DO YOU KNOW

One of the most exciting examples of sustainable design is 'Cradle to Cradle'? This concept, developed by Michael Braungaart and William McDonough, promotes the idea that products can be designed so that at the end of their life, they do not become waste but can be fully recycled and used to make new products. This creates a 'closed material cycle' that minimizes waste and encourages more responsible use of resources.



www.freepik.com

COURSE CONTENT - LECTURE

Topics 1

Physical and environmental properties of materials

The lecture is an introduction to designing for sustainability. The environmental cost of materials, the physical properties of materials, and the basics of mechanics will be presented. The concept of a material's embodied energy and lifecycle assessment for materials analysis will be discussed.

Topics 2

Introduction to sustainable design – methods to reduce product weight and maximize product lifetime

The lecture will discuss lines of force and stresses acting on designed components and strategies for reinforcing loaded components. In addition, methods of maximizing product lifetime related to increasing product durability and the possibility of disassembly, recycling, repair, and upgrade will be discussed.

Topics 3

Generative design – high-performance 3D models with optimized geometry

The lecture is about a modern approach to design - generative design - a form of artificial intelligence that harnesses the power of the cloud and machine learning while accelerating the entire process from design to object fabrication.

Topics 4

Virtual prototyping

The lecture is about parameterized CAD product modeling. In addition, product virtual manufacturing and design decision-making will be discussed.

Topics 5

Finite element simulation to support sustainable design and production

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.

By the end of this course students:

- will be able to plan and carry out computer simulations, interpret the results obtained and draw conclusions;
- will be able to select appropriate raw materials, technologies and techniques for the production, processing and testing of engineering materials. They will be able to select and apply appropriate methods and tools, including sustainable design;
- will be able to work individually and as part of a team, and to interact with others in teamwork. They will be able to independently identify directions for further learning and carry out self-learning;
- will be aware of and know the opportunities for further training and enhancement of professional, personal and social competences. They will understand the need for an interdisciplinary approach to problem solving and the need for a comprehensive, scientific analysis of problems in materials engineering.

DO YOU KNOW

The product with the most extended lifespan that exemplifies sustainable design is the so-called 'eternal light bulb'? This light bulb, known as the 'Centennial Light', was installed in 1901 at the Livermore Fire Station in California and is still glowing today! The bulb designers focused on the product's longevity, a critical element of sustainable design.

www.fripik.com

COURSE CONTENT – LABORATORY CLASSES

Topics 1

Sketch and basic modeling techniques - an overview

The laboratory aims to revise and structure knowledge about the principles of creating parametric sketches used in part modeling and the principles of creating a 3D parametric part with CAD software.

Topics 2

Advanced modeling techniques

The laboratory aims to explore some of the more complex and curvy modeling techniques used to create models with CAD programs. Students will learn to create complex sweeps and lofts and work with multi-body and derived parts.

Topics 3

Reusing parts and features

The laboratory aims to reuse parts and features in other designs. Students will learn to copy and clone features and link parameters between two files.

Topics 4

Assembly design workflows

The laboratory aims to learn the principles of correct assembly design to achieve efficiency, flexibility, and stability in projects. Students will learn how to create assembly relationships using the constraint and joint tools and how to work with assembly design accelerators and generators.

Topics 5

Project documentation

The laboratory aims to know how to generate traditional 2D annotated drawings. Students will learn how to create and maintain drawing templates, standards, and styles and generate 2D drawings of parts, assemblies, and presentations.

Topics 6

Advanced assembly and engineering tools

The laboratory aims to familiarize students with tools that increase productivity in assembly design by creating the required components directly in the assembly environment. A unique feature of these tools is the ability to use special engineering calculators.

Topics 7

Generative design – use of the shape generator for conceptual analysis

By the end of this course students:

- will be able to plan and carry out computer simulations, interpret the results obtained and draw conclusions;
- will be able to select appropriate raw materials, technologies and techniques for the production, processing and testing of engineering materials. They will be able to select and apply appropriate methods and tools, including sustainable design;
- will be able to work individually and as part of a team, and to interact with others in teamwork. They will be able to independently identify directions for further learning and carry out self-learning;
- will be aware of and know the opportunities for further training and enhancement of professional, personal and social competences. They will understand the need for an interdisciplinary approach to problem solving and the need for a comprehensive, scientific analysis of problems in materials engineering.

During the laboratory, students are introduced to a design exploration process called generative design. This approach to design uses algorithms and artificial intelligence to generate different design solutions based on user-defined criteria such as strength, material, cost, dimensions, weight, and other technical specifications.

Topics 8

Plastics design features

The laboratory aims to familiarize students with specialized tools for creating plastic part features when working in the parts modeling environment. Among other things, students will learn how to use plastic-specific tools and create an injection mold.

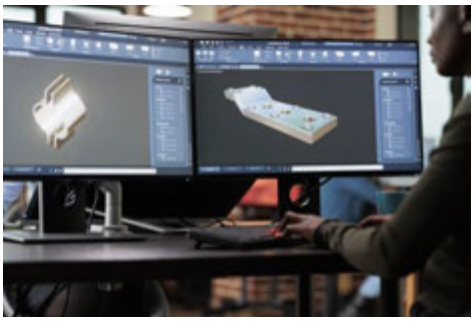
Topics 9

Stress analysis and dynamic simulation

The laboratory aims to familiarize students with performing static analysis on parts and assemblies by defining component materials, loads, constraints, and contact conditions. Students will also learn how to analyze an assembly in motion by specifying loads, constraints, motion joints, velocities, acceleration, and environmental factors such as gravity and friction. Among other things, students will learn how to set up and run stress analysis simulations and set up and run dynamic simulations.

Materials Science Masters

Co-funded by the European Union


www.fripik.com

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Design For Sustainability Using CAD/CAM Software*:

1. *Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development*. Salah M. El-Haggar. Elsevier Inc. 2007.
2. *Mastering Autodesk Inventor 2015 and Autodesk Inventor LT 2015*. Curtis Waguespack. John Wiley & Sons, Inc. 2014.
3. *Product Design Modeling using CAD/CAE*. Kuang-Hua Chang. Elsevier Inc. 2014.

Optional recommended texts include:

1. *Sustainable Design: The Science of Sustainability and Green Engineering*. Daniel A. Vallero, Chris Brasier. John Wiley & Sons, Inc. 2008.
2. *Design of Sustainable Product Life Cycles*. Jörg Niemann, Serge Tichkiewitch, Engelbert Westkämper. Springer-Verlag Berlin Heidelberg 2009.
3. *Learning Autodesk Inventor 2023. Modeling, Assembly and Analysis*. Randy H. Shih. SDC Publications 2022.

ASSESSMENT

Reports:

As a report on laboratory exercises, students submit models made independently during class or as part of a homework assignment.

Exam:

The exam verifies overall knowledge in the field of the subject.

GRADING POLICY

The *Design for sustainability using CAD/CAM software* course is scored with points. The grade results from the sum of points obtained by the student during the semester (laboratory exercises) and points obtained during the exam. The maximum number of points obtained in the laboratory exercises is 50. The maximum number of points to be obtained in the exam is 50. Student grades will be assessed as follows in the box on the left.

Assignment Weights	Percent
Reports	50%
Exam	50%
Total	100%

Grading Scale

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

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g., lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

MAUFACTURING AND CHARACTERIZATION OF SINGLE-CRYSTALLINE MATERIALS

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Materials and manufacturing

Form of tuition and number of hours:

Lecture: 30h

Laboratory: 30h

ECTS

4

(freepic.com)

Code: MCSCM

COURSE DESCRIPTION

Single-crystalline materials are widely used in many modern industries, such as aerospace, defense, automotive, energy, and electronics. Despite the more complicated and expensive manufacturing of single-crystalline materials, they are often the only option to obtain the required functional properties. The *Manufacturing and Characterization of Single-crystalline Materials* course is intended to enable knowledge about various methods of manufacturing single-crystalline materials and understand the mechanisms of growth and creation of the single-crystalline structure. During the course, students will become familiar with the manufacturing process and learn about specialized research methods used to characterize single-crystalline materials.

The lecture will present the manufacturing methods and its division in the context of growth techniques and the needs of industries. In addition, the procedures for preparing raw materials and the final processing of products will also be presented. Specialized research methods for single-crystalline materials will be also describe, especially methods for assessing the structural perfection of single-crystalline materials based on the analysis of growth defects created during material production. Economic and environmental aspects will also be discussed in single-crystalline materials manufacturing.

Laboratory classes will enable students to acquire the skills to prepare the production process and operate the equipment used in the production of single-crystalline materials, perform their tests, and interpret the obtained results.

COURSE OBJECTIVES

After completing the course, students should understand the correlation between the crystal structure of single-crystalline materials and the conditions and methods of their production, which in turn will enable participants to acquire the ability to form the required structure and properties of single-crystalline materials by selecting appropriate technological conditions. Students should also be able to operate apparatuses to produce and test single-crystalline materials and know how to interpret the results.

PREREQUISITES FOR TAKING THE COURSE

To complete the course, it is recommended to implement learning outcomes related to the basics of physics, chemistry, materials science, crystallography and materials testing methods.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extended and in-depth knowledge in the field of single-crystallization techniques, in particular, phenomena related to kinetic and thermal processes during crystallization, which is the basis for understanding the relationship between the structural perfection of single-crystalline materials and manufacturing conditions.
MS_O_02	Has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in single-crystalline materials manufacturing.
MS_O_03	Can analyze phase diagrams in terms of the possibility of obtaining single-crystalline material with a given phase composition and select the manufacturing method for a specific product.
MS_O_04	Can formulate and test hypotheses related to simple research and implementation problems related to single-crystalline materials manufacturing.
MS_O_05	Can plan and carry out experiments and measurements, interpret the results and draw conclusions.
MS_O_06	Has the ability to prepare a technological process, determining the initiate parameters of raw materials, parameters of the single-crystallization process, and final product processing.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	lectures with multimedia support, interactive lectures with problem interpretation and discussion	K_01 K_03 K_04
Meth_02	laboratory work; experiment demonstrations and observation; problem learning	S_02 S_02_eng S_03 S_03_eng

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	30	exam	MS_O_01 MS_O_02 MS_O_03	
FT_02	laboratory	30	reports	MS_O_04 MS_O_05 MS_O_06	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Preparing for classes	Query of instructions and review of topics and activities necessary to participate in classes	NO
a_02	Reading literature	Query of topic, review of literature necessary to participate in classes.	NO
a_03	Preparing reports	Preparation and development of reports. Consultations.	YES

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

LEARNING OUTCOMES

- extended and in-depth knowledge in the field of single-crystallization techniques, in particular, phenomena related to kinetic and thermal processes during crystallization
- in-depth, theoretically based and structured knowledge of modern techniques and research methods used in single-crystalline materials manufacturing
- ability to analyze phase diagrams in terms of the possibility of obtaining single-crystalline material with a given phase composition and select the manufacturing method for a specific product

COMMENTS

LECTURER

DO YOU KNOW

The components of aircraft engines, such as turbine blades, are currently most often produced using superalloys, which possess high-strength properties, even at high temperatures. The single-crystalline blades are obtained through directional crystallization, during which two main phases are created in the form of dendrites and interdendritic areas. Due to the similarity between the structure of both phases and the possibility of obtaining a clear X-ray diffraction pattern, the blades can be recognized as single-crystalline blades.

Single-crystalline materials as a base for the production of high-temperature aircraft turbine blades (freepik.com)

COURSE CONTENT - LECTURE

Topic 1: Thermodynamic, kinetic and structural aspects of single-crystallization process

The lecture will provide information on phase diagrams in the context of single-crystalline materials' chemical and phase composition. Knowledge about the kinetics of crystallization, growth mechanisms (nucleation, undercooling), and the characteristics of the crystallization front will be presented.

Topic 2: Methods of single-crystalline materials manufacturing

During the lecture, students will be familiarized with various methods of single-crystalline materials manufacturing and the process parameters. The division of the methods depending on the type and aim of the products obtained will be presented.

Topic 3: Directional crystallization

Detailed information on the Czochralski, Bridgman, and floating zone (Pfann) methods will be presented during the lecture. Directional crystallization of the eutectics as a method for obtaining single-crystalline composite materials will be explained.

Topic 4: Comparative analysis of structural perfection and technological parameters of single-crystalline materials manufacturing

The lecture will concern the influence of the manufacturing method and technological parameters on selected properties of single-crystalline materials and components. Ways to improve the structural perfection of products based on modification of process parameters will be presented.

Topic 5: Manufacturing and characterization of modern single-crystalline materials

Detailed information about properties and manufacturing of single-crystalline aircraft engine components made of superalloys and modern composite materials used in electronic industry will be presented. The specific properties of high-temperature superalloys and composite semiconductors will be described, as well as methods of testing them will also be explained.

Topic 6: Testing methods of single-crystalline materials

During the lecture, students will be familiarized with various methods of single-crystalline materials testing. The division of the testing methods depending on the physical principles and analyzed material properties will be presented.

Topic 7: X-ray diffraction in the study of single-crystalline materials

The principles of X-ray diffraction will be presented concerning the methods used to study single-crystalline materials. The methods applying X-ray radiation and the properties of single-crystalline materials that can be examined using the mentioned methods will be described in-depth.

LEARNING OUTCOMES

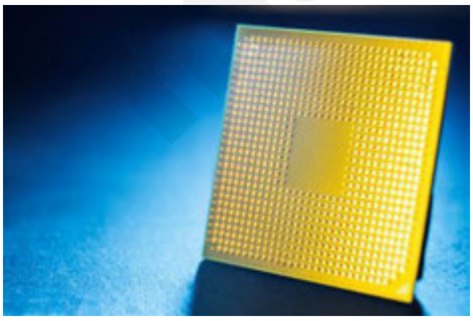
- ability to formulate and test hypotheses related to simple research and implementation problems related to single-crystalline materials manufacturing
- ability to prepare a technological process, determining the initiate parameters of raw materials, parameters of the single-crystallization process, and final product processing

COMMENTS

INSTRUCTOR

DO YOU KNOW

The production technology based on the Bridgman technique allows for obtaining single-crystalline material with the required crystallographic orientation. The proper selection of technological parameters, such as the temperature gradient and crystallization rate, will allow for obtaining material with high structural perfection, good strength, and mechanical properties. Any deviation of the required crystal orientation causes a high deterioration in the needed properties.



Single crystals as a substrate material for the production of electronic components (freepik.com)

COURSE CONTENT – LABORATORY CLASSES

Topic 1: Thermal analysis of solidification process – phase diagrams

During the exercise, participants will prepare cooling curves of simple two-component alloys that can solidify in single-crystalline form and then create a phase system from the obtained results. The obtained phase systems, as exemplary, will be analyzed concerning chemical and phase composition.

Topic 2: Raw materials preparation for single-crystallization

Based on the selected chemical compositions and stoichiometric ratios of the single-crystal phases, students will calculate the weight of individual elements of the charge and then weigh and prepare the raw materials for the single-crystallization process.

Topic 3: Single-crystallization process

During the exercise, participants will become familiar with the construction and operation of a single-crystallization furnace. The way of loading the charge in the growth chamber, preparing the device for operation, and setting and controlling single-crystallization parameters will be presented. Students will also participate in the growth process of single-crystalline material on a laboratory scale.

Topic 4: Microstructure analysis of single-crystalline materials

The subject of laboratory exercises relates to using light and electron microscopy to study single-crystalline materials. It includes the stereology analysis and chemical microanalysis of the phase structure related to single-crystalline material properties.

Topic 5: Determination of crystal orientation and symmetry

During the exercise, participants will prepare samples of single-crystalline materials to test the crystal lattice's orientation and symmetry and then perform measurements using the Laue diffraction method. The obtained results will be interpreted, among others, in the context of structural perfection.

Topic 6: Defect analysis in single-crystalline materials – X-ray diffraction topography

During the exercises, students will acquire skills in examining the defect structure using X-ray diffraction topography, particularly preparing and setting samples, performing measurements, and interpreting results.

Topic 7: Relation between manufacturing conditions and microstructure

Laboratory exercises will include an analysis of the morphology and structure of single-crystalline materials and their influence on manufacturing parameters. The relations between selected properties of single-crystalline materials will be determined based on the research results.

Airplane jet engine (freepik.com)

TEXTBOOK/READINGS

For a deeper understanding of the course subject matter, recommended texts include:

1. T. Nishinaga, "Handbook of Crystal Growth – Fundamentals" Elsevier 2014 ISBN:9780444593764, 0444593764
2. H. Arend, J. Hulliger, "Crystal Growth in Science and Technology" Elsevier 2012, ISBN:9781461305491, 1461305497
3. T. Duffar, "Crystal Growth Processes Based on Capillarity" Willey 2010 ISBN:9781444320213, 1444320211
4. G. Dhanaraj, K. Byrappa, M. Dudley, V. Prasad, „Springer Handbook of Crystal Growth" Springer 2010 ISBN:9783540747611, 3540747613
5. K. Byrappa, "Crystal Growth Technology" Springer 2003 ISBN:9783540003670, 3540003673
6. M.J. Donachie, S.J. Donachie, „Superalloys: A Technical

Guide" ASM 2002 ISBN: 978-0871707499
7. R. C. Reed, „The Superalloys, Fundamentals and Applications" Cambridge Univ. Press 2008 ISBN:9781139458634, 1139458639
8. R. Fornari, "Single Crystals of Electronic Materials, Growth and Properties" Elsevier 2018 ISBN:9780081020968, 0081020961
9. P. Luger, "Modern X-Ray Analysis on Single Crystals" DeGruyter 2014 ISBN:9783110308235, 3110308231
10. G. Cailletaud, G. Eggeler, J. Cormier, L. Nazé, V. Maurel, "Nickel Base Single Crystals Across Length Scales" Elsevier 2021 ISBN:9780128193587, 0128193581
11. H. Saka, "Introduction To Phase Diagrams In Materials Science And Engineering" WSPC 2020 ISBN:9789811203725, 9811203725
12. J. C. Russ, R. T. Dehoff, "Practical Stereology" Springer 2012 ISBN:9781461512332, 1461512336
13. J.L. Amoros, "The Laue method" Elsevier, 2012 ISBN:9780323140768, 0323140769

ASSESEMENT

Exam:

The written exam will verify theoretical knowledge of phenomena related to single-crystalline materials and manufacturing methods. Also, knowledge of the testing methods of single-crystalline materials will be verified.

Report:

The reports result from the student's work during the laboratories; they refer to the in-depth theoretical and practical knowledge of performed exercises. They are developed in laboratories and consist of a theoretical introduction, a description of the exercise's purpose and scope, and a part reporting the obtained results. They end with a discussion and conclusions.

GRADING POLICY

The final grade is based on the student achievement scoring system. The final grade consists of the grades obtained by the student during the laboratory classes and the exam.
The exam is conducted in written form - 10 knowledge questions containing a theoretical and practical part. The complete answer to each question gives 10% to the final grade.
The final grade for the laboratory is the mean grade from the opening test and a prepared reports in which:

- the 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%).

The final grade is the average of the grades obtained in the exam and the laboratories.

Final grades weight	**Percent**
Exam	50%
Laboratory classes	50%
Total	100%

Grading Scale

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

ADVANCEMENTS AND APPLICATIONS OF NANOMATERIALS IN ENVIRONMENTAL SCIENCES

Code: **AANES**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

3

Language

English

Thematic block

Applied Materials Science

Form of tuition and number of hours*:

Lecture: 20h

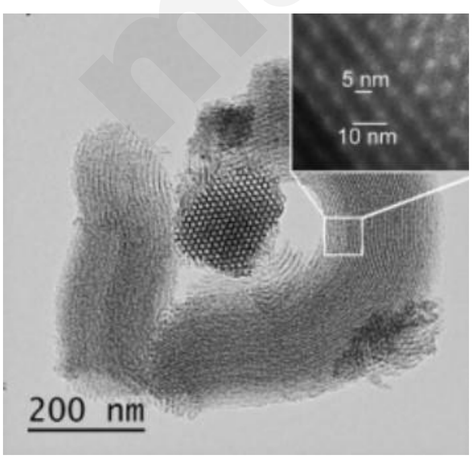
Laboratory: 30h

Conservatory:10h

ECTS

3

Lecturer: Mateusz Dulski, PhD



TEM of SBA-15

COURSE DESCRIPTION

Embark on an enthralling journey through the captivating realm of nanomaterials with our lecture series, uncovering their profound impact on our daily lives! We'll demystify these minuscule yet mighty materials, navigating from their definition and historical roots to categorization, size intricacies, physicochemical fundamentals, advantages, and potential challenges.

Our exploration will extend along diverse pathways of nanomaterial fabrication, delving into how size and surface modifications influence their features and examining their applications across various economic sectors. Aligned with contemporary trends and sustainable practices, we'll scrutinize methodologies steeped in environmental consciousness, focusing on the green chemistry approach to material fabrication.

Turning our focus to one intricate and plentiful family of nanomaterials, silica, our discussions will span the categorization of silicas into micro-, meso-, and nanoporous structures, evaluating their advantages and disadvantages in size, porosity, shape, and functionalization. Structural characteristics, depolymerization effects, and point defects will take center stage, exploring their potential applications—from serving as drug carriers to acting as molecular sieves in harmony with sustainable development principles.

This educational journey isn't confined to theory alone but also will be hands-on. Students will translate their theoretical knowledge into practical experiments in the laboratory. They will project the experiment and consider a meticulous selection of conditions mirroring those in the environment at every step, from preparation to measurement. Therefore, the course will aim to cultivate analytical skills and foster the critical evaluation of results into a comprehensive understanding of the application potential of silica in processes of purification of the environment from pollution.

COURSE OBJECTIVES

Upon completing the course, students should proficiently delineate the fundamental properties of nanomaterials, accompanied by a thorough description of their primary subtypes. Course participants gain a comprehensive understanding of both the utility and potential hazards associated with the broad applications of nanomaterials across various sectors of the economy.

PREREQUISITES FOR TAKING THE COURSE

To successfully conclude the course, it is advisable to incorporate learning outcomes encompassing the fundamentals of physics, chemistry, and materials science.

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Defines the basic concept of nanotechnology. Knows techniques for manufacturing nanomaterials, can classify individual nanomaterials, and can find detailed information about the discussed nanostructures.
MS_O_02	Has knowledge about physicochemical properties and using individual nanostructures in various areas of life.
MS_O_03	Has the skills to consider the positive and negative effects of using nanomaterials in the context of the natural environment, mainly their impact on microorganisms, higher organisms, etc. Knows the potential disadvantages and threats resulting from the use of nanotechnology.
MS_O_04	Knows basic experimental techniques for examining materials at the nanoscale and differentiates the type of information obtained from particular methods.
MS_O_05	Has general knowledge of the physical principles behind individual experimental techniques.
MS_O_06	Plans and performs analyses of selected nanostructures for their use as biocidal agents. Has knowledge and skills in using scientific literature, including English-language literature.
MS_O_07	Can prepare and present a multimedia presentation on issues related to nanotechnology in terms of environmental considerations.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the program
Meth_01	**Lectures**: Lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02 MS_O_03 MS_O_04
Meth_02	**Laboratory exercises**: Experiment preparation; laboratory work;	MS_O_05 MS_O_06
Meth_03	**Laboratory exercises**: Problem learning; debate	MS_O_07

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of Conducting Classes
FT_01	lecture	20	Exam	MS_O_01 MS_O_02 MS_O_03 MS_O_04	
FT_02	laboratory	20	Course work	MS_O_05 MS_O_06	
FT_03	conservatory	10	Course work	MS_O_07	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials, familiarization to work instruction, and review of activities necessary to participate in classes	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

COURSE CONTENT - lecture

Topics 1

A Short Overview of Nanotechnology

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 h)

Topics 2

Top-Down Versus Bottom-Up

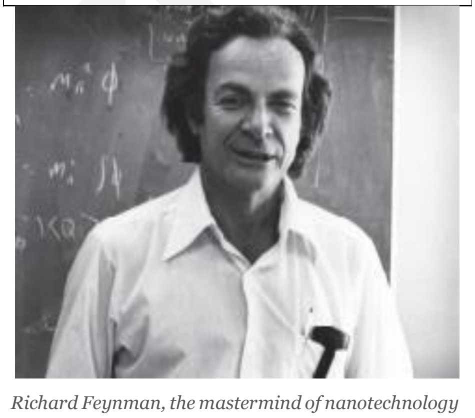
Topic 2 will look at practical techniques for fabricating nano-systems with their advantages and disadvantages, including two main approaches: "Top-down" and "Bottom-up."

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.

DO YOU KNOW

On December 29, 1959 at the California Institute of Technology, Nobel Laureate **Richard Feynman** in his esteemed lecture series entitled "There's Plenty of Room at the Bottom" describes a future where scientists control matter with atomic precision.

R. P. Feynman, "***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), February 1960, 22– 36



Richard Feynman, the mastermind of nanotechnology

www.atomicheritage.org/profile/richard-feynman

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.

(5 h)

Topics 3

Modern directions of bottom-up approach to nanotechnology.

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.
(7 h)

Topics 4

Methods for Structural and Chemical Characterization of Nanomaterials

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.
(4 h)

Topics 5

Environmental Applications of Nanomaterials

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.
(4 h)

Topics 6

Pollution control, remediation versus environmental implications

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.
(4 h)

Topics 7

Ethics of Nanotechnology. State of the Art and Challenges Ahead

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.
(4 h)

COURSE CONTENT - laboratory classes

Topics 1

Materials features versus (de)sorption

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. (2 h of theory and 4 h of practice)

Topics 2

Testing of polymers from natural products (thermoplastic starch material)

In these classes, students will comprehend porous materials' intricacies of scientific and economically viable perspectives. 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.. (2 h of theory and 2 h of practice)

Topics 3

Mechanical tests

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. (2 h of theory and 4 h of practice)

Topics 4

Structural investigations

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 judiciously select the most suitable technique for a given experiment.

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. (2 h of theory and 2 h of practice)

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing *Modern Knowledge about Nanotechnology*:

1. Koo, J. (2016). Introduction to Nanotechnology. In Fundamentals, Properties, and Applications of Polymer Nanocomposites, pp. 3-21. Cambridge: Cambridge University 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. Hornyak, G.L., Moore, J.J., Tibbals, H.F., & Dutta, J. (2009). Fundamentals of Nanotechnology (1st ed.). CRC Press

ASSESSMENT

Exam:

The written exam verifies overall theoretical knowledge of environmental nanotechnology. Questions will refer to the variable synthesis method on the physico-chemical properties of nanostructures, division of nanomaterials concerning the application, environmental problems related to nanostructure application, and ethical problems.

Report:

The reports involve results of the student's work during the laboratories; they refer to the pristine theoretical and practical knowledge of performed exercises. They are developed in laboratories and consist of a theoretical introduction, a description of the exercise's purpose and scope, and a part reporting the obtained results. They end with a discussion and conclusions.

GRADING POLICY

The final evaluation reflects the student achievement scoring system. The grade results from the sum of points obtained by the student during the semester from the laboratories and points received during the exam.
The written form of the exam includes three questions based on the scope of information presented and contains both theoretical and practical aspects. The maximum number of points to be obtained in the exam is 20.
During the assessment of one laboratory, the following rules points are granted:
- the initial test before the exercise - passing the test is a condition for participation in the exercise (1 point),

Individual or teamwork on performing the exercise and developing a report in which:
- 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)

The student receives 5 points in total.
The student must perform the 4th exercise, which gives a maximum of 20 points.
The final grade is determined by 50% of the points obtained in the exam and 50% in the laboratories. According to the table, the sum of the percentages will result in the final grade.

Assignment Weights and points	**Percent**
Laboratories	
90-100% = 18 – 20 points = A	
80-89% = 16 – 17.8 points = B	
70-79% = 14 – 15.9 points = C	
60-69% = 12 – 13.9 points = D	
Poniżej 60% = 0 – 11.9 points = F	
Grading Scale for Exam and final notes	
89.5% - 100% = A	
84.5% - 89.4% = B+	
79.5% - 84.4% = B	
74.5% - 79.4% = C+	
69.5% - 74.4% = C	
64.5% - 69.4% = D+	
59.5% - 64.4% = D	
0% - 59.4% = F	
Final score	
Exam	50%
Laboratory	50%
Total	100%
Grading Scale	
89.5% - 100% = A	
84.5% - 89.4% = B+	
79.5% - 84.4% = B	
74.5% - 79.4% = C+	
69.5% - 74.4% = C	
64.5% - 69.4% = D+	
59.5% - 64.4% = D	
0% - 59.4% = F	

COURSE SCHEDULE?

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g., lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (e.g., lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

SUSTAINABLE DEVELOPMENT IN MATERIALS ENGINEERING

Code: **SDME**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

3

Language

English

Thematic block

Applied Materials Science

Form of tuition and number of hours*:

Lecture: 15h

Auditory: 30h

ECTS

3

Lecturer: Sylwia Golba, PhD

www.freepik.com

COURSE DESCRIPTION

The course focus on the relation between social, economic and technologic development that shall be coherent and takes place with respect towards each component of the system. In the module the core action of economic, social and technologic nature between citizens and countries will be presented as they contribute to the changes in the state of being people and development of the countries. The special attention in paid to materials engineering approach that can elevate the possibility of development in modern society but also can endanger it if unproperly used. Various strategies of strengthen the wise usage of sources and also threatens that handicap the actions will be discussed.

The lecture aims to present the basic characteristics of sustainable development goals (SDG) with their tasks that bring information about practice implementation. SD genesis is to be presented with actions, observations and changes that forced the international community to propose the path of changes. In relation to the university point of interest special attention is prescribed to the tasks related to materials engineering in the field of resources gathering, technological processes, materials design and its life cycle.

The exercises are designed to immerse the students into understanding the utilitarian goals from the broad, general level into lower, daily routine actions that support (or discard) the work efficiency. The activities aim to gain a broad perspective on 17 SDG with strong impact on technological aspects and their mutual connections with social and economic ones. Moreover, the student gain the vision over global trends with the inspection of local perspective.

COURSE OBJECTIVES

After completing the Sustain Development in Materials Engineering course, the student should describe the basic goals od SD with understanding the task that support their realization. The course participant is aware of the usefulness and threats of the decision taken within material's design and usage. Student validates the economic, social and technologic impact of materials life cycle.

PREREQUISITES FOR TAKING THE COURSE

To complete the course, it is recommended to implement learning outcomes related to the basics of physics, chemistry, materials science and management.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extended and in-depth understanding in the field of general knowledge, which is the basis for understanding relationships in the processes of designing, manufacturing, testing and application of material.
MS_O_02	Has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in evaluation of materials' impact on environment.
MS_O_03	Can use information from literature, databases and other available validated sources to predefine the impact of materials' production technology and usage. Can define and solve practical engineering tasks that require the use of engineering standards and norms in the field of design of materials life cycle.
MS_O_04	He/she understands the need for an interdisciplinary approach to distinguish impact of technology, materials usage, recycling paths. He/she is familiarized with the need for a comprehensive, scientific analysis of problems in the field of materials engineering in relation to technologic, economic and social aspects.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures**: lectures with problem evolution and interpretation, interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Auditory classes**: Assimilation by description; team work; observation; conclusion;	MS_O_03
Meth_03	**Auditory classes**: problem learning; debate; case study	MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	Exam	MS_O_01 MS_O_02	
FT_02	auditory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials, review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials, familiarization to work subject and review of activities necessary to participate in classes	NO
a_03	Preparation of final result	Preparation and development of reports. Consultation.	YES

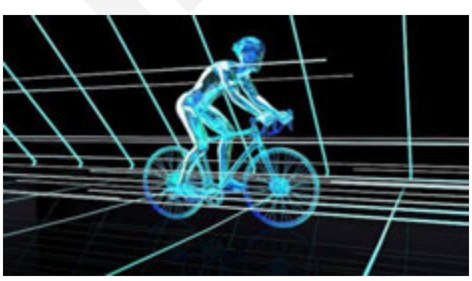
LEARNING OUTCOMES

Student has broad and in-depth understanding in the field of sustainable development goals. Also he / she knows the tasks that bring the ideas into the practice.

COMMENTS

LECTURER

DO YOU KNOW
The path of the solar cycle
This is one of the methods of using ecological transport, which involves the use of bicycles that run on sunlight. It is one of the most recognizable means of transport due to the reduction of pollutant emissions into the environment. In Denmark the solar cycle paths was installed. The solar road surfaces produce clean electricity while bearing vehicle traffic. The installations have power of 148 Wp/m².



www.freepik.com

COURSE CONTENT - lecture

Topics 1

SD genesis

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. 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. 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. (2 h)

Topics 2

SD from materials engineering approach

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

Co-funded by the European Union

LEARNING OUTCOMES

Has in-depth, theoretically based and structured knowledge of modern techniques and research methods used in evaluation of materials' impact on environment.

COMMENTS

LECTURER

DO YOU KNOW

The largest source of anthropogenic methane emissions is agriculture, responsible for around one quarter of emissions, followed by the energy sector, which includes emissions from coal, oil, natural gas and biofuels as shown by The Global Methane Budget. Cattle accounts for more than 70% of the total livestock emissions among other kinds of animals including buffalo, sheep, goats, pigs, and chickens. Animal husbandry is also a source of methane emissions from feed production and manure deposition.

www.freepik.com

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. (2 h)

Topics 3

Technology of materials production in light of SD – the sources

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. (2 h)

Topics 4

Technology of materials production in light of SD – the wastes

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

LEARNING OUTCOMES

Can use information from literature, databases and other available validated sources to predefine the impact of materials' production technology and usage.

COMMENTS

LECTURER

DO YOU KNOW
Biodegradable bags are made of starch with vegetables, which can be removed when shopping. They spread thanks to the ecological reasons, but also for safety within food. Their additional features enable the items to "breath" thanks to its vapor-permeable properties, which has proven useful when packing and transporting vegetables and fruits. Biodegradable bags take up to 100 days to decompose in industrial conditions and are thrown into BIO waste containers;

www.freepik.com

LEARNING OUTCOMES

Student can define and solve practical engineering tasks that require the use of engineering standards and norms in the field of design of materials life cycle.

COMMENTS

LECTURER

DO YOU KNOW

EUROPEN is the European Organization for packaging and the Environment. It is an EU industry association in Brussels presenting the opinion of the packaging supply chain in Europe, without favouring any specific material or system. EUROPEN members are comprised of multinational corporate companies spanning the packaging value chain (raw material producers, converters and brand owners) plus six national packaging organizations all committed to continuously improving the environmental performances of packaged products, in collaboration with their suppliers and customer

www.freepik.com

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 h)

Topics 5

Circular economy of materials – from the cradle to the grave

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 h)

Co-funded by the European Union

LEARNING OUTCOMES

He/she understands the need for an interdisciplinary approach to distinguish impact of technology, materials usage, recycling paths. He/she is familiarized with the need for a comprehensive, scientific analysis of problems in the field of materials engineering in relation to technologic, economic and social aspect

COMMENTS

INSTRUCTOR

DO YOU KNOW

The designers of manufacturer of swimsuits were inspired by the varying skin texture of a shark and produced the original material resembling this structure. The original suit came with compression and ridges in key areas and helped swimmers glide through the water. At the Olympic Games in Sydney later that year, 83% of swimmers who won a medal were wearing the suit. At the same Games, 13 of the 15 world records which were broken were done so by swimmers wearing the new type of suits. As a result, its designer was shortlisted for European Inventor of the Year.

www.freepik.com

Topics 6

Novel materials' technologies raised on the wave of SD requirements

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 h)

LEARNING OUTCOMES

Student knows the tasks that bring the ideas of SD into the practice.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Life-Cycle Design is the environmentally sound design of products based on the whole lifecycle starting from exploitation and processing of raw materials, preproduction, production, distribution, to use and returning materials back into the industrial cycles. Many companies lack the experience to systematically include environmental considerations in their product design processes. Designing that include environmental considerations into the design process requires well trained employee with broad knowledge and view.

www.freepik.com

COURSE CONTENT - auditory classes

Topics 1

Close inspection of the SD's goals – not only the cartoons.

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.

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. (3 h)

Topics 2

Carbon foot print calculators – online activity

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). 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. 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). Students will carry out carbon footprint simulations based on available calculators (UN calculator, US Environmental Protection Agency calculator) or The Greenhouse Gas Protocol.

Topics 3

Economic aspect of SD – plastics waste report

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. There is a large discrepancy on the valid approaches and methods used to evaluate the economic impacts of recycling policies. With the available data (Internet based) they will calculate the perspective outfit of the proposed path.

Topics 4

Bioinspired SD – ideas from the Nature

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. 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

LEARNING OUTCOMES

They understand the mutual dependence of the economic, social and technological aspects of materials' life cycle.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Tire manufacturers are on the verge of a breakthrough with their plans for rubber that can be industrialized and is made from dandelion plants for tire production. In recent years, with the aid of state-of-the-art growing methods and optimized cultivation systems, it has been possible to produce high-grade natural rubber from dandelion roots in the laboratory. The production of rubber from dandelion roots is far less weather-dependent than production from rubber trees. Furthermore, the new system is so undemanding in terms of agricultural requirements that it opens up a whole new potential.

www.freepik.com

creatures, as they survived. Students will be familiarised with core technological-oriented approach that translates nature's pattern into practice.

Topics 5

Green washing – for and against

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. Also the extended producer responsibility (EPR) aspect will be discussed.

Topics 6

SD in the air – materials engineering aspect

In the work the students will search for examples of materials that either use air as an utilised 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 form car fumes). In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. (3 h)

Topics 7

SD in the water – materials engineering aspect

In the activity the students will search for examples of materials/processes that either use water as an utilised 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. In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. (3 h)

Topics 8

SD on the ground – materials engineering aspect

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 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). In each case the complex influence of material / process will be evaluated to find the relation to 17 SDG. (3 h)

LEARNING OUTCOMES

He/she understands the need for an interdisciplinary approach to distinguish impact of technology, materials usage, recycling paths. He/she is familiarized with the need for a comprehensive, scientific analysis of problems in the field of materials engineering in relation to technologic, economic and social aspects.

COMMENTS

INSTRUCTOR

DO YOU KNOW
The hummingbird became the inspiration to design an extremely effective swab for collecting biological material (e.g. during COVID 19 tests). The newly designed swab collects much more material than its market counterparts, thanks to its design modeled on the channels present in the tongue of a hummingbird, which skillfully drinks nectar from the calyxes of flowers. The channels direct the collected material to the tank, which increases the sample volume and facilitates subsequent analysis..

www.freepik.com

Topics 9

SD on my own yard

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 activity is aimed at pointing how to translate generic global goals into local action. (3 h)

Topics 10

Europe vs other continents – various aspects of SD

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. According to available most update ranking 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 h)

www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing *Sustainable Development in Materials Engineering:*

1. Tetyana Nestorenko, Aleksander Ostenda, "Theoretical and applied aspects of sustainable development" Publishing house of the University of Technology in Katowice, 2020

2. Sten Karlsson, ed. Sten Karlsson, Man and materials flows: towards sustainable materials management, aut.: Engl. ed. Ann Crossley, Uppsala : Baltic University, 1987

For more profound understanding of the course subject matter, optional recommended texts include:

1. M. N. V. Prasad, Kaimin Shih, Environmental materials and waste: resource recovery and pollution prevention, Academic Press is an imprint of Elsevier, 2016

2. Pedro Garcia Duarte, Yann Giraud, Economics and engineering: institutions, practices and cultures, in History of Political Economy, vol. 52, 2020

ASSESMENT

Exam:

The written exam verifies overall theoretical knowledge in the field of sustainable development in materials engineering, the factors that influence on the possibility and efficiency of goal realization. Also knowledge of the scalability of engineering process will be verified.

Report:

The reports involve results of the student's activity during the auditory classes; they refer to the pristine theoretical and practical knowledge of undertaken actions. They are developed in class – room and consist of a practical problem development with discussion.

GRADING POLICY

The final evaluation reflects the student achievement scoring system. The grade results from the sum of points obtained by the student during the semester from the auditory classes and points received during the exam.

The written form of the exam includes 3 questions based on the scope of information presented and contains both theoretical and practical aspects. The maximum number of points to be obtained in the exam is 100.

The student is obliged to perform the 10th exercise, which gives in maximum 100 points.
The final grade is determined by 50% of the points obtained in the exam and 50% of the points obtained in the laboratories. According to the table, the sum of the percentages will result in the final grade

Assignment Weights and points	**Percent**
Auditory classes	
90-100% = 90 – 100 points = A	
80-89% = 80 – 89 points = B	
70-79% = 70 – 79 points = C	
60-69% = 60 – 69 points = D	
Below 60% = 0 – 59 points = F	
Grading Scale for Exam and final notes	
89.5% - 100% = A	
84.5% - 89.4% = B+	
79.5% - 84.4% = B	
74.5% - 79.4% = C+	
69.5% - 74.4% = C	
64.5% - 69.4% = D+	
59.5% - 64.4% = D	
0% - 59.4% = F	
Final score	
Exam	50%
Auditory	50%
Total	100%
Grading Scale	
89.5% - 100% = A	
84.5% - 89.4% = B+	
79.5% - 84.4% = B	
74.5% - 79.4% = C+	
69.5% - 74.4% = C	
64.5% - 69.4% = D+	
59.5% - 64.4% = D	
0% - 59.4% = F	

COURSE SCHEDULE?

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

Co-funded by the European Union

COMPUTER MODELING OF THE STRUCTURE AND PROPERTIES OF MATERIALS

Code: CMSPM

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

english

Thematic block

Computational methods and their applications in materials science

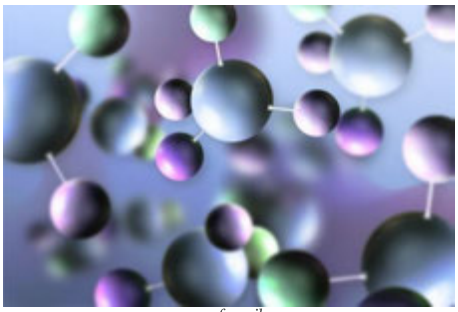
Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 45h

ECTS

3



www.freepik.com

COURSE DESCRIPTION

Computational materials' modeling is an increasingly important branch of materials science due to the evolution of modeling frameworks, the invention of novel numerical algorithms, and increased computer capability. Consequently, modeling and simulation are emerging as powerful complementary approaches to experiment and traditional theory.

The Computer Modeling of the Structure and Properties of Materials course provides a graduate-level overview of modern atomistic computer simulations used to model, understand, and predict properties of technologically important materials.

This course covers the theory and application of atomic-scale computational materials tools to model, understand, and predict the properties of real materials. The course will cover quantum-mechanical electronic structure methods (such as density-functional theory), classical force fields, molecular dynamics, and Monte Carlo.

Laboratories on each of these topics will give students extensive hands-on experience with several powerful modern materials modeling codes. The basic theoretical background behind these computational methods will be discussed. The laboratories will also emphasize practical methods for calculating the physical properties of materials.

It is expected that, in addition to attending classes, students will read, write, discuss, and engage in analysing the course content

COURSE OBJECTIVES

After completing the Computer Modeling of the Structure and Properties of Materials course, the students will be able to understand the fundamentals of modern computational materials science at the level of atomistic modeling and apply fundamental knowledge about materials modeling via computer simulations, including terminology, key concepts, methods, and study topics.

PREREQUISITES FOR TAKING THE COURSE

To complete the course, it is recommended to implement outcomes related to general physics and crystallography is recommended.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extensive and in-depth knowledge of numerical methods and modern computational methods necessary for formulating assumptions and theoretical modeling of engineering materials
MS_O_02	Has in-depth, theoretically based and structured knowledge of modern theoretical modeling techniques and research methods used in materials engineering.
MS_O_03	Can plan and carry out experiments, including measurements and computer simulations, interpret the results and draw conclusions.
MS_O_04	Can select and apply appropriate methods and tools, including advanced information and communication techniques.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the program
Meth_01	**Lectures**: interactive lectures with discussion, lectures with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: practical application of knowledge: formulating the problem caused by the content of the modeling task, data preparation and attempting to solve problem independently with the assessment of the effects	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	course work	MS_O_01 MS_O_02	Meth_01 Meth_02
FT_02	laboratory	45	course work	MS_O_03	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

LEARNING OUTCOMES

Student has in-depth, theoretically based and structured knowledge of modern theoretical modeling techniques and research methods used in materials engineering.

Can plan and carry out computer simulations, interpret the results and draw conclusions.

COMMENTS

LECTURER

DO YOU KNOW

Aurora has been the second fastest supercomputer in the world since 2023. It is expected that after optimizing its performance it will exceed 2 EFLOPS, making it the fastest computer ever.

https://en.wikipedia.org/wiki/Aurora_(supercomputer)

COURSE CONTENT - lecture

Topics 1

Role of computer modeling in materials science (1h)

During the lecture, students will be familiarized with the classes of atomistic computer modeling techniques, their essential results, and their importance in materials engineering.

Topics 2

Introduction to Monte Carlo simulation method (4h)

The topic refers to the application of the so-called Monte Carlo methods in materials science and engineering. Particularly, in the frame of the lecture, students will have the opportunity to get to know the basis of statistical physics, which is the key point for understanding the Monte Carlo approach in simulations. The main point of the lecture is an introduction to Monte Carlo methods and algorithms. The presented knowledge is supplemented by the detailed description of selected examples related to simulations of phase transitions and processes.

Particularly, the following problems are discussed:

a) Elements of statistical physics. (1h)

b) The Monte Carlo methods. (2h)

c) Selected applications of Monte Carlo algorithms in materials science. (1h)

Topics 3

The classical molecular dynamics method (3h)

The role of classical molecular dynamics (MD) simulations in contemporary materials science is described. Students learn about the foundations of molecular dynamics simulations, including numerical methods for solving Newtonian equations describing the dynamic of the atomic system, various force fields, thermostating and barostating the system and computing thermodynamic properties of a studied system from atoms' trajectories. The lectures are supplemented by the laboratory classes teaching the application of the MD method to selected materials science topics.

Topics 4

The LAMMPS parallel molecular dynamics code (2h)

The topic will focus on the use of the LAMMPS molecular dynamic code. The flow of the simulations with LAMMPS will be presented in detail. Commands related to the generation of the modeled system, commands for setting up the interatomic interactions, and commands defining the simulation's constraints will also be discussed.

Topics 5

Fundamentals of Quantum Theory (2h)

The lecture will familiarize students with the wave-particle dualism of matter, principles of quantum mechanics (postulates, mathematical formulation, Schrödinger equation), quantum solutions for single electrons in the presence of quantum walls and potential barriers, and an electron in hydrogen atoms. The indistinguishability postulate and its consequence for many-particle wave functions will be discussed.

LEARNING OUTCOMES

Can select and apply appropriate methods and tools, including advanced information and communication techniques.

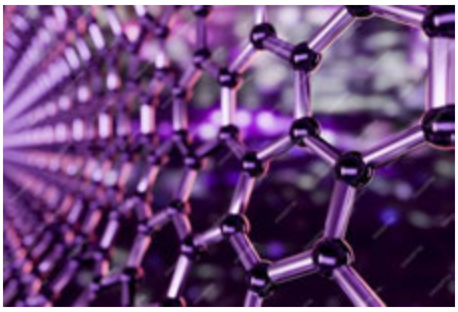
Can plan and carry out computer simulations, interpret the results and draw conclusions.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Density-functional theory (DFT) is a computational quantum mechanical modeling method used in physics, chemistry and materials science to investigate the electronic structure of many-body systems, in particular atoms, molecules, and the condensed phases.



www.freepik.com

Topics 6

Quantum methods for many-electron systems (3h)

The lecture will be devoted to quantum methods in application to many atomic systems. The lecture will outline the assumptions and most important results of approximate models of single electrons in a lattice. During the lecture, students will be familiarized with modern, advanced quantum methods for modeling the structure and properties of materials. This topic will discuss the three-step approximations, including the Born-Oppenheimer approximation, the single electron approach (Hatree-Fock method and Density Functional Theory based Kohn-Sham method), and approximations for the crystal potential. The difference between the "all-electron" and pseudopotential methods will be outlined. 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 software.

COURSE CONTENT - laboratory classes

Topics 1

Introduction to Python programming (3h)

The Python language is one of the most effective modern programming tools. 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, list. This topic includes practical programming using the mentioned above problems with select scientific libraries (NUMPY, SCIPY, MATPLOTLIB).

Topics 2

The Monte-Carlo simulations in materials science (12h)

This topic is organized in 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. The second task block refers to the application of the Metropolis Monte Carlo in simulations of simple phase transitions (e.g. order-disorder), determination of a critical point (e.g. melting point, the Curie point, etc.) - **4h**. 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**.

Topics 3

Linux operating system – terminal commands. (4h)

The Linux operating system is the base for simulations (with LAMMPS code) and visualization the results of atomistic modeling. The scope of this exercise includes working with the terminal, SSH based communication between computers, and fundamental programming in BASH shell.

LEARNING OUTCOMES

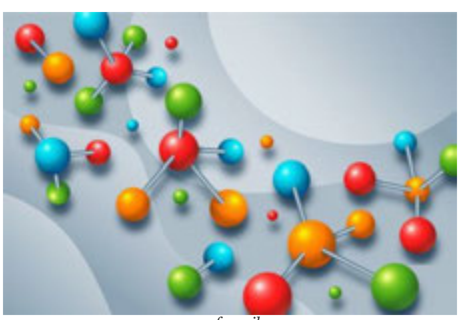
Students can plan and carry out computer simulations, interpret the results and draw conclusions. Also, she/he can prepare a scientific study and present a presentation on the implementation of a research task, containing a critical analysis, synthesis and conclusions.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Molecular dynamics (MD) is a computer simulation method for analyzing the physical movements of atoms and molecules. The atoms and molecules are allowed to interact for a fixed period of time, giving a view of the dynamic "evolution" of the system.



wwww.freepik.com

Topics 4

Compilation of LAMMPS sources code and testing simulations (2h)

The aim of this exercise is to set up two versions of the LAMMPS code: compiling and using the Message Passing Interface library, compiling the LAMMPS code for the serial an parallel execution. Another task is to learn how to supplement the LAMMPS code with additional packages (e.g., MANYBODY) and start the simulations. The first simulations will concern thermal vibrations of Si diamond lattice. The task will contain: definition of the crystal lattice, definition of the simulation box wit a proper boundary conditions, setting up conditions od simulations (NVT ansamble), running the simulations and writing data to configuration files.

Topics 5

Molecular Dynamics simulations of selected materials' properties (9h)

The set of necessary LAMMPS commands for creating a system of atoms, defining the interatomic interaction, and running the simulations will be examined. It will be applied to: calculations of the formation energy of point defects in silicon and other crystals, calculations of bulk modulus of silicon and other crystals, and silicon sphere compression to model and visualization of dislocations activity.

Topics 6

Materials modeling with Wien2k package - preliminaries (2h)

The laboratory exercise aims to familiarize the students with the structural data preparation and initialization of the calculation process using a graphical interface and commands in console mode to perform and control the calculations. Students will perform a series of preliminary calculations to determine the optimal set of control parameters decisive for the accuracy of calculations.

Topics 7

Determination of electronic structure, structural and selected physical properties of ordered materials employing DFT-based quantum method (6h)

Students will perform electronic structure calculations and determine the selected physical properties of different elemental and compound materials, including metals and semiconductors.

The scope of the exercise includes:

a) Preparation of structural data input file and initialization of the control input data files and determination of the optimal set of precision parameters:

b) Modeling of the *p(V)* equation of state, performing the volume optimization

LEARNING OUTCOMES

Students will understand the role of computational materials science in studying the properties of materials and the development of their fabrication methods..

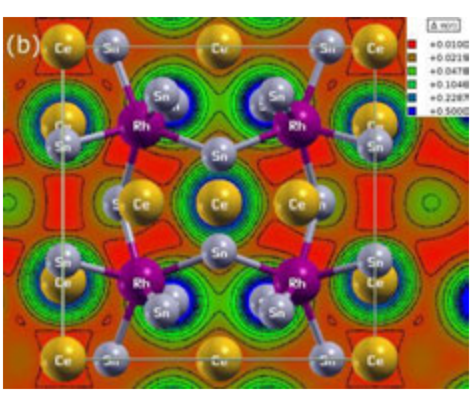
Students will get knowledge on the relationship between the microscopic modeling outcomes and the properties of materials in a macroscopic scale.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Present-day computer modeling of the structure and properties of materials on the atomistic scale, using the quantum, MD, and Monte Carlo methods, can be carried out for systems with sizes similar to the size of real objects tested experimentally containing 1 000 – 1 000 000 atoms



Electronic charge density distribution in the <001> plane of $CeRhSn_3$ compound.

c) Determination and visualization of the band structure and density of states with separation of partial atomic orbital contributions. Determination of electronic specific heat.

Topics 8

***Ab initio* modeling of disordered materials containing dopants and point defects using the supercell approach (7h)**

Students will perform electronic structure calculations and determine the selected physical properties of disordered materials. The materials with disorder driven by non-stoihiometric composition, n- and p-type dopants in semiconductors or point defects (vacancies and anti-site atoms) will be studied.

The scope of the exercise includes:

a) Preparation of superstructures for modeling the low-concentration point defects in crystalline materials:
b) superstructures modeling the vacancy and anti-site atoms in AB systems with B2 type structure,
c) superstructures modeling the p-type and n-type impurities in semiconducting materials (eg. in Si).
d) determination of the formation energies and site preference of vacancies and anti-site atoms,
e) determination and visualization of the band structure and density of states with separation of partial atomic orbital contributions in silicon with n-type and p-type impurities,
f) analysis of the effect of p-type and n-type impurities on the band structure near the Fermi energy.

TEXTBOOK/READINGS

The mandatory reading for completing *Computer Modeling of the Structure and Properties of Materials:*

1. J.G. Lee, *Computational Materials Science, An Introduction*, CRC Press, Tylor & Francis Group, Boca Raton, 2017.
2. J.M. Thijssen, *Computational Physics*, Cambridge University Press, Cambridge, 1999.
3. M.H. Kalos, P. Whitlock, *Monte Carlo Methods I: Basics*; Wiley: New York, NY, USA, 1986.
4. D.P. Landau, K. Binder, *Monte Carlo simulations in statistical physics*, Cambridge University Press, 2005.
5. J.M. Haile, *Molecular dynamics simulations: Elementary methods*, John Wiley & Sons, 1992.
6. M. Griebel, S. Knapek, G. Zumbusch, *Numerical simulations in molecular dynamics*, Springer-Verlag, 2007.

For extending and supplementing knowledge, recommended are:

1. T. Pang, *An introduction to computational physics*, Cambridge University Press, Cambridge, 2006.

2. M. E. Tuckerman, *Statistical mechanics: theory and molecular simulation*, Oxford University Press, Oxford 2010.

3. Applied Computational Materials Modeling. Theory, *Simulation and Experiment*, Eds. G. Bozzolo, R. D. Noebe, P. B. Abel, SpingerNew York 2010.

4. S. Cottenier, Density functional theory and the family of (L)APW methods: a step-by-step introduction, 2013. (available at: www.wien2k.at/reg_user/textbooks)

ASSESMENT

Exam:

The oral exam verifies overall theoretical knowledge in the field of computer simulations of materials properties and phenomena.

Report:

The reports result from the student's work during the laboratories; they refer to the in-depth theoretical and practical knowledge of performed exercises. They are developed in laboratories and consist of a theoretical introduction, a description of the exercise's purpose and scope, and a part reporting the obtained results. They end with a discussion and conclusions.

GRADING POLICY

The final evaluation is made based on the student achievement scoring system. The grade results from the sum of points obtained by the student during the semester from the laboratories and points received during the exam.

The exam is conducted in an oral form – 5 questions from the knowledge contained theoretical and practical aspects. The maximum number of points to be obtained in the exam is 10 (100%).

Completion of each laboratory topic requires the preparation of a report. When assessing the report, the following elements are analyzed:

- completeness of the report; (1 point)
- content included in the theoretical introduction (2 point)
- the correctness of the obtained results; (3 points)
- the correctness of interpretations, discussions, and conclusions; (4 points)
- the aesthetics of the report. (1 point)

and for which the student receives 10 points in total.
The student is obliged to perform eight exercises. The maximum number of points to be obtained for reports is 80 (100%).
The module grade, determined according to the scale presented in the right panel, is based on the arithmetic mean of the percentage grades obtained from the exam and laboratory exercises.

The Exam, Laboratory and Module grading scale

89.5% - 100% = A

84.5% - 89.4% = B+

79.5% - 84.4% = B

74.5% - 79.4% = C+

69.5% - 74.4% = C

64.5% - 69.4% = D+

59.5% - 64.4% = D

0% - 59.4% = F

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

Co-funded by the European Union

SMART POLYMERS

Code SP

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

1

Language

English

Thematic block

Advanced Engineering Materials

Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 15h

ECTS

3

COURSE DESCRIPTION

The course Smart Polymers embraces a wide range of different polymeric compounds that can change their color, transparency or shape in response to their environment; they are smart because of their ability to respond in a very dramatic way when small environmental changes are detected.

It only takes a small variation in temperature, humidity, pH, or light, for example, to induce a large change in smart polymer properties, and this non-linear response makes them unique. Smart polymers tend to have an all-or-nothing response, and are completely predictable, with the change being uniform throughout the material. They might alter their conformation, adhesiveness or water retention properties, and can return to their initial state when the stimulus ends.

The lecture aims to present the properties of intelligent polymers and their division into groups according to their characteristic features. Characteristic features, properties and applications will be discussed for each group.

Laboratory exercises are intended to broaden students' perspective on the usefulness of intelligent polymers. The activities are aimed at obtaining a broad perspective on aspects of the characterization and properties of polymer materials with special features.

COURSE OBJECTIVES

The SMART Polymers module is intended to enable the student to gain knowledge about intelligent polymer materials and how to obtain, classify and analyze them. Thanks to this, the student should gain a better understanding of the correlation between the structure of functional polymer materials and their properties that can be used in appropriate industries.

PREREQUISITES FOR TAKING THE COURSE

To complete the course of SMART Polymers, it is recommended to implement learning outcomes related to the basics of, chemistry, physics, biology and materials science.

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Has extended and deepened knowledge of general knowledge, which is the basis for understanding the relationships occurring in the processes of design, production, analysis and application of intelligent polymers.
MS_O_02	Student possesses in-depth, theory-based and structured knowledge of analytical techniques and methods that operate in the functional units of polymeric materials.
MS_O_03	Student is able to incorporate information from literature, databases and other sources into initial SMART applications of polymers.
MS_O_04	Student is understood that the interdisciplinary problem that occurs in the case of problems and scientific problems, analysis in the field of functional engineering of polymer materials.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures**: lectures provided with multimedia support, lectures with problem interpretation, interactive lectures with discussion,	MS_O_01 MS_O_02
Meth_02	**Laboratory exercises**: experiment demonstrations; laboratory work; observation;	MS_O_03
Meth_03	**Laboratory exercises**: problem learning; debate	MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	exam	MS_O_01 MS_O_02	Meth_01 Meth_02
FT_02	laboratory	15	course work	MS_O_01	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Preparation for classes	Query of materials and review of activities necessary to participate in classes	NO
a_02	Reading literature	Query of materials, review of activities necessary to participate in classes.	NO
a_03	Preparation of reports	Preparation and development of reports. Consultation.	YES

LEARNING OUTCOMES

The student has in-depth knowledge of intelligent polymer materials, which depends on the dependencies in the process of their design, use and analysis.

COMMENTS

The requirement is to demonstrate basic knowledge of polymer materials.

LECTURER
Justyna Jurek-Suliga, PhD

DO YOU KNOW
Dielectric elastomers called electrostrictive polymers under the influence of applied elements activating mechanical deformation. Dielectric elastomers provide greater education and power values than other alternatives (the deformation capacity is higher than in piezoceramics (10-30% vs. 0.1-0.3%)). In this respect, their parameters are similar to those of muscles. their common name - "artificial muscles"

[Kliknij tutaj, aby dodać podpis]

COURSE CONTENT - LECTURE

Topics 1

Functional Polymer Materials – intelligent 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. 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.

Topics 2

Hydrogel polymeric materials

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. 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. Main applications include dressings, contact lenses, biosensors, pH sensors, tissue engineering scaffolds and drug transport. Main applications for dressings, contact lenses, biosensors, pH sensors, tissue engineering scaffolds and tactile transport.

Topics 3

Polymers as biologically acting carriers. Slow drug delivery system

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. 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.

Topics 4

Shape memory polymers

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 under the influence of temperature changes. Shape memory polymers can be stretched elastically and cooled, thanks to which 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 T_g 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 T_g, the polymer will return to its original shape.

Topics 5

Electrically conductive polymers

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. 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 photovoltaics, power or control systems, structures of machines and robots on the micro- and nano-scale, in stealth aircraft by radars, in fabrics camouflaging soldiers against night vision goggles, and 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.

Topics 6

Self-healing polymers

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. 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.

Co-funded by the European Union

LEARNING OUTCOMES

Laboratory classes will enable students to deepen and systematize theoretically based knowledge of techniques and research methods used in the analysis of smart polymers. The laboratory will familiarize students with the possibilities of modeling and using the functional properties of polymer materials.

COMMENTS

The requirement is to demonstrate basic knowledge of polymer materials.

LECTURER
Justyna Jurek-Suliga, PhD

DO YOU KNOW
There is an innovative self-healing polymer that has extraordinary advantages: it is cheap, self-sufficient, heals even at room temperature and can be repaired many times. It is also a great binder for internal cracks in the material, closing the cracks before they start to spread. It is an "ordinary high-performance polyurethane", widely available and used, among others, in the dyeing industry. The secret is the appropriate modification of bonds between molecules (so-called dynamic chemistry).

[Kliknij tutaj, aby dodać podpis]

COURSE CONTENT - laboratory classes

Topics 1

Testing the sorption properties of hydrogels used as wound dressings.

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. 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. (3h)

Topics 2

The use of the FTIR technique in the analysis of the polymer-drug complex.

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. 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. The student will become familiar with the FTIR spectrophotometric technique and use it to analyze the polymer-drug complex. Student explores the possibilities of using polymeric materials in a controlled drug release system. (3h)

Topics 3

Polymers used in targeted therapy - DSC analysis of the polymer-drug complex.

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. 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). 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. (3h)

Topics 4

Degradation studies in an artificial biological environment of selected polymer materials used in medicine

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. 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. The student will become familiar with methods of measuring the degradation dynamics of biodegradable polymers used in medicine. (3h)

Topics 5

Polyaniline - electrically conductive polymer, synthesis and properties

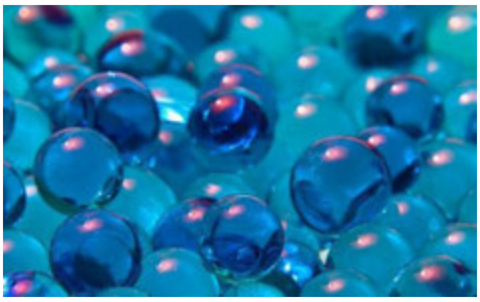
The aim of the laboratory classes is to synthesize polyaniline - a conductive polymer. Polyaniline is obtained as a result of interfacial polymerization. Interfacial polymerization - is a type of polymerization with gradual growth in which the polymerization reaction takes place at the boundary of phases 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. 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. The student will become familiar with the interfacial polymerization procedure, which will result in obtaining polyaniline - an electrically conductive polymer. (3h)

Topics 6

Shape memory polymer analysis.

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). 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. 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. (3h)



Hydrogels polymer

TEXTBOOK/READINGS

The mandatory reading for completing *SMART Polymers*:

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. Polymer Science and Technology, Joel. R. Fried, Prentice Hall, 2003

4. Smart Polymers: Basics and application; Asit Baran Samui, CRC Press, 2022

5. Science and Technology of Polymers and Advanced Materials: Applied Research Methods, Omari V. Mukbaniani; Tamara N. Tatrishvili; Marc J. M. Abadie, CRC Press, 2019

ASSESMENT

Exam:

The written exam verifies general theoretical knowledge in the field of types, characteristics, preparation, properties and applications of functional polymer materials.

Report:

The reports are prepared in laboratories and consist of a theoretical introduction, a description of the purpose and scope of the exercise, and a part describing the results obtained. They will end with a discussion and conclusions. They should contain the results of the student's work during laboratory classes and refer to the necessary theoretical and practical knowledge from the exercises performed.

GRADING POLICY

The final grade reflects the student achievement scoring system. The grade consists of the sum of points obtained by the student during the semester in laboratories and points obtained during the exam.
The written form of the exam consists of 5 questions based on the scope of information presented and includes both theoretical and practical parts. The maximum number of points to be obtained in the exam is 50.
When assessing one laboratory, the following regulatory points are awarded: individual or team work on performing an exercise and developing a protocol in which:
- completeness of the report; (1 point)
- content included in the 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)

and for this part the student receives a total of 10 points.
The student is obliged to complete all 6 exercises, for which a maximum of 100 points can be obtained.
The final grade consists of 50% of the points obtained from the exam and 50% of the points obtained from the laboratories. According to the table, the sum of the percentages will give the final grade.

Assignment Weights and points **Percent**

Laboratories
90-100% = 90 – 100 points = A
80-89% = 80 – 89 points = B
70-79% = 70 – 79 points = C
60-69% = 60 – 69 points = D
Below 60% = 0 – 59 points = F

Grading Scale for Exam and final notes

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

Final score	
Exam	50%
Laboratory	50%
Total	100%

Grading Scale

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

COURSE SCHEDULE?

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

Co-funded by the European Union

LEAN MANAGEMENT

Code: ATMMS

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

3

Language

English

Thematic block

Research & Development in Material Science and Engineering

Path:

All paths

Form of tuition and number of hours*:

Lecture: 15h

Laboratory: 30h

ECTS

4

COURSE DESCRIPTION

Today's organizations, even businesses, public or NGO, are expected to meet customers' requirements and provide high-quality products and services, considering the economic, environmental and social purposes. Quality, time, and cost concerning social development purposes and Industry 4.0 pose new challenges to the manufacturing and service sector.

The subject of *Lean management* meets these expectations and introduces methods and techniques for continuous improvements in every process and organization.

The *Lean management* course is dedicated to all paths, expanding students' knowledge of management and organization using Lean management methods and techniques.

The lecture presents the fundamentals of lean management, its principles, methods, and tools. The workshops are focused on the practical aspects of the improvement process. Through multimedia presentations, case studies, projects, discussions, clips, and quizzes, students will gain experience, learn their limitations, and develop their critical thinking abilities. Students also deepen their competencies in teamwork, presenting the research results to the audience to convince them of the proposed change.

COURSE OBJECTIVES

After completing the *Lean Management* course, the student should understand the central notions and principles of Lean Management and Process Management.

The course participant is prepared to use the appropriate Lean method and tool to improve the process, workplace, and area of performance through effective problem-solving. Students develop their competencies in teamwork, presenting the research results to the audience to convince them of the proposed change. Students develop their critical thinking abilities.

PREREQUISITES FOR TAKING THE COURSE

To complete the course there is no special pre-lesson preparation expected. Students could review knowledge about the fundamentals of management/project management/business process management/process engineering if they were included in the academic program on the engineering studies. It is not mandatory.

Select a proper graphic

LEARNING OUTCOMES OF THE MODULE

Code	Description
MS_O_01	Students will know the central concepts of the Lean management approach. Students will know the history of Lean management and process management. Students will understand the main principles of Lean (continuous improvement, respect for people, elimination of waste). Students will know the key concepts of process management and Lean principles (value, value stream, flow, pull, and perfection). Students will know the components of processes and their role in management. Students will know the benefits and limitations of problem-solving methods and tools. Students will know how to identify and eliminate waste in processes. Students will know how to apply standardisation tools and methods (e.g., SOP, 5S). Students will know how to map and analyse processes using tools like Value Stream Mapping (VSM). Students will know how to prepare and implement corrective and preventive actions. Students will know how to stimulate creativity and engage team members in problem-solving and process improvements. Students will know how to effectively organise and motivate teams for better performance. Students will understand the importance of leadership in creating a Lean culture. Students will know how to use visual management tools, such as Kanban, for workflow optimisation. Students will know how to present results and conclusions to convince stakeholders of proposed changes. Students will develop critical thinking skills to identify opportunities for improvement. Students will gain practical skills in process analysis and improvement techniques. Students will develop competencies in teamwork and effective communication. Students will understand the role of Lean principles in creating sustainable and efficient processes. Students will be able to adapt Lean tools and methods for various industries, including manufacturing and services.

METHODS OF CONDUCTING CLASSES

Code	Description	Learning outcomes of the programme
Meth_01	**Lectures**: Lectures with problem interpretation, interactive lectures with discussion, lectures with multimedia support	MS_01
Meth_02	**Workshop exercises**: Workshops, observation; problem learning, debate	MS_01

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Learning outcomes of the module	Methods of conducting classes
FT_01	lecture	15	exam	MS_01	Meth_01
FT_02	Workshop exercises	30	Mini projects	MS_01	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with teacher
a_01	Reading literature	Query of materials and review of activities necessary to participate in classes.	NO
a_02	Preparation for classes	Query of materials and review of activities necessary to participate in classes. Preparation and development of reports.	NO
a_03	Preparation of mini-projects	Preparation and development of projects. Consultation.	YES

LEARNING OUTCOMES

This course aims to teach students the fundamentals of Lean management and Lean culture, as well as methods, techniques, and tools based on this concept. It also explains the idea of Continuous improvement.

COMMENTS

LECTURER

DO YOU KNOW

According to Deming, 93% of the problems are caused by the management systems, and only 7% could be caused by employees' mistakes.

https://unilogo.com.pl/blog-2/czym-jest-lean-manufacturing-poznaj-zasady/

COURSE CONTENT - lecture

Topics 1

Introduction to Lean Management

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.

Topics 2

Lean management as a process-driven concept

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.

Topics 3

Problem-solving methods and tools

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 involves defining the problem, identifying a list of solutions, prioritising and selecting the best option, identifying limitations, and preparing the implementing and controlling plan according to the PDCA cycle. The above methods will be discussed: Brainstorming, 5Whys, 5W2H, and the Ishikawa Diagram.

Topics 4

Organisation and standardisation of the work and workplace

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.

LEARNING OUTCOMES

Students learn to select and use the appropriate methods and tools for describing, analysing and solving organisational problems. They are practically introduced the continuous improvement philosophy.

COMMENTS

INSTRUCTOR

DO YOU KNOW

Deming said that quality is the effect of well-organized processes; excellent processes produce excellent effects.

https://leanfactories.com/lean-training-materials/

Topics 5

Lean manufacturing

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.

Topics 6

Lean culture and lean leadership

The lecture will familiarize students with creating a lean culture (a culture of continuous improvement) and the principles of work for lean leaders. 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.

COURSE CONTENT - workshop classes

Topics 1

Business process management – process ingredients

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. 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).

Topics 2

Waste audit

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. Students practice using the Japanese approach (Muda, Mura, and Muri) and others like 7wastes and TIMWOODS. During the workshop, students identify the wastes using the TIMWOODS in the example process.

Topics 3

The lean principles

The practical exercises aim to analyse the process using the five lean principles (value, value stream, flow, pull, and perfection), which are

LEARNING OUTCOMES

Students develop their competencies in teamwork, presenting the research results to the audience to convince them of the proposed change. Students develop their critical thinking abilities

COMMENTS

INSTRUCTOR

DO YOU KNOW

Quality is not a coincidence; it results from well-organized processes and a management system in an organisation.

https://www.wevalgo.com/know-how/r-n-d/lean-engineering

described below. During the workshop, students will analyse the case study to identify the Lean principles.

Topics 4 .

Problem-solving – 5Whys

The practical exercises aim to introduce students to problem-solving and give them experience using the 5Whys method. Students will solve problems using 5Whys methods during the workshop and discuss the results.

Topics 5

Value Stream Mapping

The practical exercises introduce students to process mapping with value stream mapping. Students use the VSM to analyse and improve the process and discuss the project's results.

Topics 6

Standard Operating Procedure

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). During the workshop, students prepare the SOP based on the process description and discuss the project's result.

Topics 7

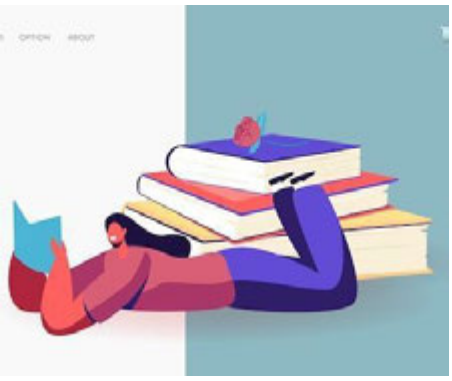
Workflow management - Kanban

The practical exercises aim to teach students how to properly and effectively manage the workflows in an organization. During the workshop, students design and practice workflow management using Kanban (paper or electronic version) and discuss the project's result.

Topics 8

Organising a teamwork

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. During the workshop, students design, plan, and organise the team and the teamwork and discuss the project's result.



www.freepik.com

TEXTBOOK/READINGS

The mandatory reading for completing *Lean Management course:*

1. Bicheno, J., & Holweg, M. (2023). LEAN TOOLBOX SIXTH EDITION: A Sourcebook for Process Improvement. PICSIE BOOKS.
2. 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
3. Marlon Dumas, Marcello La Rosa, Jan Mendling , Hajo A. Reijers, Fundamentals of Business Process Management, Springer-Verlag Berlin Heidelberg 2013,

Additional readings

Useful websites i.e.: https://businessmap.io , https://www.planet-lean.com/articles, https://www.youtube.com/; https://www.wevalgo.com/know-how/r-n-d/lean-engineering

ASSESMENT

Exam:

The test exam verifies overall theoretical knowledge in the fundamentals, methods and tools of Lean Management.

Mini-projects:

The projects are prepared during the workshops in project teams. The team discusses the results, presenting principal conclusions to the audience.

GRADING POLICY

The final evaluation is made based on the student achievement scoring system. The grade results are based on the sum of points obtained by the student during the semester from the workshops and points received during the exam.

The exam is conducted as a multiple choice test - 25 questions from the knowledge containing theoretical and practical aspects. The maximum number of points to be obtained in the exam is 50.

During the assessment of one workshop, the following are taken into account:
1. the correct use of the method/tool
2. the presentation of the conclusions

The final grade is determined by 50% of the points obtained in the exam and 50% in the workshops. According to the table on the left, the sum of the percentages will result in the final grade.

Workshops
Students are obligated to complete all mini–projects required during the semester. Students can improve projects. The number of points depends on each project. W1-5 points, W2- 5 p., W3-5 p., W4 – 5 p., W5 – 10 p., W6 – 5 p., W7 – 5 p. , W8 – 10p.

Grading Scale for Exam and final notes

89.5% - 100% = A
84.5% - 89.4% = B+
79.5% - 84.4% = B
74.5% - 79.4% = C+
69.5% - 74.4% = C
64.5% - 69.4% = D+
59.5% - 64.4% = D
0% - 59.4% = F

Final score

Exam	50%
Laboratory	50%
Total	100%

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

STUDENT INTERNSHIP IN A RESEARCH TEAM

Code: **SIRT**

Field of study
Materials Science and Engineering

Level of study
Master Study

Semester
3

Language
English

Thematic block
Internship

Form of tuition and number of hours
Workshop – 120 h

ECTS
10

Prepared by:
Joanna Maszybrocka, PhD, Assoc. *Prof.*

COURSE DESCRIPTION

Professional internships carried out by a research team operating within the structure of the university are a vital component of the study programme, which enables students to have direct contact with the actual research environment in the field of materials engineering. As part of the internship, students actively participate in the complex research process, from analysing scientific problems through designing and implementing experiments to documenting and interpreting the results. The spectrum of tasks carried out is closely linked to the specifics of the respective research team, focusing mainly on relevant areas of materials engineering, such as research into innovative materials, computer simulations of properties, failure case analyses or the development of advanced technological solutions. Participation in the internship provides a unique opportunity to fully integrate into a research team, where students learn the principles of effective work organisation and the importance of effective communication in an interdisciplinary environment. The programme emphasises developing interpersonal skills, including collaborating as a team and presenting research results professionally. Developing critical thinking skills and innovative approaches to solving research problems is also essential. Internships allow students to learn about the latest trends and technologies in the field while building an awareness of professional responsibility in technical and ethical terms. Participants gain valuable knowledge on protecting intellectual property, maintaining confidentiality and being aware of their research's environmental and social impact.

COURSE OBJECTIVES

The module aims to prepare students to conduct research independently and comprehensively, learn the principles of research teams, and acquire the skills necessary to work in research groups both at the university and in R&D departments.

PREREQUISITES FOR TAKING THE COURSE

Knowledge of basic research principles, data analysis and the ability to use tools to support the organisation of literature and research documentation is recommended.

MODULE LEARNING OUTCOMES

Code module	Description
RPMT_01	They explain how research teams function, including principles of work organisation, division of roles and responsibilities, and task and project management.
RPMT_02	Analyse the literature on the research problem, identifying key issues and research gaps.
RPMT_03	Describe the process of preparing a detailed experimental plan, considering research standards and project objectives.
RPMT_04	Interpret the relevance of the findings in the context of further research and development in materials engineering.
RPMT_05	They design a timetable for the team's work, defining milestones and targets for the following weeks of the project.
RPMT_06	Present the results of the literature review in the form of a report or presentation adapted to the audience.
RPMT_07	Perform laboratory experiments according to research protocols and accepted standards.
RPMT_08	Create a professional final report, applying the principles of scientific documentation and presentation of results.
RPMT_09	Collaborate as a team, sharing information and generating ideas during brainstorming sessions.
RPMT_10	They evaluate their performance by discussing achievements and difficulties with a mentor and accepting feedback to improve.

METHODS OF CONDUCTING CLASSES

Code	Description
Meth_01	**Workshop** Explanation/explanation; Laboratory exercise/experiment; Activation methods: discussion/debate; Demonstration,

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module
FT_01	Workshop	120	credit	Meth_01

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with Teacher
a_01	Reading literature	Query of materials and review of activities required to participate in the activities	No
a_02	Preparation for classes	Literature reading/analysis of source material	No
a_03	Preparation of reports	Production/preparation of tools, materials, and documentation necessary for class participation. Analysis of corrections/feedback from the instructor on the results.	Yes

Brainstorming
Your tool for innovation

Why is it worth it?
Brainstorming helps generate new ideas, solve problems and develop the best strategies for action.

How to do it?

1. *Assemble a team with a variety of competencies.*
2. *Set a clear objective for the session.*
3. *Allow participants to express ideas freely - no judging!*

Effectiveness in practice
Working together during brainstorming fosters innovative solutions and builds team commitment to the project.

Remember: Every idea can be the start of something great!

Research proposal - the foundation of your project

Originality and relevance:

Highlight what makes your study stand out.

Impact on knowledge:

Explain how it will contribute to development or change in the field.

Relevance:

Justify why the study is needed.

Your team:

Demonstrate that you (and your team) are qualified to carry out the project.

Remember! A well-written research proposal is the key to the success of your project.

COURSE CONTENT

Topic 1

Week 1 - Introduction to teamwork and the structure of research teams

In the first week of the module, students meet with a selected research team operating within the university's structures to familiarise them with the functioning of a professional research team and integrate its activities with the university's academic and research objectives. During the meeting, the research team presents their current projects and achievements, demonstrating how they apply their knowledge and skills to solve real-world problems in materials engineering. Students are introduced to the team's structure, the division of critical roles, and how the work is organised, allowing them to understand team dynamics better and effectively preparing them to perform analogous functions within their own PBL project.

Topic 2

Week 2 - Research problem analysis and literature review as part of teamwork in a university research team

In the second week of the module, students working as members of a university research team focus on an in-depth analysis of a research problem and a literature review. The aim is to gain a broad understanding of existing solutions and technologies and to identify key research challenges. Students analyse academic articles, industry reports, and other resources to understand existing developments and opportunities related to the topic. Each student prepares a short report or presentation from the literature review to present their findings at a team meeting. After the presentation of the reports, a brainstorming session is held where the team collectively discusses the conclusions and ideas for solving the problem.

Research team - Collaboration and Roles

A research team is a group of people working together to successfully complete a research project.

Clear roles:

Each team member has a clearly defined role and understands their responsibilities in the context of the overall project.

Close collaboration:

Team members work closely together, ensuring communication and coordination of activities to ensure that work runs smoothly.

Project leader:

The project leader (principal investigator, PI) has ultimate responsibility for all aspects of the project - from planning to implementation to reporting.

Remember, an effective research team is the foundation for the success of any scientific project.

Research Report - Why are you writing it?

You are sharing knowledge
The results of your scientific project can enrich or challenge existing knowledge in a field, contributing to the progress of science.

You build credibility
Your audience - including lecturers and other students - expect your findings to be reliable and supported by sound research methods.

Remember! Writing a report is not just part of a credit - it is a key exercise in science communication.

Topic 3

Week 3 - Practical approach to experiments: Planning, implementation and analysis of results

In the third week of the module, students working as part of the university research team carry out the practical part of the project, focusing on carrying out the planned experiments. At the beginning of the week, the research team supports the students in preparing a detailed experimental plan. Each student is responsible for completing the assigned tasks and conducting the experiments according to agreed standards. In a mentoring role, the research team actively analyses the results at the end of the week, supporting the students in critically evaluating the data collected, interpreting its meaning and verifying that the results align with the project objectives.

Topic 4

Week 4 - Summary and analysis of the results of the research project

In the fourth week of the module, students focus on a detailed analysis and summary of the results obtained during the experiments. Under the supervision of the research team, they produce a final report, which must meet scientific standards in both content and form. Documentation of the results includes precisely presenting the data obtained, their interpretation and the drawing of critical conclusions. In the report, students also formulate recommendations for further research in the thematic area of the project. The final element of the work is the preparation and delivery of a presentation summarising the project. The presentation aims to present the research results and discuss the achievements and their relevance to the development of materials engineering. The presentation occurs in front of the research team and mentor, who provide detailed comments and constructive feedback. During the discussion, the students and the research team identified areas for further improvement, both in the context of their research and in their academic and professional skills.

Rysunek: DALL·E

RECOMMENDED LITERATURE

1. Alley, M. (2018). The Craft of Scientific Presentations: Critical Steps to Succeed and Critical Errors to Avoid. Springer.
2. Hart, C. (2018). Doing a Literature Review: Releasing the Research Imagination. SAGE Publications.Khan, M. A., & Jappes, J. W. (Eds.). (2022). Innovations in additive manufacturing. Springer.
3. Leedy, P. D., & Ormrod, J. E. (2019). Practical Research: Planning and Design (12th ed.). Pearson.
4. Cargill, M., & O'Connor, P. (2021). Writing scientific research articles: Strategy and steps (3rd ed.). Wiley-Blackwell.

VERIFICATION OF LEARNING OUTCOMES

Team commitment and collaboration:

Students' teamwork activities are assessed, including their ability to communicate effectively, collaborate with other research team members and solve problems constructively. An essential element is each student's contribution to the team's objectives and ability to work effectively within the group structure.

Evaluation of the completion of assigned tasks:

The correctness and precision in defining the research problem, conducting the literature review, planning and carrying out the experiments and interpreting the results are analysed. A key element is the quality of the final report, which must meet the scientific requirements in terms of content and form and include logical conclusions and recommendations for further research.

Presentation of results:

The preparation and delivery of a professional presentation of the project results are assessed, including the clarity of the message, the logical structure and the ability to adapt the content to the audience. An important aspect is the ability to defend the conclusions factually during the discussion and look critically at one's achievements.

GRADING RULES

The maximum number of points possible is 100.

Commitment and teamwork

30% (30pkt)

Evaluation of the implementation of assigned tasks

40% (40pkt)

Presentation of results

30% (30pkt)

Grade scale

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

COURSE SCHEDULE

Day	**Date**	**Topic**	**Assignment**	**Due Today**
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

DEGRADATION OF MATERIALS IN THE NATURAL ENVIRONMENT

Code: DMNE

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

2

Language

English

Thematic block

Materials Testing Methods and Failure Analysis

Form of tuition and number of hours*:

Lecture: 15 h

Laboratory: 30 h

ECTS

4

Lecturer: Patrycja Osak, PhD

www.freepik.com

COURSE DESCRIPTION

The Materials Degradation in the Natural Environment course is intended to enable the student to gain basic knowledge about the degradation of engineering materials in the natural environment. The student will become acquainted with the impact of the production and processing of engineering materials on their destruction processes. The module is intended to provide the student with knowledge of the types of materials that degrade in the natural environment and the factors influencing the physical and chemical properties of materials. The module is also intended to enable the student to become proficient in topics related to in vitro and in vivo research to assess the susceptibility of materials to degradation and to determine the mechanisms of basic degradation processes in the natural environment. The content of the module will present the degradation processes of metals, ceramics, and polymers and the identification of the resulting degradation products. The student will be familiarized with the impact of degradation products on the natural environment. Methods of protecting materials against degradation and the use of the degradation potential of engineering materials in various industries will be discussed.

COURSE OBJECTIVES

The main goal of the Degradation of Materials in the Natural Environment course is to prepare students to work in research laboratories and production plants related to the design and operation of devices/products made of various engineering materials. After completing the module, the student has the knowledge and skills to solve problems related to material degradation processes. In accordance with the assumed learning outcomes, graduates are prepared to take up professional work in the field of production of engineering materials and related places.

PREREQUISITES FOR TAKING THE COURSE

The condition for taking the Degradation of Materials in the Natural Environment module is basic knowledge of engineering materials, their crystal structure and electronic properties, and the relationship of individual chemical bonds in a given material. While participating in the module, it is helpful to understand the concepts of electrochemical methods, mainly voltammetry used to assess the chemical composition and the principles of operation of electrochemical devices used to control material degradation products.

LEARNING OUTCOMES OF THE MODULE

Code module	Description
MS_O_01	Students will know the degradation processes of engineering materials and methods of research on the kinetics and mechanism of degradation of engineering materials.
MS_O_02	The student is able to examine the effects of material degradation and investigate the causes of their formation. Is able to select appropriate methods to reduce the degradation processes of engineering materials.
MS_O_03	The student can characterize the physico-chemical phenomena occurring during the degradation processes of engineering materials in the natural environment. They can conduct an experiment using electrochemical methods to assess the impact of degradation products on the quality of sewage water. The student is able to analyze the obtained results and evaluate the degradation products correctly.
MS_O_04	The student understands the need to shape the functional properties of the material to limit the degradation of engineering materials under the influence of the environment in economic and environmental aspects, affecting the protection of the natural environment.
MS_O_05	The student is able to formulate a research problem and select appropriate research methods. He can draw conclusions based on the results obtained. Is able to create research reports and conduct discussions on the research problem undertaken.

METHODS OF CONDUCTING CLASSES

Code	Description	Code module
Meth_01	**Lectures**: Interactive lectures, discussion of the problem, and lecture with multimedia support	MS_O_01 MS_O_02
Meth_02	**Laboratories**: Experiment carried out during classes, demonstration, observation of performed experiments, debate	MS_O_03 MS_O_04

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module	Methods of conducting classes
FT_01	Lecture	15	course work	MS_O_01 MS_O_02	
FT_02	Laboratory	30	course work	MS_O_03 MS_O_04	

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

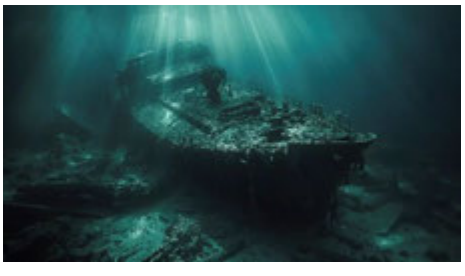
Code	Category	Name	Work with teacher
a_01	Reading literature	Familiarization with the literature necessary to perform laboratory exercises.	NO
a_02	Preparation for classes	Preparation of materials necessary to conduct classes. Preparation and development of reports.	NO
a_03	Preparation of reports	Preparation of reports. Consultation	YES

At the end of the course, Materials Degradation in the Natural Environment, the student:

- will have extensive knowledge about the degradation of engineering materials in the natural environment. Will be able to determine degradation mechanisms and the impact of degradation products on the natural environment. He will know the consequences of material degradation in many industries.
- He will be able to characterize in detail the degradation processes of metals, ceramics, polymers, and composite materials. Will have knowledge of the principles of structural design to minimize environmental damage..
- Will be able to analyze literature, formulate and draw conclusions, and solve material problems related to degradation processes in the natural environment.
- He will be able to plan and conduct experiments to determine the properties of engineering materials under the influence of environmental degradation factors and analyze the resulting degradation products. In addition, the student will develop knowledge about how to protect materials against degradation.
- Will know international ISO standards to ensure the safety and degradability of materials in the natural environment. Will be able to select in vitro tests necessary to assess degradation processes in the working environment by ISO standards.
- Will develop skills in creating reports based on the obtained research results and their presentation. The student will be able to work individually and in teams to determine a research problem and discuss the degradation of engineering materials in the natural environment.

DO YOU KNOW

As a result of the degradation of the German Franken shipwreck sunk at the bottom of the Baltic Sea, 0.06 to 0.14 mm of steel is lost from the hull every year. Assuming that 0.1 mm of steel is lost from the ship's hull per year, it can be said that after 75 years of the wreck lying at the bottom, 7 mm of the ship has already been lost. This means that Franken is on the verge of collapse. Degradation of the metal hull in seawater may cause an ecological disaster in the Bay of Gdańsk.



www.freepik.com

COURSE CONTENT - LECTURE

Topic 1

Introduction to the Degradation of Materials in Natural Environments: Overview of Engineering Materials, Causes of Degradation, and Environmental Impact on Engineering Materials

The lecture is an overview of available engineering materials, divided into individual groups of materials such as metals, ceramics, polymers, and composites. During the lecture, the basic mechanisms of material degradation will be discussed, and concepts related to the degradation of materials and the impact of degradation products on the natural environment will be explained. Issues related to the assessment of changes in the operational properties of materials resulting from changes occurring during their use will be discussed. Structural changes in materials resulting from physical and/or chemical changes caused by long-term exposure to environmental factors will be discussed. The lecture describes the principles of designing devices and structures through various methods, e.g., numerical methods, taking into account the durability of materials and their functionality for specific operating conditions. During the lecture, cases of damage caused by degradation processes leading to disasters and work disruptions in the energy, chemical, and refinery industries will be discussed.

Topic 2

Degradation of metallic materials

The topic of the lecture is related to an in-depth analysis of the causes and effects of the degradation of metallic materials. The lecture will present the main factors that cause the destruction of metals, such as temperature, humidity, and the presence of aggressive components of the natural environment. Chemical and electrochemical processes of metal destruction in the natural environment will be discussed. Metals are mainly damaged by corrosion. The content of the lecture will present the threats and effects of the degradation of metallic materials on the natural environment. The lecture emphasizes the importance of the environment, including soil, air, and water. Soil is an aggressive environment, causing frequent losses of building structures. The diversity of soil in each geographical area, including variable content of chlorides, sulfates, and nitrates, variable acidity, and resistivity of the soil, influence the kinetics and mechanism of metal degradation. The lecture will discuss the rate of metal degradation in the air, for example, in coastal areas, and the destruction processes under the influence of sewage, rainwater, and water supply. The lecture will also present other causes of degradation, such as irregularities of the metal product itself, non-compliance with the requirements in terms of composition and/or structure, the presence of contaminants on the surface of the material, and errors during assembly.

Co-funded by the European Union

At the end of the course, Materials Degradation in the Natural Environment, the student:

- will have extensive knowledge about the degradation of engineering materials in the natural environment. Will be able to determine degradation mechanisms and the impact of degradation products on the natural environment. He will know the consequences of material degradation in many industries.
- He will be able to characterize in detail the degradation processes of metals, ceramics, polymers, and composite materials. Will have knowledge of the principles of structural design to minimize environmental damage..
- Will be able to analyze literature, formulate and draw conclusions, and solve material problems related to degradation processes in the natural environment.
- He will be able to plan and conduct experiments to determine the properties of engineering materials under the influence of environmental degradation factors and analyze the resulting degradation products. In addition, the student will develop knowledge about how to protect materials against degradation.
- Will know international ISO standards to ensure the safety and degradability of materials in the natural environment. Will be able to select in vitro tests necessary to assess degradation processes in the working environment by ISO standards.
- Will develop skills in creating reports based on the obtained research results and their presentation. The student will be able to work individually and in teams to determine a research problem and discuss the degradation of engineering materials in the natural environment.

DO YOU KNOW

Scientists are working on developing plant-based materials called bioplastic, which, as a result of degradation in the natural environment, decomposes into water and compost, bringing added value to the natural environment.

www.freepik.com

COURSE CONTENT - LECTURE

Topic 3

Degradation of ceramic materials

The lecture focuses on the degradation of ceramic materials. Degradation mechanisms based mainly on dissolution, a thermodynamic concept describing the state of equilibrium, will be discussed in detail. Kinetic processes related to the speed of the ceramic dissolution process will be discussed. Ceramics will be divided according to the degradation rate, which will depend on the purity of the material, crystallographic structure, and grain size. The lecture will present the degradation environments of ceramic materials mainly related to the presence of salts. The degradation of ceramics under the influence of the atmosphere is the subject of ongoing research, mainly for economic reasons. The destruction of buildings under the influence of moisture, temperature, solar radiation, precipitation, air movement, and pressure are the key environmental elements subject to research. During the lecture, the role of engineering materials such as ceramics in sustainable development will be discussed, as this group of materials has a small impact on the natural environment and the resulting degradation products can be recycled.

Topic 4

Degradation of polymeric materials

The lecture discusses the degradation of polymeric materials, mainly polymeric materials, constituting about 80% of sea and ocean pollution. Mechanisms of polymer degradation, such as depolymerization, degradation, and destruction, as well as factors influencing these mechanisms, will be presented. The lecture will discuss chemical degradation factors such as acids, bases, and gases and physical factors such as temperature and UV radiation. Areas in which polymer materials are used will be presented, and cases of problems resulting from the degradation of this group of engineering materials in the energy industry, the automotive industry, and everyday life will be described. The lecture discusses in detail the impact of polymer degradation on the natural environment, such as tap water, seas and oceans, and air quality. Current trends in the production of polymer materials will be discussed so that degradation products do not have a harmful effect on the natural environment. The lecture will also discuss the benefits resulting from the degradation of polymers, mainly used to purify tap water.

COURSE CONTENT - LECTURE

Topic 5

Degradation of composite materials

The topic of the lecture will concern the degradation of composites, i.e., materials composed of several phases with different properties. Basic composites used in the energy, construction, and heating industries will be discussed. The lecture will discuss the degradation processes of concrete under the influence of the natural environment, such as acid rain, temperature, and biological factors. The loss of protective properties of the concrete cover towards the reinforcement due to the ingress of atmospheric gases, carbonation processes, and atmospheric precipitation will be discussed. The impact of the degradation of concrete materials on flora and fauna will be presented. The degradation processes of glass wool and changes in the properties of this material due to environmental factors will be discussed. The lecture will also show the degradation processes of laminates as a result of osmotic mechanisms. The latest engineering composite materials that do not degrade under the influence of environmental factors will be presented, as well as a number of environmental benefits resulting from the use of modern composite materials.

Topic 6

Ways to prevent the degradation of engineering materials in the natural environment

The lecture discusses ways to protect engineering materials from each material group against degradation in the natural environment. Methods of protection against degradation through the use of protective coatings will be presented. The selection of the appropriate coating will be presented depending on the type of material, environmental conditions, and the expected level of protection. Various polymer materials and other agents that create a physical barrier against degradation as a result of the natural environment will be discussed. The lecture will also discuss possible combinations of individual engineering materials in order to minimize destruction processes and their potential impact on the natural environment. Anodizing, oxidizing, and phosphating processes will be presented as possible methods of protection against damage due to degradation. The lecture will present additives to polymer products that protect them against degradation during the processing process. Additionally, techniques such as impregnation, applying special coatings and hydrophobization will be discussed, the purpose of which is to protect the surface against the penetration of harmful factors such as water and other liquids, gases, steam, as well as chemical and biological factors. The lecture will also outline the problem of material degradation, which is surface moisture and its limitation, as well as the need to increase the strength properties of engineering materials degrading in the natural environment.

At the end of the course, Materials Degradation in the Natural Environment, the student:

- will have extensive knowledge about the degradation of engineering materials in the natural environment. Will be able to determine degradation mechanisms and the impact of degradation products on the natural environment. He will know the consequences of material degradation in many industries.
- He will be able to characterize in detail the degradation processes of metals, ceramics, polymers, and composite materials. Will have knowledge of the principles of structural design to minimize environmental damage..
- Will be able to analyze literature, formulate and draw conclusions, and solve material problems related to degradation processes in the natural environment.
- He will be able to plan and conduct experiments to determine the properties of engineering materials under the influence of environmental degradation factors and analyze the resulting degradation products. In addition, the student will develop knowledge about how to protect materials against degradation.
- Will know international ISO standards to ensure the safety and degradability of materials in the natural environment. Will be able to select in vitro tests necessary to assess degradation processes in the working environment by ISO standards.
- Will develop skills in creating reports based on the obtained research results and their presentation. The student will be able to work individually and in teams to determine a research problem and discuss the degradation of engineering materials in the natural environment.

DO YOU KNOW

Concrete is resistant to degradation in the natural environment, which is why the Ancient Romans mixed slaked lime with volcanic ash to create concrete. The Romans used such cement as early as 200 BC. The Pantheon was built from this type of concrete, which still stands today.

www.freepik.com

At the end of the course, Materials Degradation in the Natural Environment, the student:

- will have extensive knowledge about the degradation of engineering materials in the natural environment. Will be able to determine degradation mechanisms and the impact of degradation products on the natural environment. He will know the consequences of material degradation in many industries.
- He will be able to characterize in detail the degradation processes of metals, ceramics, polymers, and composite materials. Will have knowledge of the principles of structural design to minimize environmental damage..
- Will be able to analyze literature, formulate and draw conclusions, and solve material problems related to degradation processes in the natural environment.
- He will be able to plan and conduct experiments to determine the properties of engineering materials under the influence of environmental degradation factors and analyze the resulting degradation products. In addition, the student will develop knowledge about how to protect materials against degradation.
- Will know international ISO standards to ensure the safety and degradability of materials in the natural environment. Will be able to select in vitro tests necessary to assess degradation processes in the working environment by ISO standards.
- Will develop skills in creating reports based on the obtained research results and their presentation. The student will be able to work individually and in teams to determine a research problem and discuss the degradation of engineering materials in the natural environment.

DO YOU KNOW

The marble used to build the Taj Mahal avoids constant degradation caused by the natural environment. Degradation processes cause the snow-white color of the building to disappear and the building becomes darker.

www.freepik.com

COURSE CONTENT - LECTURE

Topic 7

Procedures, norms and standards for testing material degradation processes in the natural environment

The lecture discusses procedures and standards used to determine the susceptibility of engineering materials to degradation in the natural environment. Research methods and requirements for specific engineering materials will be discussed. The ISO 9227 standard will be addressed, specifying procedures for testing the durability of engineering materials, along with assessing the effectiveness of applied protective and varnish coatings in conditions simulating the natural environment in which a given element will work. The ASTM D2457-21 standard for determining the gloss of applied protective coatings will be presented. The lecture will discuss the ISO 17556 standard for determining material degradation processes of various materials such as plastics, natural and synthetic polymers, and materials with additives such as plasticizers or dyes. The lecture discusses the ISO 14001 standard specifying the requirements for an effective environmental management system. Standards will be defined for the effective use of material degradation products in order to reduce waste and increase environmental protection efficiency. The lecture will also discuss the ISO 10993 standard related to the degradation of ceramics. Guidelines will be defined on how to evaluate the chemical dissociation of ceramics during in vitro tests.

Co-funded by the European Union

Co-funded by the European Union

Students will have the opportunity to:

- Assessment of the degree of degradation of materials in the aquatic environment
- Analyzes of degradation products in the natural environment using electrochemical methods such as stripping voltammetry
- Determine the selection of engineering material depending on the working environment and its arrangement in the metal voltage series
- Carry out the nickel plating process using chemical methods
- Determine the conditions for oxidizing aluminum in order to obtain a uniform, compact oxide coating

DO YOU KNOW

The degradation of materials in the natural environment is a physical process, i.e. the breakdown of material molecules into smaller particles under the influence of external factors.

www.freepik.com

COURSE CONTENT - LABORATORY

Topic 1

Degradation of engineering materials in the aquatic environment

The aim of the laboratory is to determine the impact of the natural aquatic environment on the degradation of engineering materials such as metals, ceramics, polymers, and composites. Using solutions with variable parameters such as temperature, pH, and solution composition, the impact of this environment on the behavior of materials, such as durability and degree of degradation, will be determined. Microscopic observations will be carried out to assess damage resulting from the impact of a harmful environment on individual materials.

Topic 2

Analysis of degradation products in the natural environment using stripping voltammetry

The aim of the laboratory is to familiarize people with electrochemical methods such as stripping voltammetry. During the exercise, samples of tap water and groundwater collected will be examined to identify degradation products of engineering materials. The exercise will allow you to determine the amount of ions and other substances contained in the tested samples, which are products of the degradation of engineering materials in the environment. During the exercises, current-voltage curves will be obtained. Each of such curves carries qualitative and quantitative information as well as information about the course of the electrode reaction. The concentration of ions in the tested sample will be determined based on the current values characteristic of a specific element compared with the standard.

Topic 3

Electrochemical protection – material selection depends on the working environment

The aim of the laboratory is to familiarize oneself with the structure of the voltage series of metals and to determine the chemical properties of the metal resulting from its position in the voltage series. During the laboratory, the activity of metals as a result of reaction with water, oxidizing, and non-oxidizing acids will be determined, and it will be determined whether a given metal can displace another metal from the solution. Based on the arrangement of metals in the voltage series and the reaction in a given environment, both cathodic and anodic methods of electrochemical protection of metals will be determined. This type of protection is intended to prevent or limit the dissolution of the metal and extend its trouble-free operation time in the natural environment.

COURSE CONTENT - LABORATORY

Students will have the opportunity to:

- Assessment of the degree of degradation of materials in the aquatic environment
- Analyzes of degradation products in the natural environment using electrochemical methods such as stripping voltammetry
- Determine the selection of engineering material depending on the working environment and its arrangement in the metal voltage series
- Carry out the nickel plating process using chemical methods
- Determine the conditions for oxidizing aluminum in order to obtain a uniform, compact oxide coating

DO YOU KNOW

Rigorous degradation conditions are used during laboratory tests, thanks to which it is possible to generate all possible environmental conditions in which a given material will work. In this way, you can determine whether the applied methods of protection against degradation will prove effective.

www.freepik.com

Topic 4

Chemical nickel plating

The aim of the exercise is to familiarize yourself with the chemical protection of metals by electroless autocatalytic nickel plating. It is using different times of immersion of steel samples in the electrolyte by reducing nickel ions on the metal surface using a chemical reducer. During the laboratory, the thickness of the nickel layer obtained and the quality of the coatings obtained will be determined using microscopic observation. The homogeneity of the obtained nickel coatings will be determined because the tightness of the coating affects its strength of protection. The laboratory exercise will present methods of cathodic protection of metals working in highly corrosive natural environments that influence rapid degradation processes.

Topic 5

Aluminum oxidation

The laboratory exercise aims to obtain oxide coatings on the aluminum surface. The oxide layer will be obtained electrolytically in the anodizing process of acids such as sulfuric, nitric, and phosphoric acid. During the exercises, students will dye the obtained oxide layers in order to control the quality of the obtained Al_2O_3 coatings. If a leak occurs in the films, students will be introduced to the process of sealing the film. During the exercises, the quality and uniformity of the obtained coating and uniformity of color will be determined. The adhesion of the obtained coating to the substrate will also be determined in a scratch test.

TEXTBOOK/READINGS

The mandatory reading for completing the subject *Degradation of Materials in the Natural Environment* :

1. Handbook of Environmental Degradation of Materials By Myer Kutz, Elsevier, 2018.
2. Environmental Degradation of Metals, Chatterjee U.K., Bose S.K., Roy S.K, CRC Press, 2001.
3. Advances in Ceramics: Characterization, Raw Materials, Processing, Properties, Degradation and Healing, Sikalidis C., In Tech, 2011.
4. Plactics in the Environment, Gomiero A., In Tech, 2019.

To deepen the course topics, optional recommended texts include:

1. „Electrochemistry at the Nanoscale",P. Schmuki, S. Virtanen, Springer, 2009.
2. „Electrochemistry for Materials Science", W. Plieth, Elsevier, 2008.
3. Handbook of aluminium, Totten G.E., MacKenzie D.S., Marcel Dekker Inc., New York, 2003.

ASSESMENT

Quiz:
At the beginning of each laboratory, there will be a short test regarding the topic of the given laboratory. The purpose of the test is to assess the level of theoretical preparation and familiarization with the recommended literature and lecture regarding the currently performed exercise. The test will assess readiness to carry out laboratory exercises.

Reports:
After completing the laboratory exercise, students are required to write a report on the course of the exercise. The prepared reports should consist of a theoretical introduction closely related to the subject of the exercise, a description of the experiment, experimental results and conclusions. Creating reports will consolidate knowledge in the field of Material Degradation in the Natural Environment.

Debate:
During the interview, the student will be assessed on the basis of statements, arguments, and explanations of their connection with the topic of a given laboratory exercise. Active participation in a conversation about the research problem being implemented, as well as the ability to actively listen and participate in a discussion with other participants in the conversation, will be assessed.

GRADING POLICY

The *Materials Degradation in the Natural Environment* course is credit-based. The grade consists of the sum of grades obtained during the entire course (test, reports, interview). The maximum number of points will be 100. They will be awarded in accordance with the range presented in the table.

Assignment Weights	Percent
5 Reports	50%
5 Quizes	40%
Debate	10%
Total	100%

Reports - max. 50 points
Quizes – max. 40 points
Debate – max. 10 points

Total points – max. 100 points

Grading Scale

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

Co-funded by the European Union

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

RESEARCH PROJECT – MASTER THESIS

Code: **RPMT**

Field of study

Materials Science and Engineering

Level of study

Master Study

Semester

4

Language

English

Thematic block

Research Project - Master Thesis

Form of tuition and number of hours*:

Formy prowadzenia zajęć

Seminar: 45 h

Tutoring: 125 h

ECTS

24

Developed by Joanna Maszybrocka, PhD

COURSE DESCRIPTION

The aim of the module is to comprehensively prepare students for conducting independent scientific research and writing a master's thesis. Throughout the series of seminars, students will become familiar with the research process, starting from selecting a topic and reviewing the literature to developing a methodology and analysing results. Particular emphasis will be placed on various research techniques, both qualitative and quantitative, and their application in interdisciplinary scientific projects. Students will learn to formulate valid research questions, analyse literature, and develop hypotheses. Advanced data collection and analysis tools, such as statistical software and literature management tools, will also be covered. A key component of the module includes practical workshops where, under the guidance of supervisors, students will conduct their experimental research. They will be introduced to methods for conducting experiments, documenting results, and writing scientific reports. An essential aspect of the course is the regular presentation of progress during seminars, enabling ongoing supervision of research projects. The module will culminate in preparing a complete master's thesis and a defence simulation. Students will have the opportunity to refine their presentation skills by responding to questions about their project.

COURSE OBJECTIVES

The course aims to provide students with advanced and comprehensive knowledge of scientific research, encompassing theoretical foundations and practical applications of research methods. The course will equip students with the specialised skills to formulate and solve complex research problems independently. Students will be prepared to approach research projects creatively and innovatively, capable of critically evaluating their research findings and applying them practically across various fields. A key objective is to develop the ability to creatively utilise scientific knowledge in changing socio-economic conditions.

PREREQUISITES FOR TAKING THE COURSE

It is recommended to have a basic understanding of research methodology, data analysis, and the ability to effectively use tools for managing scientific literature.

EFEKTY UCZENIA SIĘ MODUŁU

Code module	Description
RPMT_0W01	The student knows and understands the principles of planning and conducting scientific research, including formulating research hypotheses, selecting research methods and tools, and interpreting results.
RPMT_0W02	The student knows and understands advanced methods and research techniques relevant to the field of science associated with the master's thesis topic.
RPMT_0W03	The student knows and understands the principles of presenting scientific research results, especially in the context of preparing a master's thesis.
RPMT_0U01	The student can independently plan and conduct scientific research related to the master's thesis topic, selecting appropriate methods and tools.
RPMT_0U02	The student can critically analyse and interpret research results, draw conclusions, and identify limitations of the methods used.
RPMT_0U03	The student can present research results in written and oral forms, using specialised terminology and adapting the delivery to the audience.
RPMT_0U04	The student can efficiently search, select, and use scientific information necessary for research, utilising various sources such as databases, scientific journals, and conference materials.
RPMT_0U05	The student can prepare a master's thesis according to accepted standards, ensuring proper structure, chapter division, argumentation, and correctness of citations and bibliography.
RPMT_2K01	The student is prepared to manage time and resources during scientific research responsibly, demonstrating self-discipline, punctuality, and a commitment to completing all planned tasks on time.
RPMT_2K02	The student is prepared to assess their knowledge and skills critically and recognise the importance of expert knowledge in solving research problems.
RPMT_2K03	The student is prepared to think and act entrepreneurially, seeking innovative solutions to research problems.
RPMT_2K04	The student is prepared to adhere to ethical principles in scientific research and respect intellectual property rights.
RPMT_2K05	The student is prepared to responsibly and ethically use artificial intelligence (AI) tools in preparing the master's thesis, respecting academic honesty and considering the limitations of AI.
RPMT_2K06	The student is prepared to engage in scientific discussion, including formulating arguments and counterarguments and defending their theses and solutions with respect to knowledge from relevant science fields and disciplines.

METHODS OF CONDUCTING CLASSES

Code	Description
Meth_01	**Seminar** Problem-based lecture; Interactive methods: discussion/debate; Presentation
Meth_02	**Tutoring** Explanation/clarification; Laboratory exercise/experiment; Interactive methods: discussion/debate; Demonstration

FORM OF TEACHING

Code	Name	Number of hours	Assessment of the learning outcomes of the module	Code module
FT_01	Seminar	45	credit	Meth_01
FT_02	Tutoring	125	credit	Meth_02

THE STUDENT'S WORK, APART FROM PARTICIPATION IN CLASSES, INCLUDES IN PARTICULAR

Code	Category	Name	Work with Teacher
a_01	Reading literature	Querying materials and reviewing activities necessary for participation in classes	No
a_02	Preparation for classes	Reading literature / analysing source materials	No
a_03	Preparation of reports	Creation/preparation of tools, materials, and documentation necessary for class participation. Analysis of corrections/feedback from the instructor regarding the results of learning outcomes verification.	Yes

COURSE CONTENT - SEMINARS

Topic 1

Choice of research topic and creative approaches to its formulation

During the course, participants will be introduced to the theoretical foundations of research topic selection, techniques for identifying research problems and criteria that will facilitate the selection of an appropriate topic. Students will also learn creative thinking methods, such as brainstorming and individual reflection, which will help formulate a research topic precisely. Each student will prepare a short multimedia presentation outlining initial research topic proposals during the seminar. These presentations will be discussed as a group, and the instructor and other students will provide feedback, allowing for modification or refinement of ideas. During the discussion, participants will have the opportunity to ask critical questions about their colleagues' presentations, which will develop their ability to analyse and evaluate the topics' content. The seminar will become a platform for discussion and the joint exploration of research solutions.

Regularly review the literature:
Even if you have prepared a solid literature review at the beginning of your work, science is evolving rapidly. Updating your knowledge on a regular basis will allow you to incorporate the latest research into your paper, which will increase its value. Reviewing the literature on an ongoing basis also makes it easier to verify hypotheses and avoid duplicating previous research.

Topic 2

Principles of thesis writing

The seminar introduces students to the structure and principles of writing a master's thesis. The aim is to prepare participants to produce a coherent and logical thesis, presenting the research results clearly and professionally. The course will discuss the critical elements of a paper, the principles of using scientific style and avoiding the most common mistakes. Students will learn how to properly format, cite and create bibliographies according to accepted academic standards. Participants will analyse sample scientific papers, paying attention to their structure, style and content presentation. In doing so, they will acquire practical knowledge and skills that will enable them to produce high-quality scientific texts independently.

Topic 3

Methods for searching and critically analysing scientific literature

The seminar focuses on scientific literature search methods and critical source analysis principles. Students will be introduced to techniques for identifying research gaps and creating a coherent literature review, which is essential for adequately setting up a project in a scientific context. The class will discuss strategies for effectively using databases, library catalogues, and other tools to obtain reliable sources. Participants will learn to assess the quality and relevance of publications, paying attention to their timeliness, methodology and contribution to the discipline. Based on their accumulated knowledge, students will develop a preliminary research plan, including the purpose of the research, research questions, hypotheses and an overview of the methodology. They will prepare and present papers on the theoretical background of their research projects, describing the most important scientific works that form the basis for the planned research. Discussing the presentations will allow them to exchange insights, receive feedback and improve their argumentation and critical thinking skills.

Co-funded by the European Union

Document your progress regularly

Keeping a research journal from the very beginning of your project allows you to track progress, verify collected data, and analyze your decisions at each stage of the work. This makes creating reports or writing the final version of your master's thesis easier and helps you avoid last-minute information searches. Systematic documentation also enhances the effectiveness of consultations with your mentor.

Topic 4

Research Methodology

In this seminar, students will present selected research methodologies they plan to use in their projects. They will present detailed methodological plans, including a description of the selected methods, data collection procedures and a data analysis plan. Each presentation will be followed by a discussion during which the presenters and other seminar participants will be able to ask questions, provide feedback and suggest possible improvements. This stage aims to critically analyse and evaluate the proposed methodologies to ensure that the chosen approaches are relevant and realistic in the context of the research problems posed. Discussions will allow students to refine their methodological plans, identify potential challenges and develop strategies to overcome them.

Topic 5

Presentation of progress in experimental research

During the seminar, students will structure and deepen their knowledge of the principles of presenting research results. They will then present progress reports on their research projects, focusing on the experiments. They will show the results, difficulties encountered, and solutions applied. They will discuss the data collection process, the techniques and tools used and the preliminary analyses. The reports will become the basis for discussions in which the presenter and other seminar participants will ask questions, provide comments and suggest potential improvements to the research procedures. This stage aims to critically evaluate progress, identify possible problems and develop ways to solve them. The tutors will support students in interpreting preliminary data and suggest additional experiments or modifications to existing procedures to ensure the collection of complete, reliable and credible data, forming a solid foundation for further analysis and conclusions.

Topic 6

Preparation for the thesis defence

The Seminar aims to structure and deepen students' knowledge of the critical principles of effective scientific presentation. Students will learn how to present the most important aspects of a paper clearly, concisely and convincingly, including the research findings, the methods used and the significance of the conclusions reached in the context of previous knowledge in the field. They will also understand the importance of communicating effectively with the examination board, including responding to questions and concerns and defending their position.

The next stage will be defence preparation exercises, including simulations and question-and-answer sessions, allowing students to experience realistic presentation conditions under pressure.

COURSE CONTENT – TUTORING

Consult with your mentor
Regular meetings with your supervisor or mentor are a key element of the research process. These sessions allow you to discuss progress, receive valuable guidance, and obtain early feedback on issues that may require adjustments. Consultations also help in more effectively planning the next stages of your work and ensuring that your efforts are on the right track.

Topic 1

Clarifying the research topic of your master's thesis

Classes are conducted in the form of tutoring. During tutoring sessions, the student presents their ideas, initial assumptions and research questions and the supervisor, using their knowledge and experience, provides guidance and feedback. Tutoring includes discussions about the current state of knowledge in the field, potential research gaps and the relevance and innovation of the proposed topic. The supervisor assists the student in identifying critical aspects of the thesis, such as research objectives, hypotheses and methodology. An essential element of tutoring is support in the selection of literature on the topic and the identification of possible sources of data. Regular tutoring sessions enable the student to gradually refine the research topic until the final, refined version is achieved. The individual approach of the supervisor allows the topic to be tailored to the student's interests and abilities while ensuring its high scientific quality.

Topic 2

Literature review and research plan

Tutoring activities focus on the student's independent work on the literature review and developing a research plan with the support of a mentor. The student independently searches the research literature, identifies key theories, models and research findings related to the chosen topic, and identifies research gaps. The mentor has an advisory role, helping the student evaluate the selected sources and supporting the formulation of research questions and hypotheses. During mentoring meetings, the student presents progress, and the mentor provides guidance and suggestions without imposing specific solutions. The main aim is to support the student in creating a preliminary research plan and timeline. Finally, the student presents the developed documents in a seminar, where feedback is obtained before moving on to the following stages of the research work.

Topic 3

Research Methodology

During the tutoring sessions, the student is independently introduced to a variety of research methodologies that can be applied to their project. The mentor's role is to support the student in analysing the advantages and limitations of the methods, as well as in selecting appropriate data collection and statistical analysis techniques. With the mentor's support, the student develops a detailed methodological plan that includes a description of the chosen research methods, data collection procedures and analysis plan. The mentor provides guidance during meetings, but the student is responsible for developing solutions independently. Once the supervisor approves, the methodological plan is presented at the seminar, where it is evaluated before the further stages of the research project begin.

Be flexible in methodology:
In research, not everything always goes according to plan. If you encounter difficulties with the original methodological assumption, don't be afraid to make changes. Analyse what can be improved or changed in your research tools or data collection techniques to make your research more effective and achieve better results. It is important to be able to adapt to new circumstances.

Topic 4

Training in the use of laboratory equipment and safety principles in the context of the implementation of the research plan

The laboratory equipment handling and safety classes are designed to prepare students to carry out specific experiments resulting from their research plan. With their research plan already in place, students know what experiments they must carry out and what equipment they will use. Lab supervisors provide practical training to demonstrate the operation of the necessary laboratory equipment. Students learn how to operate these tools themselves while being introduced to the health and safety principles key to working safely in the laboratory. The mentor is a support, helping students better understand the theoretical aspects of safety and work efficiency. After the training, students must pass a test to confirm their knowledge of using the equipment and follow safety rules. Only after a positive assessment can they proceed to independent research, carrying out their research plan professionally and safely.

Topic 5

Conducting experimental studies

In this stage of the tutoring activity, students carry out their research projects, carrying out experimental research according to a previously developed methodological plan. The tutor acts as a mentor, offering support in solving problems that may arise during the implementation of the experiments. Students are responsible for collecting data using the chosen methods and tools, and their work is based on self-reliance and strict adherence to pre-established procedures and safety rules. During tutoring sessions, the student consults the preliminary results of their research with a mentor, who guides data analysis, verification of results and possible modifications to research procedures. The mentor does not impose solutions but helps to evaluate progress critically. The ultimate goal of tutoring is to help the student collect reliable and credible data that will form the basis for further analysis and inference in subsequent stages of the research work.

Topic 6

Conducting experimental research

As part of the tutoring activities, students independently prepare a detailed progress report of their laboratory work, in which they present the data collected, experimental results and first conclusions. The mentor is supportive, helping the students to analyse the collected data and assess its quality critically. The student discusses the difficulties encountered and proposed solutions with the mentor while learning how to document their research activities better. During the tutoring sessions, the student presents preliminary versions of the report, and the mentor provides guidance on the correctness of the description of the methods, the interpretation of the results and the assessment of the data quality. An important element is also a discussion on the usefulness of the collected data for further research. The supervisor assesses the final report, and its acceptance is a condition for the continuation of the research project.

Plan time for revisions:

When preparing to hand in your thesis, always leave yourself a margin of time to make revisions. A dissertation often requires multiple revisions - from minor formatting changes to major modifications in content. Adequate time allowance will help you avoid stress and increase your chances of achieving a higher grade by carefully refining your content.

Topic 7

Preparation of the thesis

In this part of the tutoring session, students focus on preparing a complete version of their thesis. They work independently, compiling all parts of the thesis, such as the introduction, literature review, methodology, results, discussion and conclusion, ensuring the content is coherent and logically arranged. The mentor plays an advisory role, offering guidance on the correctness of the structure and filling in missing elements, but does not intervene directly in creating the thesis. Students are responsible for independently formatting their work according to university requirements and using appropriate citation styles. Regular consultations with a mentor enable you to discuss your progress and receive support on the clarity of your argument and the compliance of your work with academic standards. These classes aim to produce a professionally edited paper for assessment and defence.

Topic 8

Preparation for the thesis defence

During tutoring, students work independently to prepare for their thesis defence with the support of a mentor who acts as an advisor. The main focus is on developing an effective presentation strategy that clearly and logically presents the most important aspects of the research. The mentor offers guidance on the structure of the presentation, suggesting which elements to emphasise and how to deal with difficult questions. Students develop the presentation independently and, during tutoring sessions, discuss progress and receive advisory guidance. The mentor does not intervene directly in creating the presentation but helps refine its content. Eventually, students present the finished presentation at the seminar, allowing them to practice the speech and get feedback before the defence.

Rysunek: DALL·E

RECOMMENDED LITERATURE

1. Alley, M. (2018). The Craft of Scientific Presentations: Critical Steps to Succeed and Critical Errors to Avoid. Springer.
2. Hart, C. (2018). Doing a Literature Review: Releasing the Research Imagination. SAGE Publications.Khan, M. A., & Jappes, J. W. (Eds.). (2022). Innovations in additive manufacturing. Springer.
3. 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.
4. Leedy, P. D., & Ormrod, J. E. (2019). Practical Research: Planning and Design (12th ed.). Pearson.

VERIFICATION OF LEARNING OUTCOMES

Progress presentations:

During the seminar, students give progress presentations of their research work. The aim is to ensure that the student completes the research according to the schedule and shows progress. Presentations must be coherent, logical, and detailed, and the students should be prepared to answer questions. Assessment is based on the quality of the information presented and the research degree.

Reports:

During tutoring, students prepare reports documenting the progress of their research. The report includes a literature review, a description of the experiments, an analysis of the results and a conclusion. According to the mentor's guidelines, reports must be concise, with correct terminology and appropriate data presentation (graphs, tables, literature references). Reports are assessed in terms of content and form.

Activity:

Activity is assessed in both seminars and tutoring. In workshops, students are evaluated for participating in discussions, asking questions and engaging with the topics discussed. During tutoring, activity is assessed based on consultation with the mentor, the ability to ask questions, propose solutions and independence in working on the project.

Thesis submission:

Students are required to formally submit a complete dissertation, which must meet the formal and substantive requirements. Submission of the thesis is a prerequisite for the module, but the assessment of the thesis itself only takes place by reviewers after submission.

GRADING RULES

The final grade in the course depends on the sum of points earned by the student for activities in seminars and during tutoring. The maximum number of points possible is 100.

Seminar 50% 50 points

Presentation of research work progress

30% 30 points

Seminar activity

15% 15 points

Compliance with schedule

5% 5 points

Tutoring 50% 50 points

Progress on assignments

20% 20 points

Quality of documentation (reports, plans)

15% 15 points

Activity and consultation with mentor

10% 10 points

Independence in the execution of tasks

5%5 points

The submission of a thesis is a prerequisite for the module, but the assessment of the thesis itself only takes place by reviewers after submission.

Total points - max. 100 points

Rating scale
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

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

COURSE SCHEDULE

Day	Date	Topic	Assignment	Due Today
1				
2				
3				
4				
5				

* In this field, provide information in what didactic form the course is implemented (e.g. lecture, seminar classes, laboratory, field activities, etc.). If the subject is implemented in several didactic forms (consists of e.g. lecture and laboratory, etc.), all forms of the subject implementation should be indicated. In this field, you should also specify the number of hours organized for a given form of classes (separately for lectures, separately for laboratory classes, etc.).

MATERIALS SCIENCE MA(S)TERS

developing a new master's degree

The document was prepared as part of the "Materials Science Ma(s)ters - developing a new master's degree" project (2021-1-PL01-KA220-HED-000035856).

Co-funded by the European Union

This project has been funded with support from the European Commission. This publication reflects the views only of the author and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Content preparation: **Joanna Maszybrocka, Tomasz Goryczka, Małgorzata Karolus, Magdalena Szklarska, Małgorzata Adamczyk-Habrajska, Bożena Łosiewicz, Grzgorz Dercz, Maciej Zubko, Sylwia Golba, Adrian Barylski, Michał Dworak, Jacek Krawczyk, Mateusz Dulski, Józef Deniszczyk, Artur Chrobak, Dariusz Chrobak, Justyna Jurek-Suliga, Justyna Maciąg, Patrycja Osak**

Technical editing: Joanna Maszybrocka

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA