MATERIALS SCIENCE MA(S)TERS

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Teacher Guides

Part 3

MATERIALS SCIENCE MASTERS

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UNIVERSITY OF SILESIA IN KATOWICE

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

REFRACTORY MATERIALS

Code: RM

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO REFRACTORY MATERIALS

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

Refractory materials are a class of materials designed to withstand extremely high temperatures, often encountered in industrial processes such as metal smelting, glassmaking, ceramics production, and in the construction of high-temperature processing units like kilns, furnaces, reactors, and incinerators. They exhibit excellent resistance to thermal, mechanical, and chemical degradation even at extreme temperatures, making them crucial in maintaining the integrity and efficiency of high-temperature applications. The lecture aims to introduce basic information and terminology typical for refractory materials, basic definitions and terms, and an overview of the Refractory Industry. Refractory definition, significance, and applications in various industries (metallurgy, glass, ceramics, etc.). Types of raw materials used (oxides, silicates, carbides, etc.), nomenclature and technical formulas. Designation of the materials. Formula expression for mineral phases classification. Use/Application of refractory products and market distributions. Introduction to the common applications of refractory materials include lining furnaces in the steel industry, insulating boilers in power plants, forming crucibles in foundries, and constructing linings in kilns for ceramics and cement production. Refractories are shaped into various forms such as bricks, castables, mortars, and monolithic linings, depending on the application requirements. Their selection depends on factors like the operating temperature, chemical environment, thermal cycling, and mechanical stresses involved. Students will learn the different loadings (Thermal, Mechanical, Chemical) which the refractories are faced. Installation, and maintenance of refractory materials are of utmost importance to ensure the efficient and safe operation of high-temperature industrial processes. Choosing the right refractory material based on the specific application and conditions is crucial for optimal performance and safety of industrial equipment. Students will analyze the importance of refractories on the base of high temperature resistance, protection of industrial production equipment, conservation of energy, chemical inertness, variety and customization, safety. During the discussion with the students, examples of different industrial refractory applications will be pointed out to differentiate them with the typical properties and process requirements.

3. Learning outcomes

Students can differentiate the refractory materials and distinguish the different refractory material groups with their advantages and disadvantages. Student can explain the basic properties of refractory materials and distinguish them from the other engineering materials. Students defien the basic nomenclature of the refractory materials.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

Chapters 1 and 2.

6. Additional notes

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Topics 2

1. The subject of the lecture

CLASSIFICATION OF REFRACTORIES

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

This lecture aims to introduce Types of Refractories according to different classification methods DIN-EN-ISO. Classification according to stage grain type, binder phase and porosity. Classification according to the chemical behavior (acidic, basic, neutral), Service temperature, shaped and unshaped refractory class. Students will learn the different classification systems which is explained below; Refractory materials are classified based on several criteria, including chemical composition, physical properties, and application temperatures. Based on chemical composition. Acidic refractories, these are composed of acidic materials like silica (SiO_2) and alumina (Al_2O_3). They resist acidic slags but are vulnerable to basic slags. Basic refractories, Comprising basic compounds such as magnesia (MgO) and dolomite (CaO.MgO). They withstand basic slags but are susceptible to acidic environments. Neutral refractories, these include materials like chromite ($FeCr_2O_4$) and carbon. They show stability in both acidic and basic conditions and are used in areas exposed to both types of slags. Based on chemical composition; fireclay refractories, made primarily of hydrated aluminum silicates, they have good resistance to heat and are used in lower temperature applications. High alumina refractories, composed mainly of alumina (Al_2O_3), they offer better resistance to higher temperatures and abrasion compared to fireclay refractories. Silica refractories, comprising silica (SiO_2), these materials have excellent resistance to high temperatures but are prone to thermal shock. Magnesia refractories, predominantly made of magnesia (MgO), these possess high refractoriness and are suitable for high-temperature applications. Based on application temperature, ordinary refractories Suitable for use in temperatures below 1,600°C (2,912°F). Includes fireclay bricks, silica bricks, and magnesia bricks. High temperature refractories, Designed for use in temperatures above 1,600°C (2,912°F). These include materials like alumina, zirconia, and chromite. Based on specific application; insulating refractories, these materials have low thermal conductivity and are used to conserve heat or reduce energy loss in high-temperature applications. Abrasion-resistant refractories, these materials have low thermal conductivity and are used to conserve heat or reduce energy loss in high-temperature applications. Refractories for steel industry; tailored to withstand extreme conditions in steelmaking processes, including furnaces and ladles. Monolithic Refractories, these are unshaped refractory materials, including castables, plastics, and ramming mixes. Shaped refractories, manufactured into specific shapes like bricks, blocks, and precast shapes for easy installation.

3. Learning outcomes

Students can differentiate the different classification methods of the refractory materials; distinguish the different refractory material groups with their advantages and disadvantages; analyze and make comment on the different usage field of refractories.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

Chapters 4,5,6,7

6.	**Additional notes**

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Topics 3

1. The subject of the lecture

BASICS OF THERMAL ENGINEERING

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

This lecture aims to introduce the basics of thermal engineering. Refractories are materials produced to withstand extremely high temperatures while maintaining their strength, shape, and resistance to thermal shock and chemical degradation. Understanding their thermal properties is crucial in selecting the right materials for specific high-temperature applications. Thermal engineering of refractories requires a multidisciplinary approach involving materials science, thermodynamics, heat transfer, mechanical engineering, and industrial processes. The goal is to create durable materials capable of withstanding extreme temperatures while maintaining their structural integrity and thermal insulation properties. Refractories are chosen based on their ability to withstand extreme temperatures, thermal shock, chemical attack, and mechanical stress. Different materials like oxides (such as alumina, silica), non-oxides (carbides, nitrides), and composite materials are used based on the specific application requirements. Understanding thermal conductivity, thermal expansion, specific heat, and heat capacity are critical. Refractories must have low thermal conductivity to minimize heat transfer and should expand minimally when exposed to high temperatures to prevent cracking or structural failure. The design and configuration of refractory structures must account for the specific heat distribution, mechanical stresses, and thermal gradients experienced in different industrial processes. Different lining and brick configurations are employed to optimize performance. Proper installation techniques are vital for the performance and longevity of refractories. Factors like anchoring systems, joint design, and proper curing procedures need to be considered during installation to ensure optimal thermal properties and structural stability.

3. Learning outcomes

Students can explain heat capacity, thermal conduction theories, theory of thermal insulation and basics of refractory wall design and calculations; define the heat transfer mechanism in refractories and thermal shock; analyze the required refractory properties according to the industrial needs by explaining the heat transfer and thermal shock behavior on the base of ionic and covalent nature of the raw materials.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

Chapters Appendices

6. Additional notes

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Topics 4

1. The subject of the lecture

REFRACTORY MANUFACTURING

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

Different manufacturing methods are used to produce refractory materials, each suited for different types of refractories and applications. Selection of the appropriate method based on the type of refractory material required, the desired properties, the intended application, and the economics of production. Each method has its advantages and limitations in terms of cost, complexity, precision, and the specific properties of the resulting refractory material. Students will learn various shaping methods (Dry pressing, Extrusion, Slip casting, Fused casting) and Firing (Sintering) Technology which is very important for refractories This lecture aims to introduce the Basics of Refractory Manufacturing process including, Coarse Ceramic Manufacturing, Fine ceramic manufacturing, Packaging, Transport and Storage, Brick shapes, Measurement and Deviations. The production process for refractories involves several steps that are crucial in creating materials resistant to high temperatures and harsh conditions. Refractories are non-metallic materials used in linings for high-temperature furnaces, reactors, and other processing units in industries like steelmaking, glass manufacturing, cement production, and more. Important manufacturing steps are;

Raw material selection; Refractories are made from various raw materials such as alumina, silica, magnesia, chromite, zirconia, and others. The selection of raw materials depends on the desired properties and the intended use of the refractory. Crushing and Grinding: Raw materials are crushed and ground into fine particles to ensure uniformity and improve the material's reactivity. The size reduction process may involve crushers, mills, or pulverizers. Mixing and blending: The crushed and ground materials are thoroughly mixed in the desired proportions to achieve the required chemical composition and properties. Binders or additives may be included in the mix to enhance plasticity, strength, or other characteristics. Forming: The mixed materials are formed into shapes such as bricks, tiles, castables, or monolithic refractories. Forming methods include pressing, molding, extrusion, or casting, depending on the specific product being manufactured. Drying: After forming, the shaped refractory products undergo a drying process to remove moisture. Controlled drying helps prevent cracking or deformation of the refractory shapes. Firing and sintering: The dried refractory shapes are fired or sintered at high temperatures in kilns or furnaces. This process helps in achieving the desired chemical and physical properties by bonding the particles together and eliminating any remaining moisture. The specific details of the refractory production process can vary based on the type of refractory being manufactured, the raw materials used, and the intended application. Additionally, advancements in technology and innovation may introduce new methods or materials in the production process to enhance the performance of refractories.

3. Learning outcomes

The students can distinguish the different refractory material groups with their advantages and disadvantages by learning their difference in manufacturing route; define various shaping methods (Dry pressing, Extrusion, Slip casting, Fused casting) and Firing (Sintering) Technology which is very important for refractories; explain the details of Refractory Manufacturing process including, Coarse Ceramic Manufacturing, Fine ceramic manufacturing, Packaging, Transport and Storage, Brick shapes, Measurement and Deviations.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

Chapters 2

6. Additional notes

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Topics 5

1. The subject of the lecture

REFRACTORY TESTING

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

Testing methods for refractory materials are crucial to ensure their performance and suitability for specific applications. These testing methods help determine the physical, thermal, mechanical, and chemical properties of refractory materials, ensuring their reliability and suitability for various high-temperature applications like furnaces, kilns, reactors, and other industrial settings. This lecture aims to introduce refractory testing. RUL (Refractoriness under load) Test: Evaluates the deformation behavior of refractory materials at high temperatures while under a specified load, HMOR (Hot Modulus of Rupture) Test : Assesses the material's strength at elevated temperatures by subjecting samples to bending stresses, Creep Testing : Determines the material's ability to withstand constant stress at elevated temperatures without deforming over time, Thermal Conductivity Test : Measures the material's ability to conduct heat. Methods include the steady-state heat flow technique or transient hot-wire method, Thermal Shock Test (depending on the chemical characteristics): Evaluates how well a material withstands rapid changes in temperature without cracking or failing, Corrosion Test (Static and Dynamic corrosion tests): Assesses the material's resistance to chemical attack or degradation when exposed to specific environments. Chemical analysis (XRF), Abrasion resistance testing, microstructural testing (SEM/EDX), mineralogical testing methods (XRD) are also frequently conducted testing methods for refractories. High temperature testing of refractories involves subjecting these materials to extreme temperatures to assess their thermal and mechanical properties. Refractories are materials designed to withstand very high temperatures and are used in industries like steelmaking, glass manufacturing, cement production, and more, where they're exposed to severe heat.

3. Learning outcomes

The students can analyze the required refractory properties according to the industrial needs; make proper selection of refractory materials for different furnace operations by learning how to evaluate the refractory properties; demonstrate how to evaluate the high temperature performance of the refractories.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

Chapters 8 and Appendices

6. Additional notes

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Topics 6

1. The subject of the lecture

ACIDIC REFRACTORY TECHNOLOGY

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

Acidic refractories are those that exhibit excellent resistance to acidic environments and are used in industries where the materials come into contact with acidic compounds or gases at high temperatures. These materials are designed to withstand the corrosive effects of acids, such as acidic slag, acidic melts (silicate glass etc.) sulfuric acid, phosphoric acid, and other acidic substances. During the lecture student will learn different class of acidic refractories which are mainly based on Alumina-Silicate Refractories and learn their selection and properties with required phase diagram understanding This lecture aims to introduce the acidic refractory technology. Alumina-Silicate Refractories and their selection and properties. Common types of acidic refractories include: Silica (SiO2) Refractories: Silica-based refractories are highly resistant to acidic reactions and are used in glass manufacturing, steelmaking, and other applications where resistance to acidic environments is crucial. Alumina (Al2O3) Refractories: Alumina-based refractories also offer good resistance to acidic conditions and find applications in various high-temperature processes like metal smelting, ceramic production, and chemical industries. Zirconia (ZrO2) Refractories: Zirconia-based materials exhibit excellent resistance to acidic corrosion and are utilized in applications where extreme temperatures and harsh chemical environments are present, such as in the production of special ceramics and certain industrial furnace. Mullite based refractories which are mainly used in severe conditions. Chamotte refractories and Alumina dependency of the properties. Students will learn more detail information on Al2O3-SiO2 phase diagram. These refractories find applications in various industries such as steelmaking (for lining furnaces, ladles, etc.), cement manufacturing, glass production, petrochemicals, and other high-temperature processes. Manufacturers continue to develop new formulations and production techniques to enhance the properties and widen the applications of acidic refractories, aiming to meet the demanding needs of various industries for high-temperature applications.

3. Learning outcomes

The students can select refractory materials for different furnace operations by considering the properties of the acidic refractory materials; demonstrate how to produce or optimize the properties of the acidic refractories according to service environment.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).
assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9: Chapters 3, 4, 5, 6, 7

6. Additional notes

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Topics 7

1. The subject of the lecture

BASIC REFRACTORY TECHNOLOGY

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

The term "basic" in basic refractories refers to their ability to withstand basic environments, as opposed to acidic environments. Basic refractories primarily consist of basic compounds like oxides of magnesia (MgO), dolomite (calcium magnesium carbonate - $CaO \cdot MgO$), chromite (chromium oxide and iron oxide - $Cr_2O_3 \cdot FeO$), and combinations thereof. This lecture aims to introduce the basic refractory technology. Magnesia and MA-Spinel Refractory Materials, their selection and properties with required phase diagram understanding. Raw materials, binder types and additives. Basic refractories are materials that exhibit strong resistance to basic or alkaline environments, typically having a high resistance to alkalis such as oxides of calcium, magnesium, and other alkaline compounds. They are widely used in industries where exposure to high temperatures and basic conditions is common, such as in cement, lime, glass, steel, and non-ferrous metal production. Student will be able to analyze the CaO-MgO-SiO_2 phase diagram and differentiate the different phase formations which effect the refractoriness of the basic refractories. Students will learn on Some common types of basic refractories include: Magnesia refractories: Made primarily from magnesium oxide (MgO), they have excellent resistance to basic slags and high temperatures. These refractories are used in steelmaking, cement, glass, and non-ferrous metal production. Magnesite refractories are chemically basic materials that include at least 85% magnesium oxide. These are made of magnesite ($MgCO_3$) and silica, both of which are found naturally (SiO_2). The physical features of this type of brick are often weak, and their main value is their resistance to basic slags, particularly lime and iron-rich slags. These are the most important refractories used in basic steelmaking processes. Basic brick is now successfully utilized in glass tank checks, lime and cement kilns, and metallurgical burners in addition to metallurgical furnaces. At high temps, acidic refractories also may react with limes and basic oxides. Dolomite refractories: Made from a combination of calcium oxide (CaO) and magnesium oxide (MgO) obtained from dolomite ore, these refractories offer good resistance to basic environments and are often used in cement kilns and steelmaking processes. Chromite refractories: Composed of chromium oxide (Cr_2O_3) and iron oxide (FeO), these refractories have high thermal stability and are used in applications where resistance to corrosion by basic slags is essential, such as in copper and nickel production. Basic refractory means refractory made of magnesium oxide and calcium oxide, including magnesite brick, magnesia alumina brick, magnesia chrome brick, dolomite brick, etc. This kind of basic refractory material has the characteristics of high refractoriness and strong alkaline slag resistance and is widely used for open hearth, oxygen converter, electric furnace, non-ferrous metal smelting equipment and other heating equipment

3. Learning outcomes

Students can select proper refractory materials for different furnace operations by considering the properties of the basic type refractory materials; demonstrate how to produce or optimize the properties of the basic type refractory materials according to service environment.

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

The topic will be realized within 2 h per week of classes. The theme will be completed in two weeks (total 4 hour).

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**.

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

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

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9: Chapters 3, 4, 5, 6, 7

6. Additional notes

Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

REFRACTORY GRAIN SIZE AND PARTICLE PACKING

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

The topics of the laboratory classes are related to refractory grain size by a sieve analysis and Refractory raw material mixture preparation according to Andreasen Particle Packing theory. Particle size analysis refers to the process of determining the size and distribution of particles in a sample, which can be solids, liquids, or gases. This analysis is crucial in various industries like pharmaceuticals, mining, agriculture, environmental monitoring, and materials science, as the size of particles can significantly impact the properties and behavior of materials. There are several techniques used for particle size analysis, however sieve analysis will be explained in this lecture. Particles are separated by passing them through a series of sieves with different mesh sizes. The retained particles on each sieve are weighed to determine the size distribution. Sieve analysis is a method used to determine the particle size distribution of granular materials like soil, sand, aggregates, powders, and other particulate substances. It involves separating particles into different size ranges using a series of sieves with progressively finer mesh sizes. It helps engineers, scientists, and manufacturers understand the composition of materials and ensure they meet specific requirements for different purposes. It's important to follow standardized procedures and use calibrated equipment to obtain accurate and reliable results in sieve analysis. The Andreasen packing theory, also known as Andreasen's model or Andreasen's packing theory, is a fundamental concept in the field of particle packing and granular materials. It was introduced by Flemming Andreasen in the 1960s to predict the packing density of particles in a granular assembly. This theory aims to estimate the packing density or void fraction of granular materials, which is crucial in various industries such as construction, pharmaceuticals, food processing, and more. The packing density refers to the fraction of space in a material that is occupied by particles compared to the total available space. Andreasen's model is based on empirical observations and mathematical formulations derived from the analysis of various types of particle arrangements. The theory provides a way to estimate the packing density of particles by considering the size distribution of the particles and the arrangement they form when packed together.

3. Learning outcomes

The student can analyze the required refractory properties according to the industrial needs by learning the importance of particle packaging theory; demonstrate the importance of particle size distribution of the raw materials and their packing, their effects on the basic refractory properties; show how to choose different particle size raw material to produce required density of refractory materials.

4. Necessary equipment, materials, etc

There is no need for special advanced device during the experiment.
Particle size distribution testing using sieves is a common method in various industries to determine the size range of particles in a granular material. The process involves passing a sample through a stack of sieves with progressively smaller mesh sizes, collecting and weighing the particles retained on each sieve.

Necessary materials
Materials for the classes involves:

- Different type refractory raw materials
- Sieves with different openings (Mesh). These are typically stacked in order of decreasing mesh size, with the finest sieve at the bottom.
- Pan. Positioned below the finest sieve to collect the smallest particles.
- Sieving test machine (Mechanical shaker). Used to agitate the sieves to ensure proper separation.
- Stereo Microscope. To analyze the particle shape
- Balance. To weigh the collected particles from each sieve

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**
problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:
G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7. Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8. Optional information

If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

Topics 2

1. The subject of the laboratory classes

SHAPING OF REFRACTORIES – DRY PRESSING

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

The topics of the laboratory classes are related to Shaping of the Low and High Alumina refractory samples with pressing technique. Pressing of refractories refers to the process of shaping refractory materials into specific forms or shapes using high pressure. Refractories are heat-resistant materials that are essential in various industrial applications, particularly in high-temperature environments such as furnaces, kilns, and reactors. Pressing is a crucial step in manufacturing refractories as it helps in achieving the desired density, strength, and shape required for their intended applications. The precise method of pressing can vary based on the type of refractory material, its intended use, and the manufacturing process employed by different industries. Dry pressing is a common method used in the production of refractory shapes, especially for ceramics and materials that can withstand high temperatures. The process of dry pressing involves compacting finely powdered materials into a desired shape using a mold and high pressure. However, there are also limitations to dry pressing: Limited to simple shapes; Complex shapes can be difficult to achieve with this method. Uniformity Challenges; achieving uniform density throughout the pressed shape might be challenging job to complete. Material limitations; Some materials may not be suitable for dry pressing due to their properties or particle size distribution. Advantages of dry pressing include: it allows for the production of precise shapes with consistent dimensions. The pressure applied during pressing can control the density and porosity of the final product. It can be a cost effective method for mass production of refractory shapes.

3. Learning outcomes

The student can analyze the required processing parameters for dry pressing shaping of the refractory brick; describe the dry pressing process according to the required final mechanical properties of the refractory materials.

4. Necessary equipment, materials, etc

There is no need for special advanced device during the experiment.
Dry pressing is a common method used in the production of refractory shapes, especially for ceramics and materials that can withstand high temperatures. Dry pressing most frequently used shaping method for Refractory materials.

Necessary materials
Materials for the classes involves:
- Calcined fire clay grains, Sinter Alumina grade grains, high alumina fire clay
- Hobart type mixer for mixing of the different raw materials

- steel mold
- 50 tons hydraulic press
- Balance

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**

problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7. Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8. Optional information

If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

Topics 3

1. The subject of the laboratory classes

SHAPING OF REFRACTORIES - REFRACTORY CASTABLE

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

The topics of the laboratory classes are related Shaping of the Low and High Alumina refractory samples with casting (monolithic) technique. Casting of refractories involves the process of creating refractory shapes, such as bricks, monolithic linings, or special shapes, by pouring a refractory mixture into molds and allowing it to solidify. Refractories are materials resistant to high temperatures and are used in various industries, including steelmaking, glass manufacturing, cement production, and more. These castables are a blend of refractory aggregates, binders, and additives, designed to withstand extreme temperatures, thermal shock, abrasion, and corrosion. Refractory castables come in different formulations tailored to specific applications, depending on factors such as temperature requirements, chemical resistance, and mechanical stress. They are often used for lining furnaces, kilns, ladles, and other high-temperature equipment, providing insulation and protection against the harsh conditions. The application process involves mixing the dry castable with a specific amount of water to form a workable paste, which is then poured, gunned, or troweled into place within the equipment. After application, the castable is typically allowed to cure and dry at ambient temperature before being subjected to high temperatures during its service life. Choosing the right refractory castable requires consideration of factors like operating temperature, thermal cycling, chemical exposure, and mechanical stress to ensure optimal performance in the intended application. Key components of refractory castables include: refractory aggregates; These are materials such as high alumina, silica, magnesia, and other refractory materials that provide the castable with its heat-resistant properties. Binders; Binders help hold the refractory aggregates together, ensuring the castable maintains its shape and strength, even at high temperatures. Common binders include high alumina cement, calcium aluminate cement, and colloidal silica. Addtives; These are included to enhance specific properties of the castable, such as flowability, setting time, thermal shock resistance, and mechanical strength. Additives may include plasticizers, deflocculants, antioxidants, and fibers.

3. Learning outcomes

The student can define and analyze the required casting or production procedures for refractory materials by monolithic technique; explain the effect of different casting variables on monolithic refractory production method.

4. Necessary equipment, materials, etc

There is no need for special advanced device during the experiment.

Monolithic refractories differ from traditional brick-shaped refractories, as they are applied in a plastic or semidry form and then formed in place to create linings or coatings. Therefore, their mixing procedure is more complicated.

Necessary materials

Materials for the classes involves:

- Calcined fire clay grains, Sinter Alumina grade grains, high alumina fire clay
- Calcium Aluminate Cement (70% alumina)
- additives
- Hobart type mixer
- steel mold
- weigh

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**

problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7. Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8. Optional information

If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

Topics 4

1. The subject of the laboratory classes

SINTERING OF REFRACTORIES

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

The topics of the laboratory classes are related to the Sintering practice for pressed and cast refractory samples. Drying operations are important process before the sintering operations. Dimension and weight measurements before and after sintering process is very important. Sintering of refractories is a crucial process in their manufacturing, involving the heating of refractory materials to a high temperature, causing them to fuse together and form a solid, cohesive structure. Refractories are materials designed to withstand high temperatures and are used in various industries like steel, glass, cement, ceramics, and more. The green body is subjected to high temperatures in a kiln or furnace. During sintering, the particles within the green body start to bond and densify due to the application of heat. This process causes the material to reach its melting point or a temperature close to it, leading to particle rearrangement and fusion. It is very important that ceramic bond will develop between the stage grain of the refractories. The sintering mechanism can be affected by various factors such as temperature, time, pressure, and the composition of the material being sintered. Additionally, the presence of additives or sintering aids can influence the process by enhancing particle bonding, controlling grain growth, or modifying the material's properties. Overall, sintering is a complex process influenced by multiple factors and involves the transformation of a powdered material into a solid mass through particle bonding and densification without complete melting. Controlling and optimizing sintering variables according to the specific material and desired properties are crucial for achieving the desired quality and characteristics in the final sintered product. Several variables affect the sintering process, influencing the final properties of the material produced. These are; temperature, time, particle size, pressure, atmosphere, heating rate, additives. Adjusting these parameters can tailor the material's mechanical, electrical, thermal, and other properties to meet specific industrial or technological requirements.

3. Learning outcomes

The student can analyze the required refractory properties according to the industrial needs; interpret the effects of sintering process on the refractory material properties; explain the effect of different sintering variables on the properties of refractories.

4. Necessary equipment, materials, etc

There is no need for special advanced device during the experiment.
Previously dry pressed refractory samples were used in the sintering experiments. Refractory samples which have different particle size distribution will be subjected to sintering operation with different time and temperature.

Necessary materials

Materials for the classes involves:

- Laboratory furnace (1700 °C)
- Caliper
- weigh

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**

problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:

G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7.	Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8.	Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

Topics 5

1. The subject of the laboratory classes

CORROSION TESTING

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

The topics of the laboratory classes are related to Corrosion testing of sintered refractory samples against different materials like, steel slag, cement, alkalis. Refractory materials are designed to withstand high temperatures and harsh environments in various industrial processes such as in furnaces, kilns, reactors, and more. Corrosion testing for refractory materials involves evaluating their resistance to chemical attack, erosion, thermal shock, and other forms of degradation under operating conditions. Testing standards and methodologies may vary depending on the specific application or industry requirements. ASTM (American Society for Testing and Materials) and other standardizing bodies often provide guidelines for conducting refractory corrosion tests. It's crucial to replicate the actual operating conditions as closely as possible during testing to ensure accurate assessment of the refractory material's performance and durability in real-world applications. There are several types of refractory corrosion. Chemical corrosion; This occurs when refractory materials react with gases, liquids, or solids present in the environment. For example, acidic or alkaline compounds in the process environment can react with refractories, leading to their degradation. Molten metals, slag, and other corrosive substances can also cause chemical corrosion on the metallic materials in particular, however, it is not limited to metallic substances but other inorganic materials can also be affected from corrosive environment. Slag Corrosion affect the metallic substances due to their nature of chemistry. In industries like steelmaking, molten slag can penetrate and erode refractory linings. The slag can chemically react with the refractory material, causing erosion, dissolution, or formation of new compounds that weaken the refractory. Selection of suitable refractory materials for certain applications are primary concern that engineering find compelling and challenging process. Hence, choosing a refractory material that is chemically compatible with the operating environment can reduce corrosion and also erosion in the course of operation. Different types of refractory materials (e.g., acidic, basic, neutral) may be suitable for different applications; having the knowledge of these refractory materials will eventually help sustainable development in refractory selection and recycling of such materials. Experiments in this topic will help students to understand the selection processes and the criteria in selecting proper materials.

3. Learning outcomes

The student can select proper refractory materials for different furnace operations based on the observation of the corrosion attack on the refractory materials; explain the corrosion mechanism and its protection precautions against different corrosive substances and conditions in the environment.

4. Necessary equipment, materials, etc

There is no need for special advanced device during the experiment.
Previously dry pressed refractory samples were used in the sintering experiments. Refractory samples which have different particle size distribution will be subjected to sintering operation with different time and temperature.

Necessary materials
Materials for the classes involves:
- Corrosion test samples (cup samples)
- Furnace
- Stereo Microscope
- Cutting Machine

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**
problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:
G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7. Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

Topics 6

1. The subject of the laboratory classes

MICROSTRUCTURE OF REFRACTORIES

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

The topics of the laboratory classes are related Observation on microstructure of the refractories at SEM. Sample preparation of the different refractory samples which are produced during the laboratory class. Secondary and Back scattered imaging, EDX analysis on corrosion samples. The term "refractory microstructure" refers to the internal arrangement and composition of materials used in refractory applications. Refractories are materials designed to withstand high temperatures and harsh conditions without undergoing significant physical or chemical changes. The microstructure of refractories plays a crucial role in determining their performance characteristics, such as thermal conductivity, mechanical strength, resistance to thermal shock, and chemical stability. Understanding the microstructural features helps engineers and scientists in designing refractories tailored for specific applications. Key components of refractory material microstructures include;

Grain structure: refractory materials are typically composed of grains or crystals that form the primary structure. The size, shape, and distribution of these grains impact the material's properties. Finer grains often contribute to higher strength and better resistance to thermal shock, while larger grains might improve thermal insulation.

Pores, porosity: the presence of pores within the refractory material affects its density, thermal conductivity, and resistance to thermal cycling. Controlled porosity is sometimes desirable for certain applications as it can enhance insulation properties.

Phase composition: refractory materials can consist of various phases, including primary phase(s) like alumina, silica, magnesia, zirconia, and secondary phases resulting from additives or impurities. The presence and distribution of these phases influence the refractory materials’ chemical stability, thermal expansion behavior, and performance under specific conditions.

Binder phases: the way grains are bonded together significantly impacts the overall strength and stability of the refractory materials. Interatomic and intermolecular bonds can be formed through various mechanisms like sintering, glassy phases, or other chemical interactions.

Inclusion and defects: external and internally produced inclusions, impurities, and defects within the microstructure can affect the refractory's performance and its ability to withstand extreme conditions.

Engineers study and manipulate these microstructural elements to develop refractory materials with tailored properties suitable for applications such as furnace linings, kilns, reactors, and other high temperature operational environments in industries like steel, cement, glass, and petrochemicals.

3. Learning outcomes

The student can distinguish the different refractory material groups with their advantages and disadvantages; analyze the properties by observing the microstructure differences under SEM investigation; comment on and define the different corrosion mechanism depending on the microstructural observation.

4. Necessary equipment, materials, etc

There is need for special advanced device during the experiment.
Previously corroded refractory samples were used in the microstructure investigated experiments.

Necessary materials
Materials for the classes involves:
- Refractory Samples with different grade and corrosion test sample
- Carbon coating
- SEM with EDX attachment

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**
problem methods: **show/demonstration**

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

Students are expected to read below texts related to the laboratory classes:
G. Routschka, Refractory Materials (Basics-Structures-Properties) 2. Edition, Vulkan Verlag, Essen, 2004.ISBN 3-8027-3154-9

7. Additional notes

-Students will give a laboratory report which includes the required outputs and data analysis of the experiments.

8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer before the experiment. Exercise manuals will be available prior to the laboratory classes.

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

POLYMERS AND LIGHT COMPOSITES

Code: PLC

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Course content – lecture

Topics 1

1. The subject of the lecture

POLYMER HISTORY

2. Thematic scope of the lecture

This course aims to explain the historical evolution of polymers and its variants and derivatives to students. The history of polymers is a fascinating journey through scientific discovery and technological advancements especially in the field of organic chemistry. The concept of polymers, large molecules composed of repeating structural units, traces back to the early 19th century. In 1833, French chemist Anselme Payen identified the first polymer, cellulose, found in plant cell walls. The subsequent decades saw incremental progress in understanding natural polymers like rubber and proteins. However, it was not until 1907 that Belgian chemist Leo Baekeland revolutionized the field with the creation of Bakelite, the world's first synthetic polymer. This marked the dawn of the age of synthetic polymers, paving the way for the development of an extensive array of plastics and synthetic materials to be used in vast majority. In the second part of the course, the industrial uses of synthetic polymers produced are mentioned.

The middle of 20th century had witnessed an explosion of the polymer research and innovation, mostly driven by the synthesis of versatile materials such as nylon, polyester, and polyethylene. These polymers found many applications in various fields of industries, still transforming our everyday life. The 1970s and 80s brought about significant advancements in polymer science, with the discovery of new polymerization techniques and the emergence of high-performance polymers. The exploration of nanotechnology in recent decades has further expanded the capabilities of polymers, leading to the development of advanced materials with unique properties. Instructor should also explain the chemical development of polymers starting from raw materials and chemical evolution up to polymers in general. Today, polymers play and imperative role in numerous industries, including packaging, medicine, electronics, aviation industry and automotive. The history of polymers reflects the continuous quest for novel materials and the transformative impact these substances have had on society, ushering in an era of unprecedented technological progress and innovation.

In this course, after explaining the definition of polymer materials and their simple structural properties, the advantages and disadvantages are discussed and how their areas of use have changed over the years.

3. Learning outcomes

Students can explain the history of polymer materials; demonstrate how the use of polymer materials has changed over the years; show the chemical structures of polymers and the difference of this structure from metal and ceramics; explain how the chemical structures of polymers affect the material properties.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Topics 2

1. The subject of the lecture

CLASSIFICATION AND PROPERTIES OF POLYMERS

2. Thematic scope of the lecture

Polymers, with their diverse structures and properties, are classified based on their origin, structure, and behavior. One primary classification distinguishes between natural and synthetic polymers. Natural polymers, such as proteins, cellulose, and rubber, are derived from living organisms, while synthetic polymers, like nylon, polyester, and polyethylene, are chemically synthesized in laboratories. Another classification criterion is based on polymer architecture, categorizing them into linear, branched, and cross-linked structures. Linear polymers have a straightforward chain-like arrangement, branched polymers exhibit side chains extending from the main backbone, and cross-linked polymers feature interconnected chains, creating a network-like structure.

Chemical composition is a crucial factor in polymer classification, leading to distinctions between homopolymers, consisting of identical repeating units, and copolymers, comprising two or more different repeating units. Copolymers can further be classified as random, alternating, block, or graft, depending on the arrangement of the different units along the polymer chain. The behavior of polymers under external stimuli or environmental factors, such as temperature, pH, or light, also influences their classification. Smart or responsive polymers, for instance, exhibit changes in their properties in response to specific conditions. Overall, the classification of polymers is a multifaceted system that considers their origin, structure, composition, and their behavior, providing a framework for understanding and harnessing their diverse applications across industries. In the course, these classification methods are explained in detail one by one in order to help the student understand the subject. In particular, the classification method according to chain structures will be explained last and how the chain structure will affect the properties of the polymer will be explained. Thus, it is aimed to establish a structure relationship with the properties that will be mentioned in the following sections. Then, the topic will be completed by focusing on the mechanical, physical and thermal properties of polymers.

3. Learning outcomes

Students can explain the classification of polymers with the help of historical development; identify the structure - property relationship of polymers; explain the mechanical, physical and thermal properties of polymers.

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

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Topics 3

1. The subject of the lecture

POLYMER COMPOSITES

2. Thematic scope of the lecture

This course introduces the subject of polymer composite materials. As is known by many students, composites are a combination of different phases or materials that are connected or rather separated by an interface between two different objects, preserving their own properties. Dissimilar materials with different properties come together and determine the physical and mechanical properties of the composites. Polymer matrix composites (PMC) are the most commonly used composite type in composite applications. One of the important features of polymer composites is the fabrication processes are most of the time easier compared with metallic composites. It has high tensile strength, stiffness, fracture toughness and is resistant to abrasion, puncture and corrosion. The important disadvantages of PMCs are their low thermal resistance and high thermal expansion properties. High performance fiber reinforced polymer matrix composites are preferred materials in a wide variety of branches due to their lightness, corrosion resistance, fatigue resistance and easy assembly. Students should be mentioned of the various areas of use of polymer composites in industrial applications and then later these applications can be given to students. These applications usually include in general various parts of spacecraft and aircraft structures, electronic packaging materials, medical equipment and household appliances. After these important applications are mentioned to the students, the usage areas of composite materials are discussed with them. Students should also be given a list of tabulated data showing the typical composites and their field of use with a specific application and if possible an image would be beneficial. In the second stage of the course, the components that make up polymer composites are discussed. Polymer matrix composites are composites containing a polymer resin as the matrix and fibers and / or other reinforcement materials as the reinforcement medium within the matrix. The interaction between the reinforcement phase and the matrix can take different forms, from strong chemical bonds to weak friction forces. Such interactions, defined as interfaces, are kept under control by using reinforcements by coating them with appropriate materials. The matrix types used in composite production and their properties are explained. Then, reinforcement materials are introduced and fiber types and their properties are explained.

3. Learning outcomes

Students can explain the concept of polymer composite materials; show and explain the usage areas and understand the advantages and disadvantages; demonstrate and show the components that make up composite materials and learn the roles of these components in the material.

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

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Topics 4

1. The subject of the lecture

Classification and Properties of Polymer Composites

2. Thematic scope of the lecture

This lecture aims to introduce the classification and properties of polymer matrix composites available in industrial applications. Polymer composites, a class of materials that combine polymers with reinforcing agents that are usually different to polymeric materials, are classified based on the nature of these reinforcements and the overall composite structure. The primary classification of polymer composites involves the type of reinforcement used, typically categorized in the form of particulate such as small size particles, and two dimensional additives such as short of long fibrous additives and structural composites. Particulate composites incorporate small, discrete particles, such as fillers or powders, into the polymer matrix with a special preparation routine. Fibrous composites, on the other hand, integrate reinforcing fibers like glass, carbon, or aramid into the polymer matrix, enhancing the mechanical properties such as the strength and the stiffness. Structural composites involve a combination of various materials, including polymers, metals, and ceramics, to create advanced materials with tailored properties. The arrangement of the reinforcing phase within the polymer matrix further classifies composites as the isotropic or the anisotropic. Isotropic composites exhibit uniform properties in all directions, while anisotropic composites display varying properties based on the direction of the reinforcing elements. Hybrid composites combine different types of reinforcements to achieve a synergistic enhancement of properties. Additionally, polymer composites can also be classified based on their application, such as aerospace, automotive, or biomedical, reflecting the diversity of industries that benefit from these versatile materials. The classification of polymer composites serves as a valuable guide in tailoring material properties to meet specific performance requirements across a wide range of applications. Understanding the classification of polymer composites is also very important to benefit from when it comes to understanding their applications in industries, just like polymers. The aim of this course is to explain the classification of composite materials to students and to form an idea about what kind of composite material they should choose or produce when necessary. Additionally when students can understand the classification in detail, they will be able to better understand both the features and production methods relevant to the polymeric composites.

3. Learning outcomes

Students can demonstrate how polymer composites are classified according to particulate tye and shapes; explain how these classes of composites give them certain properties; explain the importance of matrix - reinforcement material interaction and their mechanism of working for obtaining certain properties.

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

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Topics 5

1. The subject of the lecture

PROCESSING AND MANUFACTURING TECHNIQUES OF POLYMER COMPOSITES

2. Thematic scope of the lecture

The processing and manufacturing of polymer composites involve a series of intricate techniques aimed at achieving optimal performance and desired properties in the final material. For this reason, mastering the production process is of great importance in obtaining the composite material with the desired properties. The aim of this course is for students to learn the production processes of composite materials and how these processes affect the properties of the final material and to use this information when necessary. One fundamental method is melt blending, where polymers and reinforcing elements are mixed in a molten state. This technique is commonly employed for thermoplastic matrices and facilitates the uniform dispersion of reinforcing agents. Another widely used process is solution blending, particularly suitable for thermosetting polymers. In this method, the reinforcing material is dissolved in a solvent, mixed with the polymer, and then the solvent is evaporated, leaving behind a composite material.

Polymer composites are often shaped through molding processes like injection molding, compression molding, and transfer molding. Injection molding is favored for its high production rates and complex part geometries, while compression molding is suitable for larger, bulkier components. The technique of filament winding involves wrapping reinforcing fibers around a rotating mandrel, followed by the application of a polymer matrix, creating strong and lightweight cylindrical structures like pipes or pressure vessels. Additionally, techniques like pultrusion and extrusion are employed for continuous production of composites with uniform cross-sections.

Manufacturing techniques also encompass more advanced methods such as resin transfer molding (RTM), where liquid resin is injected into a mold containing reinforcing fibers, resulting in intricate shapes and superior strength-to-weight ratios. Furthermore, additive manufacturing, or 3D printing, is gaining prominence, allowing for the layer-by-layer construction of complex composite structures. These diverse processing and manufacturing techniques highlight the adaptability of polymer composites, making them integral to a multitude of industries, including aerospace, automotive, and construction. At the end of the course, students are asked to think about which materials to choose and which method to use for the production of a pressure vessel, for example, and they are expected to make a suggestion with cause and effect relationships.

3. Learning outcomes

Students can explain how composite materials are processed with traditional and new generation methods; demonstrate how processing methods affect the structure of composite materials; explain production methods of polymer composites; show which production method to choose in which situation; demonstrate how production methods affect the structure of composite materials.

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

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Topics 6

1. The subject of the lecture

DETERMINATION OF PROPERTIES

2. Thematic scope of the lecture

This topic aims to introduce and explain the characterization methods for polymeric materials and their extensive use in the examination of relationship between polymer type and properties in general. The topic examines the relationship between structure of polymers, physical features, mechanical and other important performance parameters and process of modification such as surface modification. The process, structure, features and performance are closely interrelated in all material conditions. For example, a change in the production route (process) a phase may disrupt the structure and hence a new feature may appear. When the structure changes, the properties change and in this case, the performance of the material is drastically affected in many ways. In previous lessons, different production methods and how these production methods can affect the properties of composite materials have been mentioned. In this topic, we will talk about how we can characterize the different properties of composite materials. Mechanical, physical and thermal properties will be discussed separately and how to determine them will be explained. In order to regulate the characterization results of composite materials, new device instrumentations and new techniques have been developed along with technology and many efforts have been made to improve the analysis results. Most commonly used tools for physical characterization processes are microscopical i.e. SEM, TEM, AFM ans structural i.e. XRD, EDX and FT-IR. The characterization is extremely important to determine the properties of any material, hence, within the scope of the course, these characterization methods will be mentioned in detail to students. It is also important that the questions of the type of characterization method should be preferred in which situations will be attempted to be answered in the classroom. Then, the conditions under which the bending test, tensile test, compression test and impact tests that we use to determine the mechanical properties of composite materials should be applied, the results to be obtained and how we can interpret the results from these experiments will be explained in detail with examples. The topic will be concluded by explaining the methods such as TG, DSC, DTA, TMA that we use to determine thermal properties.

3. Learning outcomes

Students can show how to perform mechanical tests (tensile, bending, hardness, etc.) to determine the mechanical properties of polymer composites; demonstrate the factors affecting the mechanical properties of polymer composites; show which tests perform to determine the physical and thermal properties of polymer composites; show the factors affecting the thermal and physical properties of polymer composites.

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

assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Introduction to Polymers, Third Edition, By Robert J. Young, Peter A. Lovell, CRC Press, 2011
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

6. Additional notes

Course content – laboratory classes

Topic 1

1. The subject of the laboratory classes

INTRODUCTION OF POLYMER COMPOSITE COMPONENTS

2. Thematic scope of the laboratory classes

This laboratory class will focus on to introduce the polymer composite components to the students. The matrix materials (thermoset resins and thermoplastic resins), reinforcement materials (such as carbon fibers, glass fibers, etc..) and the different shapes of the fibers (woven, unidirectional fabric, clip, etc.) that have been explained in the theoretical lesson are to be shown to the students. In this way, students will be able to develop the concepts they learned in the theoretical lessons. This laboratory class also aims to enable students to reinforce their knowledge on materials and methods they have learned theoretically in the course by experimenting and practical hands on experience. In this laboratory class, first laboratory safety will be mentioned and students will be told how to protect themselves from chemicals, and then the matrix materials and reinforcement materials we use in polymer composite production will be shown and students will be familiarized with them during the class. After the components of polymer composite material are initially introduced to students, two different polymer composite plates will be aimed to be produced using epoxy and polyester matrix with and without different additives as reinforcing phase as to show the effect of additives or reinforcing phases. This lecture will not be an alternative to following lectures. However, a comparative table for the comparing the properties of two part epoxy resin bonded composites with particles and without particles and with single type fabric will be explained to students. It also will be a discussion opportunity to ask students their observations regarding the differences they see during the production phase of polymer composites. A recipe for mixing the ingredients and a list showing the proportions of components are to be given to the students prior to the class. When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required in the workshop. Students should be advised to wear face masks. Be sure to have a circulated room and students should be equipped with leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc…

3. Learning outcomes

Student can define and interpret different matrix phases and additives; define the differences between thermoset and thermoplastic matrices based on their apperance; recognize different fibers and their purpose of use in the matrix; explain that the fibers can be reinforced into the matrix in different ways and how this can affect the properties of the composite material obtained.

4. Necessary equipment, materials, etc

- Some thermoset and thermoplastic matrices (epoxy, fenolic, polyethylene etc.)
- Some fibers (carbon, glass, aramid etc.)
-These fibers must be different forms: woven, unidirectional, clip etc.

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**

problem methods: **show/demonstration**

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

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

-- Handbook of Polymers, by George Wypych, Elsevier Science, 2022

- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

7. Additional notes

8. Optional information

Topic 2

1. The subject of the laboratory classes

POLYMER COMPOSITE PRODUCTION

2. Thematic scope of the laboratory classes

In this laboratory course, polymer matrix composite materials will be produced by using two different reinforcement materials, that are, carbon fiber and glass fiber, and epoxy resin as a boding phase. Two part epoxy resin will be used as bonding agent between fabrics. The hand lay-up method will be employed for the production for the polymer matrix composites. During the production, the mixing rule in composite materials will be explained in detail and necessary hand outs will be distributed to students; and the densities of the polymer matrix composites produced during this practical lecture will be calculated theoretically according to this rule by measuring the dimensions of specimens and considering the ratios of additives in the matrix phase. Then, densities of the obtained polymer matrix composites using Archimedes and/or volume replacement method will be recalculated and later on two different types of polymer matrix composites will be compared. An analysis and interpretation of results will be made with reference to the amount and type of reinforcements added to the matrix. The chemical and physical effect of epoxy resin can also be included to the interpretation of results as it is important to accommodate the wetting of particle surface efficiently. A short introduction to the surface wetting of particles by various resins can also be included in handouts. In this laboratory class, polymer matrix composite materials will be produced with glass fiber fabric and epoxy resins by hand with hand laying method which will be shortly explained theoretically in this laboratory class to refreshed the knowledge. A short introduction and parameters of the hand laying process will also be included in the handouts. During the application, it will be discussed the advantages and disadvantages of the production with the hand laying method. Then, specimens will be snapped and firstly optical microscope examination and then electron microscope (SEM) examination will be made on the broken surfaces obtained from the produced composite materials, and the interfacial connections will be examined and it will be tried to determine which method the layers adhere better.

<u>When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear face masks. Be sure to have a circulated room and students should be equipped with leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..</u>

3. Learning outcomes

Student can produce composite materials using glass fiber and carbon fiber; explain about carbon fiber and glass fiber by comparing the weights of the composite materials they have obtained; demonstrate that they can reach the theoretical density they achieved with the mixing rule; show that the properties of the produced material vary according to the producer while producing composite material.

4. Necessary equipment, materials, etc

glass and carbon fiber
epoxy resin
brush
mold release

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation,**

problem methods: **show/demonstration**

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

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

- Handbook of Polymers, by George Wypych, Elsevier Science, 2022
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

7. Additional notes

8. Optional information

Topics 3

1. The subject of the laboratory classes

POLYMER COMPOSITE PRODUCTION: VACUUM BAGGING

2. Thematic scope of the laboratory classes

Polymer composite materials will be produced by using hand lay-up, vacuum bagging and hot press methods, which are to be theoretically shown as production methods in this laboratory course. As reinforcement material, one group will be given glass fiber and the other group carbon fiber fabrics. Two part epoxy resin will be used as bonding agent between fabrics. Then, specimens will be snapped and first optical microscope examination and then electron microscope (SEM) examination will be made on the broken surfaces obtained from the produced composite materials, and the interfacial connections will be examined and it will be tried to determine which method the layers adhere better. During the production, the mixing rule in composite materials will be explained in detail and necessary hand outs will be distributed to students; and the densities of the polymer matrix composites produced during this practical lecture will be calculated theoretically according to this rule by measuring the dimensions of specimens and considering the ratios of additives in the matrix phase. Then, densities of the obtained polymer matrix composites using Archimedes and/or volume replacement method will be recalculated and later on two different types of polymer matrix composites will be compared. An analysis and interpretation of results will be made with reference to the amount and type of reinforcements added to the matrix. The chemical and physical effect of epoxy resin can also be included to the interpretation of results as it is important to accommodate the wetting of particle surface efficiently. In this laboratory class, polymer matrix composite materials will be produced with glass fiber fabric and carbon fiber matrix fabric using epoxy resins by vacuum bagging method which will be shortly explained theoretically in this laboratory class to refreshed the knowledge. A short introduction and parameters of the vacuum bagging process will also be included in the handouts. During the application, it will be discussed the advantages and disadvantages of the production with the vacuum bagging method.

When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear face masks. Be sure to have a circulated room and students should be equipped with leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..

3. Learning outcomes

Student can experience different production methods, which they learned theoretically, in practice; explain and compare composite materials produced with different fibers and different production methods; explain the effects of production methods on the interfacial connections of composite materials; comment on mechanical properties of polymer composites.

4. Necessary equipment, materials, etc

- glass and carbon fiber
-epoxy resin
-brush
-mold release
-hot press
-Vacuum Bag
-Peeling Fabric
-Perforated Separator Film
-Vacuum Sealant
-Vacuum Seal
-Vacuum Hose
-T Connection
-Valve Connection
-Glove

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**
problem methods: **show/demonstration**

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

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

- Handbook of Polymers, by George Wypych, Elsevier Science, 2022
- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

7. Additional notes

8. Optional information

Topics 4

1. The subject of the laboratory classes

POLYMER COMPOSITE PRODUCTION: HOT PRESS

2. Thematic scope of the laboratory classes

In this laboratory class, composite materials will be produced using continuous and discontinuous glass and carbon fibers, and then these composite materials will be subjected to bending tests and their mechanical properties will be compared. During the production of composite, the mixing rule in composite materials will be explained in detail and necessary hand outs will be distributed to students; and the densities of the polymer matrix composites produced during this practical lecture will be calculated theoretically according to this rule by measuring the dimensions of specimens and considering the ratios of additives in the matrix phase. Then, densities of the obtained polymer matrix composites using Archimedes and/or volume replacement method will be recalculated and later on two different types of polymer matrix composites will be compared. An analysis and interpretation of results will be made with reference to the amount and type of reinforcements added to the matrix. The chemical and physical effect of epoxy resin can also be included to the interpretation of results as it is important to accommodate the wetting of particle surface efficiently. In this laboratory class, polymer matrix composite materials will be produced with continuous and discontinuous glass fiber fabric and carbon fiber matrix fabric using epoxy resins by hot press method which will be shortly explained theoretically in this laboratory class to refreshed the knowledge. A short introduction and parameters of the hot press process will also be included in the handouts. During the application, it will be discussed the advantages and disadvantages of the production with hot press method. In order to investigate the effect of the fabric type on the mechanical properties of the polymer composite, a 3-point bending test will be applied to continuous and discontinuous carbon fiber reinforced epoxy composite samples produced. The advantage and disadvantages, ease of production of the two fabrics will also be discussed. When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear face masks. Be sure to have a circulated room and students should be equipped with leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..

3. Learning outcomes

Student can explain the production of composites with continuous and discontinuous fibers; show how to perform 3-point bending test on composite material and how to interpret the results; interpret the effect of continuous or discontinuous fiber on mechanical properties.

4. Necessary equipment, materials, etc

- carbon and glass fiber
-epoxy resin
-brush
-glove
-mechanical mixer
-bending tester

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

A set of practical methods: **laboratory exercise/experiment, production exercise – workshop Practice, observation**

problem methods: **show/demonstration**

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

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

- Handbook of Polymers, by George Wypych, Elsevier Science, 2022

- Polymer Composites: From Nano- To Macro-Scale: Klaus Friedrich, Stoyko Fakirov, Zhong Zhang, Springer,2005.

7. Additional notes

8. Optional information

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

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

PROCESS, STRUCTURE AND PROPERTY RELATIONS IN NON-METALLIC MATERIALS

Code: PSPRNM

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO MATERIALS SCIENCE AND NON METALLIC MATERIALS

2. Thematic scope of the lecture

This lecture aims to provide a comprehensive introduction to the fundamental principles and concepts within the field of materials science and engineering. It focuses on the intricate relationships that exist between the processing of materials, their resulting structure, and the properties they exhibit. Understanding these relationships is pivotal in the study and development of materials, as it enables us to make informed decisions in the selection and design of materials for a wide range of applications across various industries.

Materials science and engineering play a critical role in shaping the modern world. These disciplines encompass the study of diverse materials, including metals, ceramics, polymers, and composites. It is through the lens of materials science and engineering that we gain insight into the unique properties of these materials and learn how to harness these properties to meet specific needs.

One of the central themes of this lecture is the concept that the properties of a material are inherently tied to its internal structure. Whether it is the mechanical strength of a metal, the electrical conductivity of a semiconductor, or the thermal insulation of a polymer, these properties are intricately linked to how the atoms and molecules are arranged within the material. Through a thorough examination of crystallography, the study of crystalline structures, and a deeper look into non-crystalline materials with disordered structures, students will develop a solid foundation for understanding the structure-property relationships in materials.

Furthermore, this lecture highlights the critical role that processing methods play in the creation of materials with tailored properties. Materials can undergo various processes such as casting, forming, heat treatment, and more, and these processes significantly influence the microstructure of the materials. The microstructure, in turn, determines the material's mechanical, thermal, electrical, and other properties. Through real-world examples and case studies, students will gain insight into how the selection of processing methods can be a crucial factor in achieving desired material properties for specific applications.

Ultimately, the lecture will underscore the importance of these relationships between processing, structure, and properties in the design and development of new materials. By grasping these fundamental concepts, students will be well-equipped to tackle complex challenges and contribute to advancements in materials science and engineering, which are at the forefront of technological innovation and sustainability efforts worldwide. This lecture serves as the foundation upon which further studies and research in this field are built.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Explain the fundamental principles of materials science and materials engineering.
- Identify the relationships between process, structure, and properties of materials.
- Recognize the importance of materials selection and processing in designing materials for specific applications.
- Describe the different types of materials, including metals, ceramics, polymers, and composites.
- Explain the properties of different materials and how they are influenced by their structure and processing.
- Discuss the role of materials science and engineering in various industries, including aerospace and automotive.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the three-hour session, graphs related to process, structure, properties and their relationships in main material groups will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - A part of the course will include students working on establishing the relationship between process, structure and properties in non-metallic materials and how to determine the material suitable for an engineering application.

Discussion – The students will be encouraged to actively participate in discussions about the case study.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

- Callister Jr, W. D. (2018). Materials science and engineering an introduction. 10th edition. Hoboken, NJ : Wiley. (chapter 1)

6. Additional notes

Topics 2

1. The subject of the lecture

STRUCTURE AND PROPERTIES OF CERAMICS MATERIALS

2. Thematic scope of the lecture

This lecture will extensively explore the detailed aspects of the structure and properties of ceramic materials, aiming to provide students with a solid foundation in understanding this unique class of substances. The focus will be on introducing the fundamental concepts associated with ceramic materials and explaining their atomic and crystal structures.

In the pursuit of these learning objectives, students will engage in the detailed examination and depiction of crystal structures. Specifically, they will learn to delineate the unit cells of sodium chloride, cesium chloride, zinc blend, cubic structures, diamond, fluorite, and perovskite. Similarly, they will extend this ability to define the atomic structures of graphite and silica glasses.

A crucial aspect of the learning outcomes involves the application of chemical formulas to predict the crystal structure based on ionic radii. Students will develop the capability to anticipate the crystalline arrangement by considering the ionic components and their respective ionic radii in a given ceramic compound.

Furthermore, the lecture will explore defects within ceramic compounds, focusing on eight distinct ionic point defects. Students will acquire knowledge regarding the nature and identification of these defects within the structure of ceramic materials, contributing to a comprehensive understanding of their behavior and properties.

An additional facet of the learning outcomes pertains to explaining the scattering phenomena observed in fracture strength values of identical samples of the same ceramic material. Students will be able to succinctly clarify the reasons behind the variations in fracture strength values among identical samples, providing insights into the factors influencing the mechanical behavior of ceramic materials.

In summary, this lecture not only aims to cover the structural and property aspects of ceramic materials but also seeks to empower students with specific skills and knowledge. Through the outlined learning outcomes, students will develop proficiency in visualizing and defining crystal structures, predicting crystal arrangements based on chemical formulas, recognizing and characterizing ionic point defects, and explaining the observed scattering in fracture strength values. This multifaceted approach ensures a comprehensive grasp of ceramic materials, preparing students for a nuanced understanding of their applications and behavior in diverse contexts.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Define the atomic and crystal structure of ceramics materials.
- Identify the different types of ceramics materials and their properties.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the six-hour session, graphs related to crystal structure of ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - One part of the course will include students' work on calculating the theoretical density of ceramic materials.

Discussion – The students will be encouraged to actively participate in discussions about the case study.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

- Callister Jr, W. D. (2018). Materials science and engineering an introduction. 10th edition. Hoboken, NJ : Wiley. (chapter 12)

6. Additional notes

Topics 3

1. The subject of the lecture

CERAMIC PRODUCTION PROCESSES

2. Thematic scope of the lecture

This lecture will thoroughly explore the processes involved in ceramic production, covering the essential stages of preparation, shaping, and sintering of ceramic materials. With a primary focus on providing a comprehensive understanding, the lecture will go into the details of ceramic powder preparation techniques, shedding light on methods like mixing and milling. These initial steps play a pivotal role in determining the quality and characteristics of the ceramic material that will ultimately be produced.

The discussion extends to the various shaping methods employed in forming ceramics, emphasizing techniques such as pressing, extrusion, and injection molding. Each of these methods plays a distinct role in shaping the ceramic material into its final desired form. Students will gain insights into the practical applications and considerations associated with these shaping processes, facilitating a well-rounded understanding of ceramic manufacturing.

A fundamental aspect of the lecture revolves around the sintering process, a critical stage that involves subjecting the ceramic material to high temperatures to achieve densification and enhance material strength. The principles governing the sintering process and its profound impact on the microstructure and properties of ceramics will be explained. Understanding how temperature, time, and atmospheric conditions influence the sintering process is crucial for students to comprehend the factors involved in optimizing ceramic properties.

The lecture underscores the significance of process control in the production of ceramics with desired properties. By emphasizing the importance of careful control over various parameters throughout the manufacturing process, students will recognize the role precision plays in achieving consistent and reliable ceramic products. This awareness contributes to the development of a skill set essential for quality control in ceramic production.

Furthermore, the learning outcomes direct attention towards recognizing the challenges and limitations inherent in ceramic production processes. This entails acknowledging the complexities and potential obstacles that may arise at different stages of production. Understanding these challenges equips students with a pragmatic perspective, allowing them to devise effective strategies to overcome obstacles and optimize the efficiency of ceramic manufacturing processes.

In summary, this lecture serves as a comprehensive guide, offering students insights into the methodologies involved in ceramic production. By exploring the preparation, shaping, and sintering processes, students will not only understand the fundamental principles but also gain a practical understanding of the challenges and considerations that shape the landscape of ceramic manufacturing. This knowledge forms the basis for informed decision-making and effective problem-solving in the realm of ceramic materials production.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Explain the different methods used for the preparation of ceramic powders, including milling, precipitation, and sol-gel processing.
- Identify the various shaping methods used to form ceramics, such as pressing, extrusion, and injection molding.
- Describe the principles of the sintering process and how it affects the microstructure and properties of ceramics.
- Recognize the factors that affect the sintering process, including temperature, time, and atmosphere.
- Appreciate the importance of process control in the production of ceramics materials with desired properties.
- Summarize the challenges and limitations associated with the ceramic production processes.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the 15-hour session, graphs related to production methods of ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Discussion – The students will be encouraged to actively participate in discussions about the production method and its effect on sintering.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

- Rahaman, M. N. (2003). Ceramic processing and sintering. New York: M. Dekker, 567, 573. (Chapters: 1, 8, 9, 10)

6. Additional notes

Topics 4

1. The subject of the lecture

ADVANCED CERAMICS

2. Thematic scope of the lecture

This lecture will concentrate on the exploration of advanced ceramics, a category encompassing high-performance ceramics distinguished by superior mechanical, thermal, and electrical properties. The discussion will encompass various types of advanced ceramics, such as oxide, non-oxide, and composite ceramics, exemplified by materials like Al2O3, SiC, SiAlON, S3N4, BC4, AlN, BN, CaO, and ZrO2. These materials stand out for their exceptional characteristics and find applications across diverse sectors, including aerospace, electronics, and energy.

The learning outcomes aim to equip students with a comprehensive understanding of the properties and characteristics inherent in advanced ceramics, emphasizing traits like high strength, hardness, and wear resistance. Students will be able to discern between different types of advanced ceramics, namely oxide, non-oxide, and composite ceramics, establishing a foundational knowledge base essential for further studies and practical applications.

The lecture will provide insights into the preparation, processing, and characterization of advanced ceramics, offering students insights into the methodologies involved in transforming raw materials into high-performance ceramic products. Understanding these aspects is crucial for comprehending the manufacturing processes that contribute to the unique properties of advanced ceramics.

Moreover, an appreciation of the challenges and limitations associated with the utilization of advanced ceramics in various applications will be emphasized. Recognizing these challenges is essential for informed decision-making and the development of strategies to optimize the performance of advanced ceramics in different fields.

The lecture will also encourage students to engage in discussions about recent advances and future prospects in the field of advanced ceramics. Keeping updated on developments in materials science and technology is vital for individuals seeking to contribute to the ongoing progress and innovation in the realm of advanced ceramics.

In summary, this lecture serves as a focal point for understanding and appreciating the realm of advanced ceramics. By covering their properties, types, applications, and manufacturing processes, students will gain a robust foundation for comprehending the intricacies of advanced ceramic materials. This knowledge, coupled with insights into challenges and advancements, positions students to navigate the dynamic landscape of advanced ceramics and contribute meaningfully to their diverse applications in cutting-edge technologies.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Explain the properties and characteristics of advanced ceramics, including high strength, hardness, and wear resistance.
- Identify the different types of advanced ceramics, including oxide, non-oxide, and composite ceramics.
- Describe the preparation, processing, and characterization of advanced ceramics.
- Know the challenges and limitations associated with the use of advanced ceramics in different applications.
- Discuss the recent advances and future prospects in the field of advanced ceramics.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the six-hour session, graphs related to structure and applications of advanced ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - In one part of the course, students will work on comparing the properties of which advanced ceramic material will be advantageous according to the application.

Discussion – The students will be encouraged to actively participate in discussions about the case study.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

- Boch, P., & Ni, J. C. (Eds.). (2010). Ceramic materials: Processes, properties, and applications (Vol. 98). John Wiley & Sons.. (Chapters: 6, 7)

6. Additional notes

Topics 5

1. The subject of the lecture

MICROSTRUCTURE AND MICROSTRUCTURE CONTROL OF CERAMICS

2. Thematic scope of the lecture

This lecture is dedicated to an in-depth examination of the microstructure of ceramics and the crucial role it plays in enhancing properties through effective control. Focusing on fundamental concepts, the lecture will encompass key aspects of microstructure, including grain size, porosity, and phase composition. These parameters significantly influence the overall performance and behavior of ceramics, making an understanding of microstructure essential in the realm of materials science.

A central theme of the lecture will be the exploration of techniques employed for microstructure control in ceramics. This encompasses methods like doping, sintering additives, and grain growth inhibitors. Students will gain insights into how manipulating these factors during the manufacturing process can lead to precise control over microstructural features, thereby influencing the final properties of ceramics.

The learning outcomes emphasize the importance of grasping the basic concepts of microstructure in ceramics. This includes a comprehensive understanding of grain size, porosity, and phase composition, which collectively contribute to the unique characteristics of ceramic materials. Identifying the factors that impact microstructure, such as processing conditions and material composition, is vital for students to make informed decisions in materials design and engineering.

Additionally, the lecture will shed light on the profound impact of microstructure on the properties of ceramics. Whether it be mechanical, thermal, or electrical properties, the intricacies of microstructural features play a pivotal role in determining how ceramics behave in various applications. Recognizing the correlation between microstructure and properties is essential for engineers and researchers seeking to tailor ceramics for specific functions.

The appreciation of microstructure control's significance in ceramics development will be underscored throughout the lecture. Students will understand how precise manipulation of microstructural elements can lead to ceramics with desired properties, paving the way for advancements in various fields, including aerospace, electronics, and energy.

Furthermore, the lecture will introduce characterization techniques used to study microstructure in ceramics, such as scanning electron microscopy and X-ray diffraction. Understanding these analytical methods equips students with the tools needed to observe and analyze microstructural features, providing valuable insights into the composition and arrangement of ceramic materials.

In closing, the discussion will extend to challenges and opportunities associated with microstructure control in ceramics, emphasizing potential applications across diverse fields. This comprehensive exploration of microstructure and its control not only serves as a foundational knowledge base for students but also prepares them to contribute meaningfully to advancements in ceramics technology and its applications in real-world scenarios.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the basic concepts of microstructure in ceramics, including grain size, porosity, and phase composition.
- Identify the factors that affect microstructure, such as processing conditions and material composition.
- Describe the different techniques used for microstructure control in ceramics, such as doping, sintering additives, and grain growth inhibitors.
- Recognize the role of microstructure in determining the properties of ceramics, including mechanical, thermal, and electrical properties.
- Appreciate the importance of microstructure control in the development of ceramics with desired properties.
- Know the characterization techniques used to study microstructure in ceramics, such as scanning electron microscopy and X-ray diffraction.
- Discuss the challenges and opportunities associated with microstructure control in ceramics and the potential applications in various fields.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the six-hour session, microphotographs related to ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - In one part of the course, students will work on comparing the properties of which advanced ceramic material will be advantageous according to the application.

Discussion – In one part of the course, students will comment on and discuss microstructure photographs.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

Articles on the microstructure of ceramics can be given from the literature on this subject.

6. Additional notes

Topics 6

1. The subject of the lecture

MECHANICAL PROPERTIES OF CERAMICS

2. Thematic scope of the lecture

This lecture will center on a thorough exploration of the mechanical properties inherent in ceramics, with a particular emphasis on principles related to elasticity and fracture. By exploring the intricacies of mechanical behavior, students will gain a solid understanding of fundamental concepts such as stress and strain, elastic modulus, and yield strength. The lecture will extend its focus to elucidate the factors influencing the mechanical properties of ceramics, including microstructure, defects, and processing conditions.

A central aspect of the lecture will be the discussion of elasticity and fracture principles specific to ceramics. Understanding these principles is essential for comprehending how ceramics respond to external forces and the mechanisms governing their deformation and failure. The integration of theoretical knowledge with practical applications will provide students with a comprehensive understanding of mechanical behavior in ceramics.

Moreover, the lecture will explore the various testing techniques employed to evaluate the mechanical properties of ceramics. These techniques, such as indentation, bending, and compression tests, serve as invaluable tools in assessing how ceramics withstand and respond to mechanical stresses. Students will gain insights into the methodologies and significance of each testing approach, contributing to a well-rounded understanding of ceramics' mechanical performance.

The learning outcomes aim to equip students with the ability to identify the factors influencing the mechanical properties of ceramics, emphasizing the critical roles played by microstructure, defects, and processing conditions. Recognizing the interplay between these factors is fundamental for tailoring ceramics to meet specific mechanical requirements in diverse applications.

An appreciation of the role of microstructure and defects in determining mechanical properties will be emphasized throughout the lecture. Students will understand how the arrangement of atoms and the presence of defects influence the overall mechanical behavior of ceramics, providing them with a detailed perspective on material design and engineering.

The lecture will also address the challenges and limitations associated with the mechanical testing of ceramics. This includes considerations related to the accuracy and reliability of testing methods, ensuring that students develop a realistic understanding of the complexities involved in assessing the mechanical performance of ceramics.

In closing, the discussion will extend to the potential applications of ceramics with superior mechanical properties in various fields.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Explain the basic concepts of mechanical behavior in ceramics, including stress and strain, elastic modulus, and yield strength.
- Identify the factors that affect the mechanical properties of ceramics, such as microstructure, defects, and processing conditions.
- Describe the principles of elasticity and fracture in ceramics.
- Recognize the different testing techniques used to evaluate the mechanical properties of ceramics, such as indentation, bending and compression tests.
- Criticize the role of microstructure and defects in determining the mechanical properties of ceramics.
- Define the challenges and limitations associated with the mechanical testing of ceramics.
- Discuss the potential applications of ceramics with superior mechanical properties in various fields.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the five-hour session, methods to determine mechanical properties of ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - In one part of the course, students will work on the calculation of fracture toughness and bending strength.

Discussion – In one part of the lesson, students will comment and discuss the mechanical properties of ceramics.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

- Boch, P., & Ni, J. C. (Eds.). (2010). Ceramic materials: Processes, properties, and applications (Vol. 98). John Wiley & Sons.. (Chapter: 9)

6. Additional notes

Topics 7

1. The subject of the lecture

THE RELATIONSHIP BETWEEN STRUCTURE, PROPERTIES, PROCESS, AND MICROSTRUCTURE

2. Thematic scope of the lecture

This lecture will concentrate on developing a comprehensive understanding of the complex interrelationships between structure, properties, process, and microstructure in ceramic materials. A primary focus will be on elucidating the basic concepts underlying structure-property relationships in ceramics, unraveling the ways in which processing conditions and microstructural features intricately influence material properties. This foundational knowledge serves as the cornerstone for comprehending how different elements converge to define the characteristics of ceramic materials.

The discussion will extend to exploring the various factors that impact ceramic material properties. Emphasis will be placed on microstructure, processing conditions, and composition as critical influencers. By identifying these factors, students will gain insights into the multifaceted nature of ceramics and how various elements interplay to dictate their properties.

A crucial aspect of the lecture will be the explanation of different characterization techniques employed to study the structure and microstructure in ceramics. Techniques such as microscopy, X-ray diffraction, and spectroscopy will be explored, providing students with a diverse toolkit to analyze and comprehend the detailed features of ceramic materials. Understanding these techniques is pivotal for researchers and engineers seeking nuanced insights into the composition and arrangement of ceramics.

Furthermore, the lecture will delve into the various processing techniques instrumental in controlling microstructure and properties in ceramics. Approaches like doping, sintering, and heat treatment will be discussed, shedding light on how deliberate interventions during the manufacturing process can be leveraged to tailor the properties of ceramics for specific applications. This practical knowledge equips students with the tools needed to engineer ceramics with desired characteristics.

An appreciation of the challenges and limitations associated with establishing structure-property relationships in ceramics will be emphasized. Recognizing the complexities involved in correlating various factors to achieve desired material properties is crucial for fostering a realistic perspective among students.

In conclusion, the lecture will prompt discussions on the potential applications of ceramics with tailored properties across various fields. By understanding how to manipulate structure, properties, and processing, students will be prepared to contribute meaningfully to advancements in ceramics technology and its diverse applications in industries such as electronics, aerospace, and healthcare. This foundational understanding forms the basis for informed decision-making and innovation in the dynamic realm of ceramic materials.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the fundamental principles of structure-property relationships in ceramic materials.
- Identify the factors that affect ceramic material properties, such as microstructure, processing conditions, and composition.
- Describe the different characterization techniques used to study structure and microstructure in ceramics, including microscopy, X-ray diffraction, and spectroscopy.
- Recognize the importance of processing techniques in controlling microstructure and properties in ceramics, such as doping, sintering, and heat treatment.
- Debate the challenges and limitations associated with establishing structure-property relationships in ceramics.
- Discuss the potential applications of ceramics with tailored properties in various fields.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool. In the five-hour session, relationship between structure, properties, process, and microstructure of ceramic materials will be shown.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - In one part of the course, students will work on relationship between structure, properties and process on a given microstructure.

Discussion – In one part of the lesson, students will comment and discuss how microstructure effects the properties of ceramics.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

Articles on the microstructure of ceramics can be given from the literature on this subject.

6. Additional notes

Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

PREPARATION OF CERAMIC POWDERS

2. Thematic scope of the laboratory classes

This laboratory session is dedicated to the fundamental aspects of ceramic powder preparation, with a primary focus on understanding the composition and properties of these powders. The practical exercises will thoroughly explore the determination of ceramic powder composition, allowing students to gain hands-on experience in assessing the elemental makeup of these crucial materials.

The laboratory class will also extensively cover various processing techniques employed to modify the properties of ceramic powders. Among these techniques, calcination, milling, and surface modification will be thoroughly discussed. Students will not only understand the theoretical principles behind these processes but will also engage in practical applications, gaining a comprehensive understanding of how these techniques can be applied to tailor the properties of ceramic powders.

A crucial component of the laboratory class is the exploration of characterization techniques specific to evaluating ceramic powder properties. First, it is to separate the raw materials used according to their grain sizes using the traditionally used sieve analysis method.

The learning outcomes are strategically aligned with the laboratory's thematic scope. Describing various processing techniques, such as calcination and surface modification, emphasizes the practical knowledge that students will acquire during the laboratory exercises. Recognizing the significance of particle size, morphology, and composition in determining ceramic powder properties establishes a foundational understanding of the factors that influence the behavior and functionality of these materials.

Moreover, the laboratory class is designed to empower students with the ability to perform basic laboratory procedures for ceramic powder synthesis and characterization. This hands-on experience not only reinforces theoretical knowledge but also develops practical skills that are invaluable in the realm of materials science and engineering.

In conclusion, this laboratory session provides a comprehensive approach to the preparation and understanding of ceramic powders. By combining theoretical discussions with practical exercises, students will develop a robust skill set encompassing both the theoretical principles and the hands-on techniques necessary for effective ceramic powder synthesis and characterization. This knowledge forms the basis for further exploration and innovation in the field of ceramic materials.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Describe the various processing techniques used to modify the properties of ceramic powders, such as calcination and surface modification.
- Recognize the importance of particle size, morphology, and composition in determining the properties of ceramic powders.
- Perform basic laboratory procedures for ceramic powder synthesis and characterization.

4. Necessary equipment, materials, etc

- Raw materials
- Laboratory scale
- Optical microscope
- Laboratory sieves

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

Laboratory course outline:

1. Knowledge Test:

Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

Each team should start preparations for the experiment by calculating the composition. Accordingly, the necessary raw materials must be sieved. Teams must weigh the raw materials they obtain and create a sieve analysis table or graph. Each raw material must be sieved separately.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Rahaman, M. N. (2003). Ceramic processing and sintering. New York: M. Dekker, 567, 573. (Chapter 3)

7. Additional notes

8. Optional information

Topics 2

1. The subject of the laboratory classes

MIXING, MILLING AND DRYING

2. Thematic scope of the laboratory classes

This laboratory session is dedicated to the critical processes of mixing, milling, and drying ceramic powders. A primary objective is to provide students with a comprehensive understanding of these processes, emphasizing the different methods and techniques employed to achieve homogeneous ceramic powder mixtures with controlled composition and particle size distribution.

The laboratory class will explore the basic principles of ceramic powder mixing and milling, shedding light on the complexities of these procedures. It will encompass discussions on the effects of processing parameters, such as milling time, milling speed, and ball size, on the efficiency of mixing and milling. This theoretical understanding is pivotal for students to make informed decisions during the experimental phase and tailor ceramic powder mixtures to specific requirements.

A crucial aspect of the laboratory class is the identification of various methods and techniques used in the preparation of homogeneous ceramic powder mixtures. This includes an exploration of dry and wet mixing, as well as specific milling techniques such as ball milling and attrition milling. Understanding the details of these techniques equips students with the knowledge to select the most suitable approach for their intended applications.

The discussion will also encompass the recognition of the importance of particle size distribution and composition in determining the properties of ceramic powder mixtures. Students will gain insights into how these factors influence the behavior and characteristics of the resultant powders, providing a foundation for materials design and engineering.

Understanding the challenges and limitations associated with ceramic powder mixing and milling is integral to this laboratory class. Awareness of these issues is crucial for students to navigate the complexities of the processes and develop strategies to optimize efficiency.

Hands-on experience is a key component of the laboratory, with students expected to perform basic procedures for ceramic powder mixing and milling. This practical engagement not only reinforces theoretical concepts but also develops essential skills in materials science and engineering.

Furthermore, the laboratory class aims to instill analytical capabilities in students. They will be required to analyze and interpret experimental results, drawing conclusions about the properties of ceramic powder mixtures. This skill set is fundamental for researchers and engineers to make informed decisions based on empirical data.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained to design and prepare homogeneous ceramic powder mixtures with specific properties and applications. This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering. In summary, this laboratory session serves as a crucial learning experience, laying the foundation for students to engage effectively in the synthesis and manipulation of ceramic powders.

3. Learning outcomes

By the end of this laboratory class, students will be able to:

- Know the principles of ceramic powder mixing and milling.
- Identify the different methods and techniques used to prepare homogeneous ceramic powder mixtures, including dry and wet mixing, ball milling, and attrition milling.
- Describe the effects of processing parameters, such as milling time, milling speed, and ball size, on mixing and milling efficiency.
- Recognize the importance of particle size distribution and composition in determining the properties of ceramic powder mixtures.
- Explain the challenges and limitations associated with ceramic powder mixing and milling.
- Perform basic laboratory procedures for ceramic powder mixing and milling.
- Analyze and interpret experimental results to draw conclusions about the properties of ceramic powder mixtures.
- Apply the knowledge gained from the laboratory class to design and prepare homogeneous ceramic powder mixtures with specific properties and applications.

4. Necessary equipment, materials, etc

- Laboratory scale
- Laboratory mill
- Particle size analyzer

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

Laboratory course outline:

1. Knowledge Test:

    Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

    Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

The raw materials prepared by each team are placed in the mill and dry/wet grinding is performed. The ratio of the grinding balls to be placed in the mill to the raw material will be calculated by weighing. At the end of 10, 15 and 20 minutes, a sample is taken from the mill and the grain size is measured with a laser grain size measuring device. Accordingly, the optimum grinding time will be determined for the ceramic powder mixture obtained from similar raw material compositions.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Rahaman, M. N. (2003). Ceramic processing and sintering. New York: M. Dekker, 567, 573. (Chapter 2)

7. Additional notes

8. Optional information

Topics 3

1. The subject of the laboratory classes

POWDER PRESSING

2. Thematic scope of the laboratory classes

This laboratory session focuses on the process of powder pressing with ceramic powders, emphasizing different methods and techniques for crafting green compacts with controlled shape and density. The primary aim is to provide students with a comprehensive understanding of this process, particularly the principles of powder pressing and the influence of processing parameters on compactability and green density.

During the laboratory class, students will explore various methods and techniques for preparing green compacts, including uniaxial and isostatic pressing. Understanding these techniques is crucial for students to make informed decisions based on their specific applications.

The discussion will also cover the effects of processing parameters, such as pressure, temperature, and holding time, on compactability and green density. Gaining insights into these effects is essential for students to navigate the intricacies of the powder pressing process.

Furthermore, the importance of green density and porosity in determining the properties of green compacts will be emphasized. These characteristics play a pivotal role in shaping the behavior and functionality of the compacts, providing foundational knowledge for materials design and engineering.

Understanding the challenges and limitations associated with powder pressing of ceramic powders is integral to this laboratory class. Awareness of these issues is crucial for students to navigate the complexities of the process and develop strategies to optimize the quality of green compacts.

Hands-on experience is a central component of the laboratory, with students expected to perform basic procedures for powder pressing of ceramic powders. This practical engagement not only reinforces theoretical concepts but also develops essential skills for future endeavors in materials science and engineering.

Moreover, the laboratory class aims to instill analytical capabilities in students. They will be required to use characterization techniques, including density measurements, porosity analysis, and mechanical testing, to evaluate the properties of green compacts. This analytical skill set is fundamental for researchers and engineers to make informed decisions based on empirical data.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained to design and prepare green compacts with specific properties and applications. This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering. In summary, this laboratory session serves as a crucial learning experience, laying the foundation for students to engage effectively in the synthesis and shaping of ceramic powders through powder pressing.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the principles of powder pressing of ceramic powders.
- Identify the different methods and techniques used to prepare green compacts, including uniaxial and isostatic pressing.
- Describe the effects of processing parameters, such as pressure, temperature, and holding time, on compactability and green density.
- Recognize the importance of green density and porosity in determining the properties of green compacts.
- Identify the challenges and limitations associated with powder pressing of ceramic powders.
- Perform basic laboratory procedures for powder pressing of ceramic powders.
- Use characterization techniques to evaluate the properties of green compacts, such as density measurements, porosity analysis, and mechanical testing.
- Analyze and interpret experimental results to draw conclusions about the properties of green compacts.
- Apply the knowledge gained from the laboratory class to design and prepare green compacts with specific properties and applications.

4. Necessary equipment, materials, etc

- Ceramic powders
- Laboratory scale
- Steel die
- Hydraulic pressing machine

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

Laboratory course outline:

1. Knowledge Test:

Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

Each team weighs the ceramic powder mixture and prepares it for pressing at 10 MPa, 20 MPa and 40 MPa hydraulic pressure. The powders are placed in a steel mold and pressed. The dimensions of the samples obtained are measured, their weights are weighed and as a result their density is calculated. According to these data, the density-hydraulic pressure graph is drawn.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Reed, J. S. (1995). Principles of ceramics processing. (Chapter 22)

7. Additional notes

8. Optional information

Topics 4

1. The subject of the laboratory classes

SINTERING

2. Thematic scope of the laboratory classes

This laboratory session is dedicated to the detailed examination of the sintering process for ceramic powders. The focus is on various methods and techniques employed to transform green compacts into dense, solid ceramic materials with controlled microstructure and properties. The primary goal is to provide students with a comprehensive understanding of the principles of sintering and the interplay of processing parameters on densification and microstructural development.

The laboratory class will thoroughly cover the fundamental principles of sintering, elucidating the effects of critical processing parameters, such as temperature, heating rate, and holding time, on the overall densification process and the resultant microstructural features. Acquiring insights into these factors is crucial for students to comprehend the intricacies of the sintering process and make informed decisions during the experimental phase.

During the laboratory class, students will explore various methods and techniques used to sinter ceramic materials. This includes discussions on conventional sintering, hot pressing, and spark plasma sintering. Understanding these techniques is essential for students to choose the most suitable approach based on the specific requirements of their intended applications.

Furthermore, the laboratory class will emphasize the importance of microstructure and properties in determining the performance of sintered ceramics. Students will gain insights into how the microstructural features developed during the sintering process influence the overall behavior and functionality of the ceramics. This knowledge forms the foundational understanding for materials design and engineering.

Understanding the challenges and limitations associated with the sintering of ceramic powders is integral to this laboratory class. Awareness of these issues is crucial for students to navigate the complexities of the sintering process and develop strategies to optimize densification and microstructural development.

Hands-on experience is a central component of the laboratory, with students expected to perform basic procedures for the sintering of ceramic powders. This practical engagement not only reinforces theoretical concepts but also develops essential skills for future endeavors in materials science and engineering.

Moreover, the laboratory class aims to instill analytical capabilities in students. They will be required to analyze and interpret experimental results, drawing conclusions about the properties of sintered ceramics. This analytical skill set is fundamental for researchers and engineers to make informed decisions based on empirical data.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained to design and optimize sintering processes for specific applications. This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering. In summary, this laboratory session serves as a pivotal learning experience, laying the foundation for students to engage effectively in the sintering processes crucial for the production of advanced ceramic materials.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the principles of sintering of ceramic powders.
- Identify the different methods and techniques used to sinter ceramic materials, including conventional sintering, hot pressing, and spark plasma sintering.
- Describe the effects of processing parameters, such as temperature, heating rate, and holding time, on densification and microstructural development.
- Recognize the importance of microstructure and properties in determining the performance of sintered ceramics.
- State the challenges and limitations associated with sintering of ceramic powders.
- Perform basic laboratory procedures for sintering of ceramic powders.
- Analyze and interpret experimental results to draw conclusions about the properties of sintered ceramics.
- Apply the knowledge gained from the laboratory class to design and optimize sintering processes for specific applications.

4. Necessary equipment, materials, etc

- Laboratory furnace

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

Laboratory course outline:

1. Knowledge Test:

   Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

   Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

   Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

Each team will recommend sintering temperature and sintering time for their composition. The samples will be sintered using two different sintering parameters determined by the teacher. As a result, teams will compare and interpret the parameters they propose.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Rahaman, M. N. (2003). Ceramic processing and sintering. New York: M. Dekker, 567, 573. (Chapter 7, 8)

7. Additional notes

8. Optional information

Topics 5

1. The subject of the laboratory classes

Mechanical testing of ceramics

2. Thematic scope of the laboratory classes

This laboratory session is dedicated to the in-depth exploration of mechanical testing for sintered ceramics. The focus lies on various methods and techniques employed to evaluate critical mechanical properties, including strength, fracture toughness, and hardness. The primary objective is to equip students with a thorough understanding of the principles of mechanical testing and the interplay of microstructure and processing conditions on resulting mechanical properties.

The laboratory class will thoroughly cover the fundamental principles of mechanical testing, elucidating the effects of microstructure and processing conditions on essential mechanical properties. Gaining insights into these factors is essential for students to comprehend the complexities of mechanical behavior and make informed decisions during experimental assessments.

During the laboratory class, students will explore different methods and techniques used to evaluate the mechanical properties of ceramics. This includes discussions on strength, fracture toughness, and hardness measurements, providing students with a detailed understanding of the diverse aspects of mechanical behavior.

Furthermore, the laboratory class will emphasize the importance of mechanical properties in determining the overall performance of ceramics. Students will gain insights into how these properties influence the behavior and functionality of ceramics, forming a foundational understanding for materials design and engineering.

Understanding the challenges and limitations associated with mechanical testing of ceramics is integral to this laboratory class. Awareness of these issues is crucial for students to navigate the intricacies of testing processes and develop strategies to obtain reliable and meaningful results.

Hands-on experience is a central component of the laboratory, with students expected to perform basic procedures for mechanical testing of sintered ceramics. This practical engagement not only reinforces theoretical concepts but also develops essential skills for future endeavors in materials science and engineering.

Moreover, the laboratory class aims to instill analytical capabilities in students. They will be required to use characterization techniques, such as stress-strain curves, fracture surface analysis, and hardness profiling, to evaluate the mechanical properties of ceramics. This analytical skill set is fundamental for researchers and engineers to make informed decisions based on empirical data.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained to design and optimize the mechanical properties of ceramics for specific applications.

This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering. In summary, this laboratory session serves as a pivotal learning experience, laying the foundation for students to engage effectively in assessing and enhancing the mechanical performance of sintered ceramics.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the principles of mechanical testing of sintered ceramics.
- Identify the different methods and techniques used to evaluate the mechanical properties of ceramics, including strength, fracture toughness, and hardness.
- Describe the effects of microstructure and processing conditions on the mechanical properties of ceramics.
- Recognize the importance of mechanical properties in determining the performance of ceramics.
- Perform basic laboratory procedures for mechanical testing of sintered ceramics, including compression testing, flexural testing, and indentation testing.
- Use characterization techniques to evaluate the mechanical properties of ceramics, such as stress-strain curves, fracture surfaces, and hardness profiles.
- Analyze and interpret experimental results to draw conclusions about the mechanical properties of ceramics.
- Apply the knowledge gained from the laboratory class to design and optimize mechanical properties of ceramics for specific applications.

4. Necessary equipment, materials, etc

- Universal mechanical testing machine
- Vickers hardness test
- Optical microscope

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

Laboratory course outline:

1. Knowledge Test:

Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

Each team will examine the mechanical properties of the samples they sintered. First, 3-point bending strength or compressive strength will be measured. Afterwards, hardness and fracture toughness will be measured. After the data obtained, strength and hardness graphs will be created against sintering time or temperature.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Boch, P., & Ni, J. C. (Eds.). (2010). Ceramic materials: Processes, properties, and applications (Vol. 98). John Wiley & Sons. (Chapter 8)

7. Additional notes

8. Optional information

Topics 6

1. The subject of the laboratory classes

Density measurement of ceramic bodies

2. Thematic scope of the laboratory classes

This laboratory session is specifically designed for a comprehensive exploration of density measurement for sintered ceramics, employing the Archimedes method as the primary focus. The objective is to provide students with a detailed understanding of the principles underlying density measurement, emphasizing the influence of microstructure and processing conditions on the density of ceramics.

The laboratory class will thoroughly cover the fundamental principles of density measurement, elucidating the intricate effects of microstructural features and processing conditions on the overall density of ceramics. Gaining insights into these factors is crucial for students to understand the detailed aspects of density determination and make informed decisions during experimental assessments.

A key component of the laboratory class will involve discussions on various characterization techniques used to evaluate the density of ceramics. This includes insights into the applications of X-ray diffraction and scanning electron microscopy, providing students with a comprehensive understanding of the analytical tools available for density assessments.

Furthermore, the laboratory class will underscore the importance of density in determining the overall performance of ceramics. Students will gain insights into how density influences critical aspects of ceramic behavior and functionality, forming a foundational understanding for materials design and engineering.

The hands-on experience in this laboratory is integral, with students expected to perform basic procedures for density measurement of sintered ceramics. This practical engagement not only reinforces theoretical concepts but also develops essential skills for future endeavors in materials science and engineering.

Moreover, the laboratory class aims to instill analytical capabilities in students. They will be required to use characterization techniques, such as X-ray diffraction and scanning electron microscopy, to evaluate the density of ceramics. This analytical skill set is fundamental for researchers and engineers to make informed decisions based on empirical data.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained in optimizing the processing conditions of ceramics for specific applications based on density requirements. This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering. In summary, this laboratory session serves as a pivotal learning experience, laying the foundation for students to engage effectively in density measurements critical for the characterization and optimization of sintered ceramics.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Know the principles of density measurement of sintered ceramics.
- Describe the effects of microstructure and processing conditions on the density of ceramics.
- Recognize the importance of density in determining the performance of ceramics.
- Perform basic laboratory procedures for density measurement of sintered ceramics, including sample preparation and data analysis.
- Analyze and interpret experimental results to draw conclusions about the density of ceramics.
- Apply the knowledge gained from the laboratory class to optimize the processing conditions of ceramics for specific applications based on density requirements.

4. Necessary equipment, materials, etc

- Archimedes scale

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

Laboratory course outline:

1. Knowledge Test:

 Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

 Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

 Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

 In order to measure the density of the samples obtained, each team must pre-weigh the dry weight of the samples and boil them with pure water for at least 24 hours. Then, it completes this procedure by weighing the fresh weight and suspended weight of the samples. As a result of the values obtained, it draws density, porosity and water absorption graphs.

5. Results Analysis:

Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

https://www.mt.com/us/en/home/applications/Laboratory_weighing/density-measurement.html

7. Additional notes

8. Optional information

Topics 7

1. The subject of the laboratory classes

Microstructure investigation

2. Thematic scope of the laboratory classes

This laboratory session is tailored to immerse students in the intricacies of microstructure investigation for sintered ceramics. The primary focus is on exploring different techniques and utilizing specialized equipment, such as scanning electron microscopy (SEM) and X-ray diffraction (XRD), to comprehensively analyze the microstructure of ceramics. The overarching goal is to equip students with the skills and understanding needed to unravel the detailed features related to grains, grain size, phase contrast, and the presence of various phases within the structure, along with insights into cracks and pores.

The laboratory class will delve into the fundamental principles of microstructure investigation, shedding light on how processing conditions intricately influence the detailed characteristics of ceramics. Understanding the detailed aspects of grain structure, variations in grain size, and the interplay of phases within the material is essential for students to gain insights into the relationship between processing parameters and resulting microstructural features.

A key component of the laboratory class involves discussions on various characterization techniques used to evaluate the microstructure of ceramics, with a particular emphasis on grain features, size distribution, and the identification of phases. This includes insights into phase contrast analysis, providing students with understanding of the analytical tools available for microstructure assessments, specifically focusing on the details of grains, phases, and their distribution.

Furthermore, the laboratory class will highlight the significance of microstructure in determining the overall performance of ceramics. Students will gain insights into how specific microstructural features, such as cracks and pores, impact the material's behavior and functionality, forming a foundational understanding for materials design and engineering.

Hands-on experience is integral to this laboratory, with students expected to operate scanning electron microscopy and utilize X-ray diffraction for microstructure investigation. This practical engagement not only reinforces theoretical concepts but also develops essential skills for future endeavors in materials science and engineering, especially in the context of detailed grain analysis and phase identification.

Moreover, the laboratory class aims to instill analytical capabilities in students. They will be required to use characterization techniques, such as grain size analysis, phase contrast assessment, and identification of cracks and pores, to evaluate the microstructure of ceramics. This analytical skill set is fundamental for researchers and engineers to make informed decisions based on empirical data, particularly when dealing with specific details like grain characteristics and structural features.

The ultimate goal of this laboratory class is to empower students to apply the knowledge gained in optimizing the microstructure of ceramics for specific applications, emphasizing aspects like grain refinement and phase control. This application-oriented approach ensures that the theoretical understanding acquired in the laboratory translates into practical skills for materials synthesis and engineering, with a heightened focus on the detailed microstructural features crucial for ceramics performance. In summary, this laboratory course will be instructive in establishing the relationship between microstructure and material properties by enabling students to learn terms related to microstructure.

3. Learning outcomes

By the end of this lecture, students will be able to:

- Be acquainted with the principles of microstructure investigation of sintered ceramics.
- Identify the different techniques and equipment used to analyze the microstructure of ceramics, including SEM and XRD.
- Describe the effects of processing conditions on the microstructure of ceramics, such as sintering temperature and time.
- Recognize the importance of microstructure in determining the performance of ceramics.
- Perform basic laboratory procedures for microstructure investigation of sintered ceramics, including sample preparation and data analysis.
- Use characterization techniques to evaluate the microstructure of ceramics, such as grain size analysis and porosity measurement.
- Analyze and interpret experimental results to draw conclusions about the microstructure of ceramics.
- Apply the knowledge gained from the laboratory class to optimize the processing conditions of ceramics for specific applications based on microstructure requirements.

4. Necessary equipment, materials, etc

- XRD
- SEM

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

Laboratory course outline:

1. Knowledge Test:

Assess participants' understanding of relevant theoretical concepts through a pre-course test, ensuring a baseline comprehension before engaging in practical exercises.

2. Introduction:

Provide an overview of the laboratory course, outlining its objectives, scope, and relevance. This section familiarizes participants with the course's purpose and sets the stage for subsequent activities.

3. Course of the Exercise:

   Detail the step-by-step procedures and activities that participants will undertake during the laboratory session. This section serves as a practical guide, ensuring a clear understanding of the hands-on components of the course. In addition, teams can be formed according to the number of students.

4. Research:

   Each team selects the sample with the highest strength. Powder is prepared for xrd analysis from this sample. Images are taken on SEM to examine the fracture surface of the bulk sample. Teams interpret the microstructure images obtained by SEM analysis along with the phase analysis and comment on the increase and decrease in strength.

5. Results Analysis:

   Instruct participants on how to interpret and analyze the data collected during the research phase. This step involves critical thinking and application of analytical tools to draw meaningful conclusions from experimental outcomes.

6. Summary:

   Conclude the laboratory course by summarizing key findings, reinforcing the connection between theoretical knowledge and practical application. This section may also address any unexpected outcomes, lessons learned, and potential avenues for further exploration.

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

Boch, P., & Ni, J. C. (Eds.). (2010). Ceramic materials: Processes, properties, and applications (Vol. 98). John Wiley & Sons. (Chapter 3)

7. Additional notes

8. Optional information

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

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

CASTING AND CASTING TECHNOLOGY IN INDUSTRY

Code: CCTI

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO THE CASTING AND CASTING TECHNOLOGY IN INDUSTRY

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

This lecture aims to introduce the casting process and its technology as a part of the manufacturing process. This lecture will also cover the technological challenges of casting industry that are affected by the world trade rules and technological advances. Casting industry is the driving force for the most sectors that are in manufacturing such as machine manufacturing, mould making for sheet metal forming, civil engineering and automotive spare parts manufacturing etc. These sectors are in constant need of casting industry and hence, casting sector has to improve its efficiency and technology in order to overcome the difficulties related to the production of parts needed. Casting sector has challenges such as digitisation, work force quality, changing customer requirements, world trade manipulations and sustainability of resources in local country and world. The way most foundries work will change in the near future due to climate change, raw materials availability issues and digitisation. New and more efficient techniques are being introduced and the industry has to keep up with those in a cost effective way and also consider recycling of post production waste. For example, the digitalization will force employees work with computer systems at the production level and they will have to know what data their equipment is supposed to deliver, and they need to be able to document their work. In this context, a discussion of the advantages and disadvantages of the casting method within the manufacturing processes will also be made involving students. In addition to these challenges, basic definitions and terms, pattern making, mould making, core making, melting and pouring of molten metal, cleaning and finishing operations will also be explained with respect to conventional casting operations. Students will be asked to join the discussion regarding the future of the casting industry and technological advances that the industry may be going through near future.

3. Learning outcomes

Students can
- differentiate the types of casting processes,
- explain the casting processes and their role and limits in industrial production,
- comment on the capacities of each casting methods,
- analyse the casting sector and its needs and commercial bottlenecks,
- explain the importance of casting methods.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 1 and 2.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

Topics 2

1. The subject of the lecture

CASTING TECHNIQUES

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

This lecture aims to introduce the different casting processes such as Gravity casting, Pressure casting methods, Sand casting, Die casting, Centrifugal casting, Investment casting, and Thixocasting (Semi-solid casting methods). Students will be given a set of detailed instructions to discuss the processes of sand casting, die casting, centrifugal casting, investment casting and semi solid casting by real examples from industry and various applications. A dedicated section will be prepared to enlighten students basic and advances applications with respect to type of materials intended for the use with dedicated applications. Gravity casting and sand casting and also investment casting processes are basically similar processes for large volume and precision parts whereas pressure casting methods are more focused on the number of production and quality of the product. These differences will be mentioned in detail with respect to their operational principles. The main advantages and disadvantages of these casting methods will also be discussed with students based on their experience in industry if any and documents given in the lecture. A separate electronic document can be given to the students such as articles about the new coming casting techniques and various specific and interesting applications. The other classification casting techniques will include low pressure, ambient pressure and high pressure casting techniques. These classifications can be given in a tabulated form in order to make students learn and consult this information later. It is advised to mention by the instructor that the applications in industry may substantially differ in terms of sequence of processes but in general it will be scientifically applicable wherever needed. Hence, students are asked to read and research relevant information regarding the lecture content prior to the lecture. Various applications in industry will also be shown to students such as real examples from foundries including defects and accidents relevant to the subject. It is also important to show the capacity of each casting technique for reference. A debate on the future of casting should be initiated with the students for the clarity of subjects that have been given in the lecture and an essay can be optionally requested by the instructor.

3. Learning outcomes

Students can

- explain the different definitions of the casting process,
- define the casting methods available for industry,
- define the casting method's advantages and disadvantages based on their knowledge and documents given in the lectures,
- recognise the casting techniques and classify them according to operating pressure, gravity

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 16.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 3

1. The subject of the lecture

BASICS OF SOLIDIFICATION

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

This lecture aims to introduce the basics of metal solidification and explain the Nucleation and growth concept during solidification. Also, explanations on the solidification macrostructure. The student will be able to rehearse the shrinkage of molten metal during the solidification in castings and students can do basic calculations of the basic feeder and runners in sand casting processes. The solidification process of castings are very important part of the casting processes as the molten metal spool may contain some non metallic residues that may lead to the formation defects during and after the solidification and it may affect the rolling and forming into blooms and slabs for further processing. These processing routes include rolling of slabs into the thick plate or even thin sheets of metal on which it is more important to remove these defects for the surface roughness of the final products. Typical solidification diagrams for metallic materials will be produced with respect to the type of metals and alloys separately, and theoretical calculations regarding driving force for the solidification and for melting will also be made available to students from the thermodynamics point of view. A phase separation during the solidification and the reading on the phase diagram can be presented to students and calculations regarding the phase and percentages can be given with the help of lever rule on a simple and slightly complex system. A list of defects related to the solidification process should be given to the students and students should consult this information during the lecture. A detailed list of solidification macrostructures may also be given in various casting of different steels and metallic materials; this may be a good reference value for all students, especially working in the industry. Effect of cooling rate on macro properties of castings can be mentioned and the changes on the solidification curve may also be mentioned accordingly. A theoretical principle of solidification process in large volume and small volume castings can be given in detail and practical applications in order to produce defect free casting and relevant post casting processes may also be mentioned in the classroom.

3. Learning outcomes

The students can

- explain the nucleation and growth concept during solidification of casting of metallic parts.
- explain the solidification macrostructures relevant to the metallic materials, especially cast iron and steel casts,
- define the shrinkage concept in castings and can perform the basic feeder and runner calculations in sand casting processes,
- recognise of the defects in solidified metallic systems and their formation which are originated from the melting practice.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 5, 11 and 12.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 4

1. The subject of the lecture

SAND MOLDING AND CORE MAKING

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

This lecture aims to introduce the basics of foundry sands that are effectively used in sand casting processes more than once. Students will be given information regarding the type of sand and their rules of selection prior to casting process. Properties of sand molds that are used for the compaction of sands can be elaborated from the perspective of its material and durability during the casting of molten metal. The casting or mold sand can have different compositions for different casting temperatures i.e. even for the different cast iron compositions and these sand compositions can sometimes be strictly controlled in order to keep the optimised recipe for the benefit of company. However, the best composition of sand can be crucial for the reuse of it or recycling for the next batch of sand mixing. In order to produce casting sand for the compaction, the send mixture is mixed at a certain ratio of used and unused or fresh sand. Some additions are added to the sand mixture in order to keep the moisture and flowability at a certain value. Sand molding additives are basically clay, coal, dextrin. etc… can be added for many purposes such as firmness of the sand during the transportation of the mould, and also to withstand the heat of cast molten metal without the cracking of the walls of the mould. The resistance to burning or flammability against the heat of molten metal is very important as it determines the reusability of sand for the next batch. Another important aspect of the sand is that permeability of produced gasses forming during the exposure to heat from the molten metal due to the additives mixed with the sand. The additives can generate gasses in contact with the molten metal and these gasses should be allowed to escape in order to prevent the deformation of sand moulds just after casting of molten metal. Hence, the casting temperature and the additive type and ratio play important role in this respect. This lecture also gives the basics of core-making technology and core-making chemistry. Students will be asked to join a discussion on the properties of sand compositions and its effects on the porosity present in the parts.

3. Learning outcomes

Students can

- differentiate the difference between the sand types and the selection of sands according to the casting type,
- express the casting method’s advantages and disadvantages according to the casting sand selection,
- explain the presence of the defects which may be originated from sand molding and core making.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 4 and 15.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 5

1. The subject of the lecture

CAST IRON

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

This lecture aims to introduce classification and types of cast irons that are frequently used for machine parts and mining hardware etc... Cast iron is one of the oldest ferrous metals in commercial use. It is primarily composed of iron (Fe), carbon (C) and silicon (Si), but may also contain traces of sulfur (S), manganese (Mn) and phosphorus (P). It has a relatively high carbon content of 2% to 5%. It is typically brittle and non - malleable (i.e. it cannot be bent, stretched or hammered into shape) and relatively weak in tension. Cast iron members tend to fracture with little prior deformation. As cast irons are relatively inexpensive, easily cast into complex shapes and readily machined, they are an important group of materials. Unfortunately most grades are not weldable and special precautions are normally required even with the so-called weldable grades. Cast iron, however, has excellent compressive strength and is commonly used for structures that require this property. The composition of cast iron, the method of manufacture and heat treatments employed are critical in determining its final characteristics. Typical types of cast iron include: Gray cast iron, Ductile cast iron, White cast iron, Malleable cast iron, Compacted graphite iron and, Alloy cast iron.

Students should be given detailed information regarding the differences between Gray cast iron, Nodular cast iron, compacted graphite cast iron, and White cast iron types based on their macrostructures, microstructures and mechanical properties. The instructor should prepare a list of cast iron types with relevant microstructures and their hardness, tensile strengths and wear resistance in addition to their place of use. Selection procedure of cast iron types according to the service requirements should be emphasized with real examples from industrial applications. Students should be given some information regarding the effect of each alloying element on the final properties and also be given metallographic procedures for the cast iron types and define microstructural constituents with respect to type and cooling rate of cast iron. The formation of each microstructure should be elaborated and defects of cast irons can also be defined with optical images. A discussion should be initiated with regards to the modification of cast iron to improve their certain properties such as surface roughness and coating by various techniques and their limitations.

3. Learning outcomes

Students can:

- differentiate the types of cast iron and can select the correct type for intended application based on their knowledge gained during the course of this study,

- distinguish the micro and macrostructures of cast irons and define the defects relevant to the type of cast iron,

- define the effect of cooling rate and the effect of each alloying elements on the final microstructures and properties.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 16.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

- The topics will be covered in next week’s lecture.

Topics 6

1. The subject of the lecture

MELTING AND CASTING

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

This lecture aims to introduce the principles and properties of different induction furnaces that are extensively used in casting industry to remelt or melt the charge obtained from recycled metals or raw metals. For the sake of simplicity, the subject will be focused on recycled metal charges and their re-melting prior to casting. An induction furnace primarily consists of a crucible, which holds the material to be melted, and a water cooled induction coil placed around the melting crucible and is connected to electrical power supply operated with frequency above the 50 Hz. The frequency range can be classified as low frequency, medium, high and ultra high frequency. Common frequencies used in induction furnaces range from 50 Hz to a few MHz. The frequency of an induction furnace has a significant impact on its heating efficiency. Higher frequencies, such as those above 1 kHz, result in faster and more efficient heating. The copper coil around the crucible is energized with a high-frequency electrical current, which generates a fluctuating magnetic field around the crucible. Then, two options are possible: the crucible is made from a non-conductive material (e.g. ceramics), and the magnetic field induces an electric current in the material within the crucible, which generates heat through resistance. The second option is when the crucible is also made of a conductive material such as graphite. Then both the crucible and feedstock are heated with induction currents. The crucible material needs to be able to withstand high temperatures and prevent contamination of the heated material. The principles of charge preparation for cast iron and steel castings. Students should be given information about the thermal analysis (cooling curve analysis) of the melts in detail as in the case of indusction heating and in conventional way. The melting in furnaces is also done for alloying the melt through special process called inoculation. The inoculation concepts (eutectic cell concept) in cast iron production are freely used to produce special alloys and also cast iron with nodular properties. Spheroidization method for nodular cast iron production is a primary example of this process. Students should be shown examples of induction furnaces from industry and possible dangers that these furnaces pose during pouring and melting.

3. Learning outcomes

The students can able to differentiate the different melting methods especially focused on induction heating and melting. The student can distinguish the different types of induction furnaces with their advantages and disadvantages regarding industrial use and remelting practices such as raw and recycled metals. The students can define dangers which are originated from casting practice thorough using induction furnaces and conventional furnaces.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 3, 16 and 17

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 7

1. The subject of the lecture

CASTING DEFECTS

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

This lecture aims to give an extensive definition of the classification and interpretation of casting defects observed in conventional castings and special casting practices. This lecture should also include defects classification with respect to types of re-melting furnaces and melting furnaces both using raw and recycled materials. A list of defects and their classification with respect to type of furnace, type of casting, casting material should be given to students in order to refresh their knowledge and produce a list that has a reference value for the students for later use. A special emphasis should be given to the definition of defects with images and sources of defects with respect to mostly cast iron and iron based alloys, i.e. ferrous alloys. Another set of casting defect listings should be produced for non ferrous alloy castings for example copper and alloys, aluminium and alloys and also highly alloyed systems i.e. Nickel based alloys or Cobalt based alloys and superalloys. Several defects can be defined such as gas porosity: blowholes, open holes, pinholes; shrinkage defects: shrinkage cavity; mould material defects: cut and washes, swelling, drops, metal penetration, rat tail; pouring metal defects: Cold shut, misrun, slag inclusion and finally metallurgical defects: Hot tears, hot spot. Mechanisms in which the defects form should be documented and explained to students. Chemical homogeneity within recycled charges, unintended and unwanted impurities and external source of contamination can be emphasised when explaining the source of defects. A small portion of defects may be sourced directly into contamination from recycled metallic materials such as rusting on the surface, non ferrous additives or mixing up with non ferrous materials during melting. The main problem with defects is that it usually cannot be eliminated by dissolving and has to be filtered out. This filtering process can also be mentioned within the context of defect elimination during melting and after pouring of molten metal into moulds. Defects can be sourced from mould sand, mould core, solidification process, melt and molten metal, casting process, compositional differences, post operations etc…). Students should be able to define the strategies for the prevention of defect formation sources in foundries.

3. Learning outcomes

The students can differentiate between the various sources of casting defects and their source during melting and solidification, also pouring processes. The student can analyze the relationship between the composition and type of defects and determine if it is internal or externally sourced. Students can define casting defects and proposes proper solutions to correct the casting process.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

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

problem methods - **conversational lecture**

a. Lecture conducted with the use of multimedia.

b. During the lecture, there is a discussion with the students.

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

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

John Campbell. Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques. Butterworth-Heinemann is an imprint of Elsevier ISBN–13: 978-1-85617-809-9

Chapters 7 and 8.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

6.	**Additional notes**

- The topics will be covered in next week's lecture.

Course content – laboratory classes

Topics 1

1. The subject of the laboratory classes

Foundry Sand and Sand Mold Preparation

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

This topic practical class aims to present the relevant information on the sand that are used for the moulding in sand casting process and the preparation of sand mould using classical and conventional tools. This topic of the laboratory classes are related to Foundry sand and its AFS number determination by a sieve analysis and Sand mold preparation. This topic also describes an experiment to determine the AFS grain fineness number of a sand specimen. It provides background on sand composition and properties. The experiment involves sieving a sand sample using 11 standard sieves to determine the weight percentage retained on each sieve. These values are used to calculate the AFS fineness number, which describes average grain size. The AFS Grain Fineness Number (AFS-GFN) is one means of measuring the grain fineness of a sand system. GFN is a measure of the average size of the particles (or grains) in a sand sample. By itself, GFN does not identify if the sand will be a good molding material or produce the qualities needed in a particular metalcasting sand system. Because GFN represents an average fineness, sands with very different grain size distribution may have similar GFN numbers. Sand used for moulding can be classified according to their grain size and grain shape. Shape and size of grains will determine its specific surface which may be defined as the total surface area of grains contained in unit mass. Specific surface area gives rough idea how much binder needs for the sand in the mould. Students will be asked to put their extensive knowledge obtained in the class into the practice and will be also asked to prepare a sand mould with sufficient strength such that it is stiff enough to hold the molten metal and resist the heat after pouring of hot metal. A recipe of sand mixing will be given to the student prior to practical class and revise it with the instructor if necessary. It can also be done with team of 2 or 3 students. Students will learn the testing of the foundry sand for their moisture content and its durability against hydrostatic pressure and also learn how to prepare the casting sand mixture preparation by the help of different machines.

3. Learning outcomes

The student will be able to distinguish the different casting techniques with their advantages and disadvantages by learning the sand preparation and also explain the problems of casting defects by testing the sand quality.

4. Necessary equipment, materials, etc

- Different foundry sand, bentonite, and coal powder.
- Sieves with different openings (Mesh)

- Sieving test machine
- Stereo Microscope
- Weigh
- Mixer
- cope-drag

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

assimilation methods/providing - **reading**,

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

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

b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

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

Classes are held in the following order:

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

Students prepare the final report independently at home.

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

Students should prepare a theoretical introduction to the laboratories. Student should refer to “How to determine AFS grading Or Grain fineness number of the sand“, A. Amir of University of engineering and technology of Lahore, and „Experiment No. 2.1 Sand Control Test: AFS Grain Fineness Number“, by Dhajany Dimphi available in scribd.

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

7. Additional notes

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8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer.

Topics 2

1. The subject of the laboratory classes

Melting and Casting

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

The topics of the laboratory classes are related to Melting and casting metals into sand molds. Students will learn the basics of induction melting practice. Operation of high-frequency induction furnace and melt preparation for the Al-12Si alloy casting, gravity sand mold casting demonstration. The document describes the sand casting process which involves melting aluminum alloy ingots, preparing a sand mold by packing sand around a pattern, and pouring the molten aluminum into the mold cavity. Key steps include heating the aluminum to melting temperature, creating runners and risers in the sand mold, pouring the molten metal, and allowing it to cool before breaking the mold and inspecting the casting. Sand casting has various parts associated in the process. These parts have historical names, and are presented here for completeness and can be found in the appendix for future reference. Typical sand molds, which are often called two part flasks, are used in sand casting process and have upper and lower halves that contain the various parts that are significant in the casting process. It is one of the purposes of this lecture to demonstrate and discuss the sand casting process during the practical lecture through an interaction with students and ask them to realise environmental and global impact of this process, as well. It is also an opportunity to allow students to identify the limitations of the sand casting process. Student will discover how sand cast materials can have defects and small voids that are not visible on the surface and determine how properties of a metal can be altered through processing during the casting through "seeding" and also allowing the cast parts cooled faster or slower. It should be emphasized that safety regulations and procedures are followed during machine operation for melting, mold preparation, and metal pouring. Safety of the student is of the highest concern. <u>When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear jeans and closed toed shoes. Be sure to have a leather apron, face shield and high temperature gloves for the individuals responsible for handing the crucible and pouring of the molten metal.</u>

3. Learning outcomes

The student can distinguish the different casting techniques with their advantages and disadvantages by learning melting and casting, also express the problems of casting defects by cast temperature measurement and charge selection. Students can also describe the procedure for melting and casting via real equipments.

4. Necessary equipment, materials, etc

- High-frequency induction furnace
- Thermocouples
- Al-12 Si alloy
- Personal protection equipment

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. 1 hour: Melting process. Charge preparation; 1 hour: Casting operation.

assimilation methods/providing - **reading**,

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

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

b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

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

Classes are held in the following order:

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

Students prepare the final report independently at home.

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

Notes on "Sand Casting of Metals", by Elizabeth Merten, Department of Materials Science & Engineering University of Washington (https://materialseducation.org/educators/matedu-modules/docs/Sand_Casting.pdf)

Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013

7.	Additional notes

- The topics will be covered in the next week's lectures.

8.	Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer.

Topics 3

1. The subject of the laboratory classes

Core Making

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

The topics of the laboratory classes are related to Core making. Sand cast cores are used in casting to form hollow spaces or internal cavities in castings. They are made separately from molds using various core making processes and materials like sand. There are different types of cores based on materials used and processes employed. Dry sand cores made with binders like resin are baked separately before inserting into molds, while green sand cores are part of the mold. Precise core placement in molds is important to achieve the desired casting design. Cores must withstand molten metal pouring and support themselves during handling. Following topics will be covered in thei practical class: Types of different core-making methods. Core making with CO_2 method (cold method). Core making with Novalac resin with curing at high temperature (hot method). Supplementary operations during core making like coating, finishing operations, and montage of core making will also be covered theoretically. A core is essentially a body of materials which forms components of the mold. It possesses sufficient strength to be handled as an independent unit. Core is an obstruction which when positioned in the mold, naturally does not permit the molten metal to fill up the space occupied by the core. In this way a core produces hollow casting. Core should bear following properties: sufficient strength to support itself and to get handled without breaking, high permeability to let the mould gases escape through the mould walls, smooth surface to ensure a smooth casting, high refractoriness to withstand the action of hot molten metal penetration, high collapsibility in order to assess the free contractor of the solidifying metal, the sand may possess those ingredients which do not generate mold gases (if necessary and possible). When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear jeans and closed toed shoes. Be sure to have a leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..

3. Learning outcomes

The student can distinguish the cores used in sand casting and different core-making methods with their advantages and disadvantages by learning cold and hot core making, also express the problems of casting defects resulting from cores.

4. Necessary equipment, materials, etc

- CO_2, Sodium Silicate, Hexamin, Novalac Resin
- Mixer
- Oven for curing
- core molds

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. 1 hour: cold core making with CO_2 and sodium silicate ; 1 hour: hot core making with Novalak resin and Hexamin with curing in oven.
assimilation methods/providing - **reading**,
a set of practical methods - **laboratory exercise/experiment; observation**

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

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

Students prepare the final report independently at home.

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

Notes on “Sand Casting of Metals”, by Elizabeth Merten, Department of Materials Science & Engineering University of Washington (https://materialseducation.org/educators/matedu-modules/docs/Sand_Casting.pdf)

Laboratory Manual, 18mel38b /18mel48b Foundry, Forging And Welding Lab, Atria University, Department Of Mechanical Engineering, Atria Institute Of Technology, Bengaluru, India

7. Additional notes

- The topics will be covered in the next week’s lectures.

8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer.

Topics 4

1. The subject of the laboratory classes

Solidification

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

The topics of the laboratory classes are related to the cooling curve for pure metals and alloys, the observation of shrinkage concept, Solidification macrostructure observation at different cast sections. This lecture also provides information for a laboratory session on solidification processing in sand casting. Students will experiment the solidification procedure and learn about tools, equipment, materials and processes for sand casting. They will also analyze a case study, discuss mold configuration and properties. The report requirements are specified, including an introduction, materials used, process description, case study analysis, conclusions and references. Process sheets are also included to document mold details and inspection of casted parts. Casting is a manufacturing process by which a liquid material (usually metal and polymers) is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together such as epoxy, concrete, plaster or clay. In a casting process, the material is first heated to completely melt and then poured into a cavity of the mold. As soon as the molten metal is in the mold, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts. Solidification involves a change of phase of the material and differs depending on whether the material is a pure element or an alloy. A pure metal solidifies at a constant temperature, which is its melting point (freezing point). For alloys, the solidification occurs over a temperature range depending upon the composition. The objectives are to illustrate the use of cooling curves to determine alloy compositions and calculate heat transfer of pure tin during solidification. Students will create cooling curves for pure tin, a mystery alloy, and two tin-lead alloys by melting samples and recording temperature over time. Studnets will use the provided phase diagram to identify the mystery alloy and explain dendrite structure formation and differences between pure metal and alloy cooling curves.

When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear jeans and closed toed shoes. Be sure to have a leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..

3. Learning outcomes

The student will be aware of the cooling and solidification differences between pure metals and alloys. The student will be able to learn the reasons for shrinkage and analyze the casting defects and proposes proper solutions to correct the casting process.

4. Necessary equipment, materials, etc

- Pure Tin
- Pb-Sn alloy
- Al-12Si alloy
- Thermocupl with data logger
- İnduction furnace
- Molds

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. 1 hour: Cooling curve determination of pure metal; 1 hour: Cooling curve determination of alloy; 1 hour: Casting and macrostructure investigation of the different thickness cast sections for shrinkage.

assimilation methods/providing - **reading**,

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

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

b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

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

Classes are held in the following order:

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

Students prepare the final report independently at home.

6.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**
	Metal Casting Principles and Techniques, First Edition, American Foundry Society, Editor: Ian Kay, 2013 Lecture notes on Casting and Soldification processes, IE 337: Materials and Manufacturing Processes
7.	**Additional notes**
	- The topics will be covered in the next two week lectures.
8.	**Optional information**
	- If any health problems (allergy, inhalation health problem) please inform the lecturer.

Topics 5

1. The subject of the laboratory classes

Metallography of Cast Iron

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

The topics of the laboratory classes are related to Metallographic sample preparation and analysis (including mechanical properties) of different cast iron types. Introduction of ASTM, ISO, EN, and DIN norms for the microstructure the cast iron. This lecture presents the production and properties of various types of cast iron thorugh its macro and microstructures. It explains that cast iron contains 2.5-4% carbon and 1-3% silicon, which causes graphite to form in different shapes depending on the cooling rate. Grey iron has flake graphite and is used for machine bases and engine blocks. Ductile iron has spherical graphite nodules and is stronger/more ductile than grey iron. Compacted graphite iron controls graphite formation for improved properties. Austempered ductile iron is quenched and held at 250-400°C to form a high strength microstructure used in wear parts. Metallography is important for quality control and determining graphite morphology. The difficulty in the metallographic preparation is to retain the true shape and size of the graphite in its flake, nodular or tempered form. During grinding the matrix is smeared over

the graphite and unless it is followed by a very thorough diamond polish, the graphite is not shown in its true form. Cast irons with a soft ferritic matrix especiallu tend to easily smear and they are also prone to the deformation and the scratching during handling and polishing. Plane grinding with silicon carbide paper is highly recommended for all types, followed by fine grinding and polishing with diamond solutions of different particle sizes. Various metallographic applications will be advised to the students starting from etchants and selective etching compounds, too. Students should be advised on how to clear the effect of ethcing with regards to graphite errosion and cast porosity.

<u>When this experiment is carried out, prepare students beforehand. Proper safety attire should always be required. Students should be advised to wear jeans and closed toed shoes. Be sure to have a leather apron, face shield and gloves. Any student who has allergy to dust should come forward to be excused from the lecture of he or she will be given proper prevention measures such as face masks etc..</u>

3. Learning outcomes

The student will be able to distinguish the different cast irons and select appropriate grinding materials and polishing solution for the best outcome as microstructure. Students can analyze the constituents of macro and microstructures of typical cast irons and comment on the type of cast iron through features of intragrains.

4. Necessary equipment, materials, etc

- Metallographic sample preparation
- Optical Microscope
- Cast Iron samples with different class

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions. 1 hour: Introduction to related material standards; 1 hour: Metallographic sample preparation (from cutting to etching); 1 hour: Microstructure investigation with the microscope; 1 hour: Discussion on the observation on the basis of standards.

assimilation methods/providing - **reading**,

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

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

b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

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

Classes are held in the following order:

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

Students prepare the final report independently at home.

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

Students should prepare a theoretical introduction to the laboratories.

Janina M. Radzikowska, Metallography and Microstructures of Cast Iron, ASM International Handbook of metallography and microstructures, G. F. Vander Voort, Volume 9, 2004

Metallographic preparation of cast iron, Struers application notes, 05.06 / 62140306

MATERIALS SCIENCE MASTERS

Co-funded by the European Union

7. Additional notes

- The topics will be covered in the next three weeks lectures.

8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer.

Topics 6

1. The subject of the laboratory classes

Casting Defects

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

The topics of the laboratory classes are related to the Observation of casting defects. Defects originated from sand, mold making, models, casting practice, metal composition, melting practice, core and core making, solidification and finishing operations. Metal casting in foundries is a complex process. Testing methods are in place to help inspect castings for quality assurance. These inspection methods help identify potential casting defects. Like other manufacturing processes, casting is vulnerable to several types of defects, whether it's sand casting or lost-wax casting. Defects in casting represent unwanted abnormality in the metal casting manufacturing process. The different types of defects include surface defects, inclusion defects, molding and pouring defects, and cooling defects. Some casting defects like a very rough surface are visible to the unassisted eye. There will also be an inspection through ultrasound detection of parts. Several types of defects may occur in castings, considerably reducing the total output of castings besides increasing the cost of their production. Defective castings offer an ever present problem to the foundry industry. A defect may be the result of a single clearly defined cause or of a combination of factors. It is therefore essential to understand defects and the causes behind these defects so that they may be minimized or eliminated. The common types of defects found in castings, their causes and remedies are to be given during the practical lecture. Dimensional tolerance or surface finish problems can often be seen with visual inspection and measurement. In order to detect the defects, various tests, for example, tensile testing for mechanical properties can be done or even impact toughness at room temperature can also be indicative of the voids and defects in cast iron parts. Some of the other problems, like porosity and shrinkage cavities, are internal to the casting. A classification can be made as; types of defects based on location: External and Internal defects; defects based on type or geometry: Geometric Integrity; based on Size / Severity: Small, Minor, Large and major; based on casting rocess: Moulding related void filling and related solidification related problems. Students will be asked to define the casting defects in real samples and make an analsysis regarding the source and prevention, too.

3. Learning outcomes

The student will be able to analyze the casting defects and proposes proper solutions to prevent the formation of such defects. Students can differentiate between the defects formed externally and internally through the analysis of its shape and location. Students can visually recognise the defects and suggest a series of preventive measures to avoid it in the casting procedure.

4. Necessary equipment, materials, etc

- Samples with different casting defects
- Presentation

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

During laboratory classes, students work in a group (in some experiments individually), sharing tasks and working together to establish a work plan, analyze the results and draw conclusions.

assimilation methods/providing - **reading**,

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

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

b. During laboratory classes, students independently plan the course of the experiment and perform it on their own.

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

Classes are held in the following order:

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

Students prepare the final report independently at home.

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

Janina M. Radzikowska, Metallography and Microstructures of Cast Iron, ASM International Handbook of metallography and microstructures, G. F. Vander Voort, Volume 9, 2004

lesson 5 casting process: casting defects, https://msvs-dei.vlabs.ac.in/mem103/Unit3lesson5.html

7. Additional notes

8. Optional information

- If any health problems (allergy, inhalation health problem) please inform the lecturer.

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

TESTING STANDARDS AND QUALITY ASSURANCE

Code: TSQA

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

DEFINITION OF QUALITY ASSURANCE AND STANDARDIZATION

2. Thematic scope of the lecture

Quality control and standards are fundamental pillars of industry, serving as the backbone for ensuring product reliability, safety, and customer satisfaction across multiple sectors. The implementation of rigorous quality control measures, along with adherence to established standards, is paramount to maintaining the integrity of manufacturing processes and the excellence of final products. Quality control involves a series of systematic procedures designed to measure and regulate the quality of products and processes. It includes regular inspection, testing, and validation activities designed to identify and correct defects, prevent quality losses, and ensure that products meet or exceed customer expectations and regulatory requirements.

Standards, on the other hand, are established by recognized bodies and provide a framework of specifications, guidelines, and characteristics for products, services, and processes. They help establish performance benchmarks and safety criteria, facilitate interoperability between products, and promote technological innovation and efficiency. Standards cover a wide range of issues, including material properties, manufacturing processes, test methods, and environmental considerations, ensuring consistency and compatibility in the global marketplace.

The importance of quality control and standards in the industry cannot be overstated. They are critical to building trust between manufacturers and consumers, as adherence to recognized standards assures customers of the quality and safety of products. In highly regulated industries such as aerospace, automotive, healthcare, and construction, adherence to standards is not only a matter of quality, but also a legal and ethical obligation, with non-compliance resulting in significant legal liability and reputational damage.

In addition, quality control and standards drive competitiveness and innovation within industries. By setting high benchmarks for performance and quality, they push companies to continuously improve their products and processes, fostering innovation and efficiency. This dynamic environment encourages the development of new technologies, materials and manufacturing techniques, contributing to economic growth and technological progress.

In the context of globalization, standards facilitate international trade by ensuring that products manufactured in one country can meet regulatory requirements and customer expectations in another, thereby reducing barriers to entry and expanding market access for businesses. Quality control and standards also play a critical role in addressing sustainability and environmental challenges by including criteria for energy efficiency, waste reduction, and the use of environmentally friendly materials, thereby promoting sustainable practices across industries. In this course, quality control and standards will be mentioned and their importance in the industry will be discussed.

3. Learning outcomes

Students can explain the history of quality control and standards; demonstrate the purposes of standardization in experimental design; show the benefits of standardization in many sectors and industrial applications; explain standard and their classification and types with respect to industry

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://apps.cce.csus.edu/sites/arb/pqao/docs/mod2_pres/2_Where_Did_All_This_QC_Stuff_Come.pdf

6. Additional notes

Topics 2

1. The subject of the lecture

ASTM E8/E8M-21 STANDARD TEST METHODS FOR TENSION TESTING OF METALLIC MATERIALS

2. Thematic scope of the lecture

Tensile testing of metals is an indispensable technique in materials science and engineering, providing critical insight into the mechanical behavior and properties of metal specimens under uniaxial tensile stress. This test method is critical for determining fundamental material properties such as yield strength, tensile strength, elongation, and Young's modulus. These properties are essential for material selection, design considerations, and quality control in manufacturing processes. By applying a controlled tensile force to a metal specimen until failure, tensile testing reveals how the material will behave under real-world loading conditions, helping engineers predict how materials will perform in their intended applications, whether in construction, automotive, aerospace, or other industries requiring materials with specific strength and ductility characteristics. Conducting tensile tests according to established standards, such as those developed by ASTM International or the International Organization for Standardization (ISO), is fundamental to ensuring the reliability, repeatability, and comparability of test results. Standardized test procedures specify the dimensions of the test specimen, the rate at which the test is performed, and the manner in which data is collected and reported. This standardization is critical to reducing variables that can affect test results, allowing materials scientists and engineers to make accurate comparisons between different materials or between different batches of the same material. In addition, adherence to these standards ensures that materials meet regulatory requirements and industry specifications, thereby assuring the quality and performance of end products. In essence, tensile testing to a standard is essential to provide a consistent and objective evaluation of the mechanical properties of a metal. This process underpins the development, certification and use of metals in various sectors, ensuring that materials used in critical applications are both safe and effective for their intended use, protecting investments, reputations and, most importantly, lives. In this course, the subject will be introduced by explaining the tensile test for metal materials and the ASTM E8/E8M-21 Standard Test Method will be introduced within the subject.

3. Learning outcomes

Students can explain why tensile testing standards should be employed when performing materials characterization through tensile tests; perform standard tensile tests according to ASTM E8/E8M-21 Standard; analyse and interpret the data obtained as a result of tensile tests.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E8/E8M-21 Standard Test Methods for Tension Testing of Metallic Materials

6. Additional notes

Topics 3

1. The subject of the lecture

ASTM D3039/D3039M-08 STANDARD TEST METHOD FOR TENSILE PROPERTIES OF POLYMER MATRIX COMPOSITE MATERIALS

2. Thematic scope of the lecture

Tensile testing of polymers is critical to understanding the mechanical behavior of the material and ensuring its suitability for specific applications. Polymers, with their wide range of properties and applications-from packaging materials to aerospace components-require rigorous evaluation to determine their tensile strength, elongation at break, and Young's modulus. These properties are critical to predicting how a polymer will perform under load, and determine its ability to withstand stretching, bending, or compression forces without failure. The importance of tensile testing of polymers also extends to quality control, materials development, and research, allowing manufacturers to optimize formulations, processes, and applications to meet desired specifications and performance criteria.

Conducting tensile tests according to recognized standards, such as those established by ASTM International or ISO, is essential to ensure the accuracy, repeatability, and reliability of test results. Standards provide detailed guidelines for specimen preparation, test conditions, and data analysis that are critical to minimizing variability and ensuring comparability of results between different studies or production batches. For example, the geometry of the specimen, the speed of the testing machine, and the environmental conditions can all significantly affect the behavior of the material under load. By following standardized procedures, engineers and scientists can confidently evaluate and compare the tensile properties of polymers, facilitating global trade and collaboration. In addition, standardized tensile testing supports regulatory compliance and safety assurance - critical issues in industries such as medical devices, automotive, and construction, where material failure can have serious consequences. It enables manufacturers to demonstrate that their products meet the required safety and performance standards, thereby building trust with consumers and regulators. In summary, tensile testing of polymers to established standards is essential to characterize material properties, drive innovation, ensure product quality, and ensure end-user safety, underscoring its integral role in the life cycle of polymer-based products. In this course, the subject will be introduced by explaining the tensile test for polymer and polymer composite materials and the ASTM D3039/D3039M-08 Standard Test Method will be introduced within the subject.

3. Learning outcomes

Students can establish why tensile test is important for polymer composite and what is differences from metal materials; discover how to perform tensile tests for polymer composite materials according to ASTM D3039/D3039M-08 Standard; analyze and interpret the data obtained as a result of tensile tests for polymer composites.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM D3039/D3039M-08 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

6. Additional notes

Topics 4

1. The subject of the lecture

ASTM E9-19 STANDARD TEST METHODS OF COMPRESSION TESTING OF METALLIC MATERIALS AT ROOM TEMPERATURE

2. Thematic scope of the lecture

ASTM E9-19, Standard Test Methods for Compression Testing of Metallic Materials at Room Temperature, serves as an important guideline for evaluating the compressive properties of metallic materials. This standard outlines the procedures for conducting compression tests on metallic specimens to determine their behavior under compressive forces, providing important data on yield strength, deformation, and modulus of elasticity. The importance of ASTM E9-19 lies in its comprehensive approach to ensuring consistency, accuracy, and reliability in compression testing in various industries, including aerospace, automotive, and construction. By specifying specimen dimensions, test rate, and load application method, ASTM E9-19 aims to minimize variables that could affect the integrity of test results. This standard ensures that tests are performed under controlled conditions, making the results comparable and reproducible. Adoption of ASTM E9-19 for compression testing is essential for material selection, design engineering, and quality control processes. It enables manufacturers and engineers to evaluate the mechanical properties of materials and their suitability for specific applications, especially when materials are subjected to compressive loads in service. This standard not only facilitates the development of new materials and products, but also assists in the improvement of existing products by providing a benchmark for evaluating material performance. In addition, compliance with ASTM E9-19 is critical to meeting regulatory requirements and industry specifications to ensure that products are safe, reliable, and of high quality. The role of the standard extends beyond the technical aspects of testing; it also contributes to consumer confidence and market acceptance of products by assuring that the materials used have been rigorously tested and meet established criteria. In summary, ASTM E9-19 is an essential tool in the field of materials science, providing a standardized method for pressure testing that supports the innovation, safety, and performance of metallic materials in a wide variety of applications.In this course, the subject will be introduced by explaining the compression test for metal materials and the ASTM E9-19 Standard Test Method will be introduced within the subject.

3. Learning outcomes

Students can discover why they should use standards when performing compression tests; comprehend the importance of compression test and perform compression tests according to ASTM E9-19 Standard; analyze to interpret the data obtained as a result of compression tests for metallic materials.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E9-19 Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature

6. Additional notes

Topics 5

1. The subject of the lecture

ASTM D695-15 STANDARD TEST METHOD FOR COMPRESSIVE PROPERTIES OF RIGID PLASTICS

2. Thematic scope of the lecture

ASTM D695-15, Standard Test Method for Compressive Properties of Rigid Plastics, is an essential protocol that provides a systematic approach for determining the compressive strength, modulus, and deformation of rigid plastic materials. This standard is critical for manufacturers, engineers, and researchers involved in the development and application of rigid plastics in a variety of industries, including automotive, construction, and packaging. By specifying the procedures for specimen preparation, setting the speed of the testing machine, and defining the criteria for measuring compression properties, ASTM D695-15 ensures that test results are consistent, reliable, and comparable across different test environments and material batches. The importance of this standard lies in its ability to provide a consistent methodology for evaluating the mechanical behavior of rigid plastics under compressive loads, thereby providing valuable insight into their suitability for specific applications and their expected performance under service conditions. Compliance with ASTM D695-15 is essential for quality control processes, allowing manufacturers to verify that their products meet required specifications and performance criteria. It also plays a key role in material selection and design processes, where understanding the compressive properties of materials is critical to ensuring the structural integrity and durability of end products. In addition, this standard facilitates innovation in materials science by providing a benchmark for comparing the performance of new plastic formulations against established materials. In summary, ASTM D695-15 is a cornerstone in the field of materials testing, providing a comprehensive and standardized approach to evaluating the compressive properties of rigid plastics that is fundamental to advancing the development, application, and quality assurance of plastic materials in various industries. In this course, the subject will be introduced by explaining the compression test for rigid plastic materials and the ASTM D695-15 Standard Test Method will be introduced within the subject.

3. Learning outcomes

Students can explain the reason why they should use standards when performing compression tests for plastics; discover how to perform compression tests according to ASTM D695-15 Standard; establish to interpret the data obtained as a result of compression tests for rigid plastic materials.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM D695-15 Standard Test Method for Compressive Properties of Rigid Plastics

6. Additional notes

Topics 6

1. The subject of the lecture

ASTM E290-14 - STANDARD TEST METHODS FOR BEND TESTING OF MATERIAL FOR DUCTILITY

2. Thematic scope of the lecture

ASTM E290-14, Standard Test Methods for Bend Testing of Material for Ductility, plays a critical role in materials engineering and manufacturing by providing a standardized approach to evaluating the ductility of materials through bend testing. This standard outlines the procedures for conducting flexure tests on metallic specimens in which the materials are bent to a specified degree without fracture. Such tests are essential for evaluating the ability of a material to resist plastic deformation under flexural stress, thereby providing information on its ductility, flexibility, and toughness. The standard specifies the dimensions of the specimens, the manner in which the force is applied (e.g., three-point bending or guided bending), and the criteria for evaluating the results, including the angle of bend and the presence of surface cracks or defects after testing. Adherence to ASTM E290-14 is critical for industries where materials are expected to perform under conditions that may cause bending or flexing, such as construction, automotive, aerospace, and pipeline applications. By ensuring a consistent methodology for flexure testing, ASTM E290-14 enables manufacturers and engineers to compare materials and select those best suited for their specific needs based on their flexural properties and overall ductility. In addition, this standard aids in quality control processes by identifying and eliminating materials that do not meet required ductility standards, thereby preventing potential failures in service. In addition, ASTM E290-14 supports materials development and research by providing a benchmark for evaluating new alloys and treatments designed to improve ductility. Adherence to this standard assures stakeholders of the reliability and safety of the material, thereby promoting confidence in the use of these materials for critical applications. In summary, ASTM E290-14 is essential for ensuring the high performance and durability of materials through rigorous ductility testing, underscoring its importance in the advancement and quality assurance of materials engineering practices. In this course, the application of the bending test to determine the bending strength of materials according to ASTM standards will be discussed.

3. Learning outcomes

Students can determine the bending test types based on the requirements from the specimens; explain the need for bending tests and theoretical basis; perform the bending test should be applied according to ASTM E290-14 – Standard; analyze and interpret the results with data obtained from testing machine.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E290-14 - Standard Test Methods for Bend Testing of Material for Ductility

6. Additional notes

Topics 7

1. The subject of the lecture

ASTM D790-17 STANDARD TEST METHODS FOR FLEXURAL PROPERTIES OF UNREINFORCED AND REINFORCED PLASTICS AND ELECTRICAL INSULATING MATERIALS

2. Thematic scope of the lecture

ASTM D790-17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, is a meticulously designed protocol that serves as a cornerstone in the field of materials science, particularly for evaluating the flexural strength and flexibility of plastic materials. This standard provides a comprehensive framework for evaluating the flexural behavior of both unreinforced and reinforced plastics and electrical insulation materials, providing insight into their mechanical performance and applicability in a wide range of industrial and commercial applications. The test methods outlined in ASTM D790-17 involve subjecting a specimen to a three-point or four-point flexure load to measure properties such as flexural strength, flexural modulus, and stress at a given strain, among others. These properties are critical to understanding how materials will perform in applications that require flexure or support during their service life. The importance of adhering to ASTM D790-17 lies in its ability to ensure consistency, accuracy, and repeatability in flexure testing in laboratories and manufacturing facilities worldwide. By standardizing specimen dimensions, loading rates, and failure criteria, this standard makes it easier to compare materials and validate material specifications for quality control purposes. For manufacturers and engineers, the data derived from these tests is essential for material selection, product development, and verification of compliance with performance and safety standards. For example, in industries such as automotive, aerospace, construction, and electronics, where materials are often subjected to flexural stress, understanding flexural properties ensures that the materials selected will withstand operational demands without failure. In addition, ASTM D790-17 plays a key role in promoting innovation in materials technology. By providing a clear benchmark for flexural performance, it encourages the development of new plastics and composites that offer improved strength, durability, and weight savings without compromising flexibility or electrical insulation properties. This standard also supports environmental sustainability efforts by facilitating the testing of bio-based and recycled plastics, helping to advance the use of sustainable materials in various industries. In essence, ASTM D790-17 is more than just a set of test methods; it is an essential tool for ensuring the structural integrity and reliability of plastics and electrical insulation materials used in a wide variety of applications. Its widespread adoption underscores its importance in maintaining quality, driving materials innovation, and ensuring the safety and performance of products in the global marketplace. In this course, students will learn how to determine the bending strength of reinforced and unreinforced plastics according to ASTM D790-17 Standard standards and how to interpret the results.

3. Learning outcomes

Students can determine how the bending test should be applied according to ASTM D790-17 Standard; analyze the requirements for test specimens for plastic materials with and without reinforcement and insulating materials; explain why the testing procedures are needed for plastics with and without reinforcement; analyze and interpret the results based on theoretical basis.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM D790-17 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

6. Additional notes

Topics 8

1. The subject of the lecture

ASTM E23-18 STANDARD TEST METHODS FOR NOTCHED BAR IMPACT TESTING OF METALLIC MATERIALS

2. Thematic scope of the lecture

ASTM E23-18, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, represents a critical methodology in the field of materials science, particularly for evaluating the toughness and fracture resistance of metals under sudden loading conditions. This standard describes the procedures for performing Charpy and Izod impact tests in which a notched specimen is struck with a pendulum hammer and the energy absorbed by the specimen during fracture is measured. The inclusion of a notch is intended to simulate a point of stress concentration, thereby providing insight into how the material would behave in the presence of flaws or imperfections under real-world conditions. The energy absorbed is a direct indicator of the toughness of the material, providing valuable data for comparing the relative brittleness or ductility of different materials, or the effects of heat treatments and other processes on material properties. Adherence to ASTM E23-18 is critical in several industries, including aerospace, automotive, and construction, where materials are expected to perform reliably in dynamic and potentially harsh environments. By establishing consistent test conditions-such as specimen dimensions, notch geometry, and test temperature-this standard ensures that impact test results are comparable and reproducible, facilitating material selection and design decisions based on quantifiable measures of toughness. In addition, ASTM E23-18 helps identify materials that may be susceptible to brittle fracture, a critical consideration in applications where failure could be catastrophic. In addition, the impact test methods described in ASTM E23-18 are critical to research and development efforts aimed at improving the fracture resistance of metallic materials. Through systematic testing, researchers can evaluate the effectiveness of new alloys, treatments, and manufacturing processes in improving material toughness, thereby driving technological advances and innovation in materials engineering. Adherence to this standard also supports quality assurance processes by ensuring that materials meet required specifications for safety, performance, and durability. Essentially, ASTM E23-18 is essential for ensuring the structural integrity and reliability of metallic materials under impact loading. Its rigorous approach to notched bar impact testing provides a foundation for understanding material behavior under demanding conditions, thereby informing engineering design, promoting materials innovation, and ensuring the safety and functionality of critical components in a wide range of applications. This course explains how to perform and interpret the notch impact test of metallic materials according to the ASTM E23-18 standard.

3. Learning outcomes

Students can perform the notch impact experiment according to ASTM E23-18; analyze and interpret the results from test specimens; explain why impact testing is needed for specimens working in different environments for metallic materials; describe the procedures and notch making process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E23-18 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

6. Additional notes

Topics 9

1. The subject of the lecture

ASTM D6110-18 STANDARD TEST METHOD FOR DETERMINING THE CHARPY IMPACT RESISTANCE OF NOTCHED SPECIMENS OF PLASTICS

2. Thematic scope of the lecture

ASTM D6110-18, Standard Test Method for Determining Charpy Impact Resistance of Notched Specimens of Plastics, is an important protocol that quantifies the toughness of plastic materials by measuring their ability to withstand impact forces. This standard outlines a precise methodology for conducting Charpy impact tests on notched plastic specimens, providing a critical assessment of the material's resistance to sudden loading and its ability to absorb energy before fracture. The notched design of the specimens introduces a stress concentration point that mimics real-world conditions where flaws or discontinuities may exist, making this test particularly relevant for evaluating material performance in real-world applications. The importance of ASTM D6110-18 lies in its usefulness in a variety of industries where plastics are used, from automotive and aerospace components to consumer goods and packaging. By specifying specimen dimensions, notch angle and depth, and test conditions, this standard ensures that the impact resistance of plastics can be reliably and consistently measured. Such standardized testing allows manufacturers, engineers and designers to compare different materials and make informed decisions based on quantifiable measures of toughness and durability. Compliance with ASTM D6110-18 is critical to the material selection process, especially in applications where impact resistance is a critical property. It assists in the development of new plastic formulations and the improvement of existing materials to ensure they meet required safety, quality, and performance standards. In addition, this test method supports quality control and regulatory compliance by providing a benchmark for manufacturers to verify that their products are capable of performing under expected service conditions.

In summary, ASTM D6110-18 plays an indispensable role in the plastics industry by providing a standardized approach to evaluating the Charpy impact strength of plastics. Its widespread adoption underscores the importance of understanding and optimizing the impact resistance of plastic materials, contributing to the development of safer, more reliable, and higher performing products in a variety of applications. This course explains how to perform and interpret the Charpy impact test of plastic materials according to the ASTM D6110-18 standard.

3. Learning outcomes

Students can perform the Charpy impact test of plastic materials according to ASTM D6110-18 Standard; analyze and interpret the results from test specimens based on theoretical principles; explain why impact testing is needed for specimens working in different environments for plastic materials; describe the procedures and notch making process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM D6110-18 Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics

6. Additional notes

Topics 10

1. The subject of the lecture

ASTM D3846-08 STANDARD TEST METHOD FOR IN-PLANE SHEAR STRENGTH OF REINFORCED PLASTICS

2. Thematic scope of the lecture

ASTM D3846-08, Standard Test Method for In-Plane Shear Strength of Reinforced Plastics, is an important specification for evaluating the shear strength of composite materials, particularly those reinforced with high-strength fibers. This standard provides a systematic approach for determining in-plane shear strength by applying a compressive load to a notched specimen, a method that simulates real-world stresses and strains experienced by composites in various applications. The notches are introduced into the specimen to create a uniform stress field, facilitating the accurate measurement of shear strength, which is critical to evaluating the structural integrity and performance of the material under shear loading. The importance of ASTM D3846-08 extends to all industries that use reinforced plastics, including aerospace, automotive, and construction, providing a reliable metric for material selection, quality control, and design optimization. By specifying specimen dimensions, load application method, and failure criteria, this standard ensures that the shear strength of reinforced plastics can be consistently and accurately evaluated, allowing for meaningful comparisons between different materials and manufacturing processes. Compliance with ASTM D3846-08 is essential for manufacturers and engineers who want to design products that meet the highest standards of safety, durability, and performance. It enables the identification of materials with superior shear strength properties suitable for applications where materials are subjected to complex loading scenarios. In addition, this standard supports research and development efforts to improve the mechanical properties of reinforced plastics, driving innovation in materials science and engineering. In essence, ASTM D3846-08 is essential for ensuring the reliability and safety of reinforced plastic materials through the accurate measurement of in-plane shear strength, thereby supporting the advancement of technology and materials excellence in various sectors.This course explains how to determine in-plane shear strength of reinforced plastics according to the ASTM D3846-08 standard.

3. Learning outcomes

Students can perform the in plane shear test for reinforced plastic materials according to ASTM D3846-08 Standard; analyze and interpret the results from test specimens based on theoretical principles; explain why impact testing is needed for specimens working in different environments for reinforced plastic materials; describe the testing procedures and specimen preparation process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM D3846-08 Standard Test Method for In-Plane Shear Strength of Reinforced Plastics

6. Additional notes

Topics 11

1. The subject of the lecture

ASTM E10 – STANDARD TEST METHOD FOR DETERMINING BRINELL HARDNESS OF METALLIC MATERIALS

2. Thematic scope of the lecture

ASTM E10, Standard Test Method for Determining Brinell Hardness of Metallic Materials, is a fundamental document that outlines the procedure for measuring the hardness of metals using the Brinell hardness test. This method involves indenting the metal surface with a hardened steel or carbide ball under a specified load and then measuring the diameter of the impression left on the material. The Brinell Hardness Number (BHN) is calculated from the load applied and the area of the indentation, providing a quantifiable measure of the material's resistance to deformation or penetration. The importance of ASTM E10 lies in its wide applicability to various industries, including manufacturing, construction, and metallurgy, where understanding the hardness of a material is critical to determining its suitability for specific applications and its wear resistance properties. ASTM E10 ensures that Brinell hardness testing is performed consistently and accurately, providing a reliable means of comparing the hardness of different metallic materials. By standardizing indenter size, applied load, and other test parameters, ASTM E10 facilitates reproducibility of results across laboratories and test facilities. This standard not only aids in material selection and quality control, but also supports the development of new alloys and heat treatment processes by providing a benchmark for evaluating the effects of such treatments on material hardness.

In addition, compliance with ASTM E10 is essential to ensuring that metallic products meet required performance and durability specifications. It provides manufacturers, engineers, and quality assurance teams with a critical tool for evaluating material properties, thereby enhancing the safety, reliability, and longevity of metal components and structures. In summary, ASTM E10 plays an indispensable role in the field of materials science by providing a standardized approach to determining the Brinell hardness of metallic materials, which is essential to advancing technology, improving product quality, and fostering innovation in materials development and application. This lecture will focus on to determine brinell hardness of metallic materials according to ASTM E1O and comment to results.

3. Learning outcomes

Students can determine the brinell hardness of metallic materials based on the principles of hardness measurements; perform the hardness test for ceramic, plastic and metallic materials according to ASTM E10 Standard; analyze and interpret the results from test specimens based on theoretical principles; explain why hardness testing is needed for specimens working in different environments for various materials; describe the testing procedures and specimen preparation process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E10 – Standard Test Method for Determining Brinell Hardness of Metallic Materials

6. Additional notes

Topics 12

1. The subject of the lecture

ASTM E18 – STANDARD TEST METHOD FOR DETERMINING ROCKWELL HARDNESS OF METALLIC MATERIALS

2. Thematic scope of the lecture

ASTM E18, Standard Test Method for Determining Rockwell Hardness of Metallic Materials, is a basic protocol that provides guidelines for measuring the hardness of metals using the Rockwell hardness test. In this test method, a specified initial load is applied followed by a large load to create an indentation in the surface of the material. The depth of this indentation, which correlates with the material's resistance to penetration, is used to calculate the Rockwell hardness number (HR). ASTM E18 is of paramount importance in several industries, including manufacturing, aerospace, automotive, and construction, where the hardness of metallic materials is a critical property that affects their performance, wear resistance, and suitability for various applications.

The strength of ASTM E18 lies in its ability to ensure standardized, accurate, and repeatable hardness measurements for metallic materials. By specifying the indenter type, load values, and test procedures, this standard facilitates consistent testing across laboratories and manufacturing facilities, allowing for meaningful comparisons between materials and quality control processes. This uniformity is essential for material selection, where hardness is a key criterion in determining the suitability of a metal for specific applications. It also helps engineers and metallurgists evaluate the effects of heat treatments, alloy compositions, and processing methods on material hardness. Compliance with ASTM E18 is essential to ensure that metallic products meet required hardness specifications and standards. This standard provides manufacturers and quality assurance teams with a standardized approach to evaluating material hardness, which is critical to product reliability and durability. By following this protocol, industries can improve the safety and performance of their components and structures, ultimately resulting in improved product quality and longevity. In summary, ASTM E18 plays an indispensable role in the field of materials science and engineering by providing a standardized method for determining the Rockwell hardness of metallic materials. Its widespread use underscores its importance in quality control, materials research, and materials selection for a wide range of applications, contributing to the advancement of technology and the improvement of product performance and reliability. This lecture will focus on to determine rockwell hardness of metallic materials according to ASTM E18 and comment to results.

3. Learning outcomes

Students can determine the Rockwell hardness of metallic materials based on the principles of hardness measurements; perform the hardness test for ceramic, plastic and metallic materials according to ASTM E18 Standard; analyze and interpret the results from test specimens based on theoretical principles; explain why hardness testing is needed for specimens working in different environments for various materials; describe the testing procedures and specimen preparation process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E18 – Standard Test Method for Determining Rockwell Hardness of Metallic Materials

6. Additional notes

Topics 13

1. The subject of the lecture

ASTM E92-17 STANDARD TEST METHODS FOR VICKERS HARDNESS AND KNOOP HARDNESS OF METALLIC MATERIALS AND ASTM D2240-15 STANDARD TEST METHOD FOR RUBBER

2. Thematic scope of the lecture

ASTM E92-17, Standard Test Methods for Vickers and Knoop Hardness of Metallic Materials, serves as an important set of guidelines for evaluating the hardness of metals using the Vickers and Knoop hardness tests. These methods involve pressing a diamond indenter into the surface of the material under a specified load, measuring the resulting indentation, and calculating the hardness based on the geometry of the indentation. The Vickers hardness test uses a square-based diamond pyramid indenter, while the Knoop hardness test uses a rhomboid-based diamond indenter. These tests are essential in industries such as manufacturing, metallurgy, and aerospace, where understanding the hardness of a material is critical to assessing its suitability for specific applications, wear resistance, and the effects of heat treatments. ASTM E92-17 ensures that Vickers and Knoop hardness tests are performed consistently and accurately, allowing reliable comparisons to be made between different metallic materials. By specifying test conditions, including indenter geometry, load values, and measurement procedures, this standard supports the reproducibility of results across laboratories and manufacturing facilities. Uniformity in test procedures is essential for quality control and material selection, as hardness is a key factor in determining material performance and durability. Researchers and metallurgists can use this standard to evaluate the effects of alloy compositions, heat treatments, and processing methods on material hardness, contributing to the advancement of materials science and engineering. ASTM D2240-15, Standard Test Method for Rubber Property-Durometer Hardness, is an important standard in the field of rubber testing, providing an accurate and standardized approach to measuring the hardness of rubber materials. Durometer hardness is a key mechanical property of rubber that defines its resistance to indentation or penetration by a specified indenter at a specified force. This test method is widely used in a variety of industries, including automotive, manufacturing, and consumer goods, where rubber components play a critical role in product performance. ASTM D2240-15 describes the procedures for performing durometer hardness tests, including the selection of the appropriate durometer type (Shore A, Shore D, etc.), the preparation of test specimens, and the calculation of hardness values. Adherence to this standard is essential for quality control, allowing manufacturers to ensure that rubber products meet the required hardness specifications, which is critical for proper performance and durability.

3. Learning outcomes

Students can determine the Vickers and Knoop hardness of metallic materials based on the principles of hardness measurements; perform the hardness test for ceramic, plastic and metallic materials according to ASTM E92-17 Standard; analyze and interpret the results from test specimens based on theoretical principles; explain why hardness testing is needed for specimens working in different environments for various materials; describe the testing procedures and specimen preparation process prior to testing.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASTM E92-17 Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials

6. Additional notes

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

NUMERICAL AND APPLIED METHODS IN MATERIALS CHARACTERIZATION

Code: NAMMC

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Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO QUANTITATIVE ANALYSIS IN METALLOGRAPHY

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

This topic aims to introduce the overview of systematic errors encountered during the evaluation of microstructural constituents and sampling processes in many material systems such as alloy and ceramic, including composite systems. This topic also aims to give basic definitions and terms of microscopy, types of microstructures, and an overview of the microstructural development in various metallurgical processes such as heat treatment, welding and deformation processes. Students should be content with the need for evaluation of microstructures which is well founded in industry due to the standardisation and quality control procedures in place for the better selection of raw materials or intermediate products for manufacturing final products. The metallographic procedures will also be provided to students in general for both ceramic and metal based specimens in order to refresh the knowledge gained previously. Certain morphology or microstructure revealing/etching procedures employed during metallographic processes of specimens such as the depth of etching prior to microscopy are important intermediate stages that affect the quality of final optical images. The importance of this stage Sampling principles of materials that are clearly an initial step in quality control and reliable calculation of properties or correlation between the properties of materials, which will be given to the students in great detail. This principle can be applied to the number and places of images to be taken in a specimen in order to reach a sufficient percentage i.e. at least % 1 or 25 locations in an image and also determine the number of total specimen for a reasonable outcome. The measurement errors, as they are prominent step in the definition of microstructures and their effect in final stage of property relations, are to be provided to students using practical examples and a breath of error calculations using practical examples from either industrial applications or laboratory based studies carried out using conventional structural alloy samples. Students should be introduced to the sources of measurement errors in general and in optical microscopy images. Prior to measurement errors, a short definition of statistics and its impact on the outcomes on the property definitions and finally a theoretical and practical microstructure grouping and development of microstructures in different set of materials will also be provided by examples.

3. Learning outcomes

Students can differentiate between the sampling procedures for the evaluation of components in 2D, especially from images, and bulk sample; analyse the effect of each components for the outcomes such as mechanical and physical properties; define the procedures for microstructural quantitative measurement procedures with its error dependent calculations and the use of statistics in sampling processes with respect to materials type and metallographic controllable parameters.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

G. F. Vander Voort, Quantitative metallography, ASM Handbook, ASM International, 2019

6. Additional notes

Topics 2

1. The subject of the lecture

PLANES AND PLANAR SURFACES

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

This topic introduces the basic concepts and overview of the effective use of optical microscopy in the field of metallurgical and materials characterization in addition to its general principles regarding the operational procedures for each type of microscope and its parts for which the standardisation is almost complete and effective use of them with the scientific principles. The use of different light sources and their effect on the quality of image will also be introduced to students with a technological development in the field of optical and electron microscopy. The basics of image formation in the image sensor with background electronics and software knowledge will be provided to students. A sufficiently oriented knowledge on the image corrections in optical microscopy and digital image manipulations such as contrasting, hue, image corrections, red eye and scratch removal will be included into the lecture in addition to digital image formation and the type of image formats are to be included when the image processing software is being introduced. A well-founded analysis of any metallurgically treated metallic or metallographically treated ceramic specimen is mostly possible with microscopy which is the only way of which the evaluations are simplified due to its measurable nature as it is clearly and easily observable by the quality control personnel. Students will be informed the fact that microscopy is also easy to prove what have been measured and analysed in regard to the place of measurement and a collectively uncomplicated ways of analysis can be extended to the whole image and series of images that represent the bulk specimen with a margin of error that stem from the user skill, non systematic and systematic measurement techniques. For this reason, measurements would extensively be analysed by statistical methods as the measurements are representative of the whole, but in microscopy, the measurements are made from the surfaces and this should be reflected to results i.e. the planar and non planar surfaces and also the objects that are found on the surface i.e. in the image plane. Students will be involved in discussions regarding the sufficient number of images and its percentage that represent the whole image and its relevancy to the general properties.

3. Learning outcomes

Students can obtain digital images from the optical microscopy and measure the components of an optical digital image that are visible under the microscope; describe types of digital images together with their properties. Students can define the capacity of microscopy and errors emanating from user and equipment; analyse the images with respect to components in the digital images obtained using optical microscopy.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

A. M. Gokhale, Quantitative Fractography, ASM Hanadbook, ASM International, 2002

6. Additional notes

Topics 3

1. The subject of the lecture

IMAGE CAPTURE AND ITS PROCESSING PRINCIPLES

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

This topic aims to give an advanced understanding of image formations and standards that are used in the analysis of property related outcomes with additional information regarding Metallographical preparation. As the type of images are given in previous lecture, this lecture topic will deal with the image processing procedures based on a non commercial image processing software that will be introduced during the lecture and students will be able to download freely, and also to practice what they learn during the lecture. A short introduction to modern technological equipment used for the capturing the images from various optical microscopes and image processing software that are extensively used in industry quality control labs and scientific labs. An image processing software will be selected and introduced to the students e.g. Image J software - by Wayne Rasband, National Institute of Health, the USA – and various calculations, calibration procedures and quantifications will be shown on this software with examples from its database and from specimens from industry and lab based studies. The theory behind the image processing procedure with reference to the image processing software operational instructions are also to be introduced to students with regards to the effect of several parameters on the image quality. Image processing software differs depending on the purpose of use i.e. quality control purpose in a factory or quality control lab to quickly decide if it is ok to go for production, for example, the casting, rolling and many quality concerns can relate the mechanical or physical properties with microstructural variants such as grain size, interparticle distance, the size, the shape and location of second phase particles. The definitions of particles within the grain boundary or winde the grain e.g. intragrain morphology will also be included in this stage of lecture with many examples from the literature. With this difference, the industrial applications of measurements are more decision based and concentrated on certain properties to comply with the standards or technical specifications of customers. These differences together with examples from industry will be provided to the students.

3. Learning outcomes

Students can explain how the images are digitally formed in the microscope and also analysed on the specimens prepared via metallographic procedures; analyse the images using well known image analysis software; differentiate between the needs for industrial software and research based software with a specific reference to the needs of the user and institution; describe the several functions of software with a specific purpose of use. Students can define the procedures that effectively characterize the components of microstructures.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

D. Aliya, Metallographic Sectioning and Specimen Extraction, ASM Handbook, ASM International, 2004

6. Additional notes

Topics 4

1. The subject of the lecture

EXPERIMENTAL PLANNING

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

This topic aims to introduce the detailed experimental planning procedures for the specimens to be investigated through metallographic examination, optical microscopy and be analysed using statistical methods. The initial topic for the lecture will include the specimen orientation when taking a sample from the bulk. This is an important part of specimen preparation as the mechanical properties of rolled steels are dependent on the direction of rolling. The specimen preparation for the analysis of microstructures will be briefly introduced with scientifically proven and practically used methods in general and later methods of analysis for the quantitative result will be introduced based on the optical images that have been prepared using methodology given in previous lecture topics. The first method of analysis is point counting on optical and electron microscopy images and its varieties that are commonly employed for 2D images and its historical background will be explained starting from space explorations. Point counting is one of the lineal methods while aerial calculations are more complex and meaningful for the correlations of general properties of specimens. However, the percentages of success from which the results are interpreted in terms of representing the whole specimen are dependent on the amount of number of specimens and area of fraction. Other methods of microstructural analysis such as lineal intercept method is to be introduced and exemplified with many cases from previous studies carried out metals and alloys in an extensive detail. ASTM standards on major metallographic measurements will be briefly mentioned and grain size analysis and its effect on the mechanical properties of metals and alloys will be provided using available literature. Methods of evaluation of secondary phase particles in metallic systems will be given on case base and solutions with solved examples are to be provided to the students. Major outcomes of point, lineal and volumetric measurements are important when the correlation needs to be established, which will be explained it is done using a computer program(s). Students should be involved in a discussion regarding the experimental planning in composites and other non metallic materials for all aspects of microscopy.

3. Learning outcomes

Students can describe the effect of orientation in rolled materials; determine the number of required methods of analysis using images of which its microstructural constituents are defined using metallographic procedures and then optical microscopy; define the each method of analysis with required analytical tools to provide a report of results based on the measurements; define the internal morphology of grains and intragrain species.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 2, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 5

1. The subject of the lecture

VOLUME FRACTION FROM PLANAR SURFACES

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

This topic begins with the brief definition of quantitative analysis in terms of analytical approach for the quantification process and procedures. The meaning of quantitative will be benefitted in order to explain the standards of procedures, however, one of the most used value, that is, volume fraction concept is to be briefly explained to students, as it was given in previous lecture, and the relations of volume fraction will be visualized based on the animations and explanations. The volume fraction is of importance in the visualisation of the distribution of second phase particles and also secondary phases and shows a strong relationship with mechanical and physical properties in metallic materials. The mesh and graticule counting systems are both lightly introduced and will be strengthened by mathematical and practical point of view. A non-commercial software is to be used to visualize the procedure and exemplify the various calculations, e.g. Image J software, and students will be asked to create their own data set and solutions with a prospect of generating report to present their results. Similar procedures will be applied to the images as shown in studies before by using the lineal point counting and correlate them with the volume fraction results. A report to be generated at the end of the lecture with fellow students (to be formed in teams) and be shared via oral presentation. The majority of the lecture will be on the creation of data set and preparation of case report and hence the subjects will be briefly distributed between the case studies and property calculations, i.e. brief introduction of subject will be given and students will be asked to repeat the procedure and complete the work by the end of the lecture. The images are to be provided to the students who will use their previously learned techniques and methods of analysis in previous lectures to solve the case. At the end of the lecture topic, students will be asked to join a discussion regarding the effectiveness of the methods used and also make a comment on more efficient methods that would increase the effectiveness of methods thought so far and new techniques. This discussion will benefit students in terms of basics of the processes to strengthen their practical knowledge and provide deeper learning of the subject.

3. Learning outcomes

Students can determine the processes and / or methods by which the quantitative metallographic analysis is done and shown in is progresses and resulting reporting is achieved; effectively choose an efficient method for different types of materials such as ceramics, composites and highly segregated specimens; make volume fraction determination based on the images via the use of point counting and graticule counting systems; apply their knowledge on practical level and collaborate with fellow students to share the results and prepare report from the experimental images prepared by optical images.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 3, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 6

1. The subject of the lecture

LINEAR INTERCEPT SIZE FROM PLANAR SURFACES

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

This topic aims to introduce the principles of linear or lineal intercept measuring methods used in the quantitative metallography based on the images with planar depth from optical microscopy studies. Grain size in a metallic or ceramic system which may have been produced using conventional production methods or powder metallurgy is very important factor in the determination of general overall strength by which the analytical solution is derived. It is sometimes very imperative to have no grain size in some metallic systems as it is undesired for the creep properties at high properties with a static load applied onto the part of the structure. If there is an abundance of grain size in a metallic material, its effect can be closely relatable to general properties of base metal at different conditions of applications, hence, the effective measurement of grain size is of practical use in many structures. Although, the grain size has to be measured using an international standard, such as the ASTM grain size measurement standard with or without table comparison or graphical table, there are other methods that are not widely used as ASTM grain size measuring standard. The grain size measurements are carried out differently when it is done manually by measuring intercepts or using computerized systems based on the pixel counting procedure. Following the introduction of lineal intercept method and relevant grain size standards and measurements, some definitions regarding grain boundary, size and their relation to volume fraction of grains is to be introduced with mathematical definitions and exemplary solutions to the equations that have been prepared specifically for this topic. In the final stage of this topic, many exemplary images from mostly metallic systems including cast iron, steels and non ferrous materials should be used to analyse the grain size distribution in such materials. These pre founded measurement methods will also be applied on ceramic systems and more complex systems which include composites of metallic or ceramic based. Finally, students are expected to carry out team work based on given data sets or optical microscopy images and prepare a report using their analysis results and present them to in the form of end of class essay. A discussion in the classroom should be started based on the results of their findings, for example, the grain size variations in different type of materials and the difference in methodology.

3. Learning outcomes

Students can define the intercept grain size concept and its measurement on a planar surface obtained from optical microscopy using pre determined methods defined by standards and approved valid methodology; determine the grain size and methods of measurement; apply the methodology that has been defined by the standards such as ASTM and derived methods of analytical approach; analyse the results from data set of images of optical microscopy and prepare a report based on their results regarding the analysis they made.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 3 and 4, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 7

1. The subject of the lecture

COLONY SIZE AND GRAIN SIZE FROM TREATED PLANAR SURFACES

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

This topic is aimed to introduce generalized grain size structures and variety of grain sizes encountered in different and conditionally treated systems. Duplex structures of two phases frequently occur in metallurgical microstructures. One classical example is the ferrite/ pearlite structure of air cooled low carbon steels, in which the pearlite colony size and the ferrite grain size are both of importance in determining the mechanical properties. This topic is also aimed to present the subject of about duplex structures such as martensite in the matrix of ferrite grains or Fe_3C carbides within the cementite + ferrite matrix which are distributed arbitrarily or regularly as in pearlite. Another example of duplex structure is austenite phase within the matrix of ferrite with varying amounts of intermetallic phases such as omega, delta or sigma phases. Such phases are not fully desired due to their brittle nature and inducement of chemically imbalanced formation within the region of precipitate formations. High flux of alloying elements is drawn by these extra phases, leaving decreased amount of less alloyed regions within the matrix, which may be critical to the general properties of steel or to the surface properties. Such affliction is seen in stainless steels with comparatively higher carbon to titanium ratios. In this topic, an example of martensite + pearlite structure in micro alloyed steels will be given as an example to the duplex structures and the effect of mechanical and physical property relationship configurations in these steels will be evaluated in the context of this topic. The examples will be selected from the industrial applications and calculations are to be carried out both using manual method and computerized method via Image J program. As was given in previous topic that the grain size formations are predicted via various methods but examples for planar surfaces are given by boundary counting method by taking colony size or rather subgrain individual formations which forms within the grain due to orientations during the growth of grains. In addition, the distinction of two or more phases is to be introduced into generalised grain measuring systematic. Colony size is relatively light term for subgrain but in this case, it is meant to cover areas of different phases i.e. closed perimeters of ferrite zone and pearlite or even ferrite to ferrite zones separated by dislocations lines. Finally the topic will be end with the boundary counting in addition to volume fraction of phases, subgrains i.e. colony size, also the length of boundary lengths and point counts. Another example will be given in nucleation and growth in phase transformation subject.

3. Learning outcomes

Students can differentiate the types of duplex structures within an image of planar surface obtained from optical microscopy and subgrains that are formed during the solidification or heat treatment etc…; perform relevant measurements of intra grain features including the colony sizes that exist in a grain; calculate the correct size by measuring grain boundary size and length using optical image; analyse the microstructures and can calculate relevant properties of duplex structures.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 4, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 8

1. The subject of the lecture

SIZE DISTRIBUTION OF SECOND PHASES PARTICLES AND PROPERTY RELATIONS

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

This lecture aims to introduce the measurement methods of size distribution of any phases and second phase particles that exist in the microstructure of optical microscopy image. As discussed in previous topics, particle sizes may be in a size range where they are most conveniently measured on plane sections by optical or scanning electron microscopy, or they may have to be measured from transmission electron micrographs of extraction replicas or thin foils. In all cases the method of measurement is the same, but the analysis of the data to obtain the size distribution in the volume, which is frequently the one of interest, is different. Students should also be made familiar with reactions in liquid state, solidification and solid state reactions occurring at high temperatures in this stage a brief introduction to the precipitation in metallic systems can be given and some exemplary images can be shown in the classroom. It is usual to assume that the particles are spheroidal in the volume so that they can be considered in terms of equivalent sphere diameters or equivalent circle diameters in sections. Analyses for other shapes such as circular plates or rods have also been derived by Fullman, De Hoff and Rhines, Underwood, but are more complex and will not be considered here, but may be in following topics. It is normal practice to measure particle sizes from micrographs, rather than directly in the microscope and it is essential that the magnification of the image is accurately calibrated. However, the analysis of planar sections using analytical methods will also be for different shapes such as plates and discs. The shape and the size distribution of circles in the planar section therefore differ markedly from the distribution of spheres in the known volume. The probability of observing circles in this largest size group could then be calculated and the residual probability distributed to the smaller size groups of circles. This procedure enables the size distribution of spheres in the volume to be derived from the observations of the size distributions of circles on the plane of polish, but the successive subtractions involved led to large statistical uncertainties in the numbers of particles in the smallest size groups of spheres. This topic seems to be more leaning towards secondary phase particles, but, the grain size and subgrain sizes etc. measurements that have been mentioned in detail are also to be used to relate the properties such as tensile strength, yield strength, elongation, ductility, impact energy, hardness etc… This part of the topic appears to be very practical and results will be interesting for the students as it may directly be used in industry. Relevant materials need to be obtained from the academic resources. Another sub topic will be introduced to students to show how to prepare thin foils and its properties to reveal its formation using metallographic procedure. A discussion can be initiated on the reliability of measurements on different images from the same specimens and how to correct these discrepancies.

3. Learning outcomes

Students can differentiate between the analysis of planar sections using analytical quantification methods that will also be used for different shapes such as plates and discs; demonstrate the measurement method for the analysis of second phase particles in optical and scanning electron microscopy images; employ various analytical calculation methods for overall quantification of second phase particles in planar sections.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 1-4, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 9

1. The subject of the lecture

INTERPARTICLE SPACING: SIZE OF PARTICLES

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

The lecture aims to give an extensive introduction to spacing between particles and other constituents of images from the optical and scanning electron microscopy. In relating properties to microstructure, interparticle or even intercolony spacing rather than particle size is often the critical parameter for the determination of various properties such as mechanical properties and physical properties i.e. hardness and tensile strength. However, interparticle spacing may be defined in different ways, so an extra care must be exercised in selecting the appropriate definition for a specific purpose. In all cases, the interparticle and intercolony spacings are sometimes not measured directly from micrographs, but are calculated from the particle parameters derived in the earlier examples in this topic. This topic will also be introducing the spacing effect along the line and spacing along the plane in planar systems. It is imperative to consider the fact that spacing between the object is also related to the volume fraction of the aforementioned particles of colonies and hence, volume fraction calculation using spacing will also be considered with appropriate analytical methods and measurement techniques. For the consideration of diffusion fields around the particles and within the grain and its kinetic effects, the interparticle spacing in the volume, i.e. the distance in any direction from one particle centre to a neighbouring particle centre is the appropriate one to use for the averaging and predicting the volume fractions and hence general properties. The spacing between and of the particles in a plane dominated or planar systems and also their distribution are particularly important in the interpretation of mechanical properties of whole system i.e. bulk properties of materials or sometimes to explain other physical properties such as hardness and hardening after cold deformation and also hot deformation processes, because dislocations interact with particles that intersect their crystallographic slip planes. This topic will also be introducing many examples regarding the interplanar distance calculations and its importance in predicting the properties from the first hand examples. A discussion should be initiated with students on the relation between the size of particles and interparticle spacing and its possible effect on the general properties of materials being tested. A discussion should be initiated on

3. Learning outcomes

Students can explain the effect of spacing effect between second phase particles and precipitates and colonies within the grain structures on the prediction of overall mechanical and physical properties; analyse and interpret the spacing between the measurements of particles and sub grain constituents using optical and scanning electron microscopy images; relate between the interparticle spacings and other properties of base metal.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 5, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 10

1. The subject of the lecture

DISLOCATION STRUCTURE DETERMINATION

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

This lecture aims to introduce a general view on the measurement of dislocation structures and density within the thin foil specimens. Students should be introduced to the methods for the quantification of dislocations in a confined area in an electron microscopy specimen and implications should be discussed with the students if the area of measurement should be considered reliable. There are two methods for measuring the dislocation density; end counting and the intercept method. The method used depends on the dislocation density, type of material the skill of the operator and the accuracy required. For both of the methods described below, an electron micrograph of the area of interest is taken, usually with multi-beam conditions, to allow the maximum fraction of dislocations to be in contrast. If it is possible to image individual dislocations, for example Transmission Electron microscopy image from a foil, then a simple measure of the dislocation density can be determined by counting the 'ends' of the dislocations. These 'ends' are produced by the intersection of the dislocation by the top and bottom surfaces of the foil which involves the number of points per unit area of intersection of dislocations with a plane, assuming random orientation of the dislocations with respect to the plane. Another method of measuring is the intercept method that involves the analysing the transmission electron microscopy image. The advantage of this technique is that it can be used in thicker parts of the foils where the dislocation ends cannot be easily distinguished. The technique does, however, require the thickness of the foil to be measured. Although it is a procedural step as part of the analysis from the images, the thickness of the foil is relatively operator dependendent process, i.e. to extract this information user should be aware of the equiptment parameters and operating principles as it requires to make a subtle assumption and auxillary tools for the result. There are a number of methods of measuring the misorientation in thin foils. The method used depends mainly on the degree of accuracy required, the equipment available and the skill of the operator. Grain orientations are primary causes in the formation of subgrains and has to be configured to misorientation analysis. Regardless of the technique used to measure the density, electron micrographs should be taken from a number of sub-grains and in several different foils to obtain a statistically meaningful average. This is necessary because of variations in dislocation density between sub-grains and variations between grains of different orientation. There are two techniques for the measurement of sub-boundary. misorientation. These are from a thin foil in the TEM and from a surface by Electron Back Scattered Diffraction (EBSD). These techniques will also be introduced for a short period of time just to enlighten the students.

3. Learning outcomes

Students can explain the different types of techniques by which the orientations in grains and subgrains are determined using transmission electron microscopy images via thin foil thickness and planar images; describe the function of dislocations that are important part of mostly metallic structures and measuring such quantity needs careful statistical practice and operational parameter controlled processes; analyse the dislocation density from an image and also make a substantial comment of the orientation of grains and subgrains by suggesting methods of interpretation.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. L. Higginson and C. M. Sellars, Chapter 6, Worked Examples in Quantitative Metallography, IOM, Maney Publ. 2003

6. Additional notes

Topics 11

1. The subject of the lecture

INDUSTRIAL APPLICATIONS: IMAGE PROCESSING FOR QUALITY CONTROL

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

This lecture aims to introduce the basics of image processing software used in industry and their working principles by initially introducing their potential areas of use. The quality control and research and development purposes are the main areas of use as was indicated in previous topics. The recent advances in sensors quality and processing power provide us with excellent tools for designing more complex image processing and pattern recognition tasks. In this topic, the existing applications of image processing and pattern recognition in materials engineering area are reviewed and practical examples are also given to complete the topic. The benefits of image processing are varied. One of the advantages is it replaces shortage of skilled labor that such automation improves the consistency and quality of inspection tasks and optimize workflows. The second one is early detection of faults and defects that is ensured of high-quality production processes and avoids production downtimes. The most important one is the identification of quality issues which are are revealed to help avoid rejects. Data collection and processing time are reduced in the production time scale. Inspection processes are analyzed based on the captured data and the results can be used for proactive maintenance. Considerably faster quality assurance due to high speed data processing and predefined learning results provide reduced costs for manual and/or visual tests and inspections. Automated quality assurance with a reliability of 99.98% improves both productivity and product quality. A dissemination of some image processing techniques, feature extraction, object recognition and industrial robotic guidance are also presented. Advanced image processing offers industry and application specific solutions based on digital image processing systems that are designed for the continuous monitoring and quality control of production processes. Digital image processing systems and camera technology increase quality and productivity by providing high resolution images obtained from the optical and scanning electron microscopes. Using these software, standards for the production of metallic or ceramic based parts of industrial importance are considered when it is designed for the quality control via the recognition of microstructural constituents such as martensite, bainite or pearlite. It is also the subject of this topic to reveal the principles of recognition as to how these microstructural constituents are determined using the pre defined digital data previously defined in database of the software. It is also important to include the machine learning of how to define the microstructures and process the data obtained using reporting system. As a guide to the image processing, low carbon no alloyed plain steels and their microstructures are to be provided to the students and explained how these microstructures are obtained with the help of carbon cementite phase diagram and also there microstructures are used as training module and briefly shown to be employed to define grain size determination in steels.

3. Learning outcomes

Students can define the image processing procedure for the determination of microstructures that are common in steels; define and analyse the images from industrial alloys with the knowledge of industrial applications of such image processing systems available in industry; describe the benefits of image processing and suggest a methodology to define the images properly; analyse images using image processing and patern recognition techniques in quality control of finished parts or pre production parts that need to be approved for the production.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

L. Wojnar, K. J. Kurzydłowski, J. Szala, Quantitative Image Analysis, ASM Handbook, ASM International, 2004

6. Additional notes

Topics 12

1. The subject of the lecture

THERMAL ANALYSIS PRINCIPLES AND ANALYSIS CALCULATIONS

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

This topic is intended to introduce the thermal analysis techniques that are frequently used in the characterization of materials to reveal various reactions dependent on the temperature and heat exchange during phase transformations. The topic will begin with an introduction of various techniques such as DTA, TG, DSC, DTG and TT tests with relevant examples from metallic materials and polymers as well as pharmaceutical specimens. These techniques are mostly definitive techniques in the quantification of transformation points and transition range. Students will be introduced to the thermal analysis from the perspective of analysis types and reliability of results. The reliability of results has significant implications in reporting the analysis results and needs an extra care hence the parameters should be vigilantly tested and selected such as heating rate and temperature at which the test is carried out. The topic should later continue with the introduction of each technique that has been mentioned and cons and pros should be discussed in detail. The analysis of the results from each technique should be introduced separately but the students should be given a treat of mathematical or empirical relationships between techniques and parameters which should be accompanied with the relevant examples from real samples and exemplary questions and their solutions should be given in the classroom. Students should be able to put forward their ideas on how the reactions are developing and the effect of heat release i.e. enthalpy of the reaction is calculated through the analysis graph. Although, the software already produces such outcome, students should be clearly understand the processes and hence the role of parameters on the outcome. The analysis of results should include the definition and visuals (peaks or transition zone) of dissociation, association, solidification, melting, glass transition, weight loss, weight gain through reaction with air or gas medium, crystallisation, boiling point, separation of reacting species. Students should also be introduced to thermometric titration technique and its uses should be emphasized, too. Other techniques such as DMA (Dynamic Mechanic Analysis), dilatometric analysis and TMA can be introduced students and their uses should be explained with examples to students. This topic should end with thermodynamical explanation of processes (enthalpy and calculation of heat capacity through DSC technique) with respect to endothermic and exothermic reactions and their interpretation in the analysis of metallic systems. The activation energy calculations must be included in the last stage of the topic through DSC using Arrhenius i.e. Flynn-Wall relationship) and Kissinger relationship with exemplary table of values that has been prepared using varying heat rate and peak temperature values. Students should be involved in a discussion regarding the heating rate and evolution of peaks as to how they affect the analysis of DSC curves.

3. Learning outcomes

Students can explain the principles of working of thermal analysis techniques that are frequently used to determine the transformation points; analyse DTA, TG, DTA curves with respect to transformation points and determine if it is exothermic or endothermic reaction; decide the use of appropriate techniques depending on the type of materials and desired outcome; calculate the activation energy using various techniques using DSC data points that has been prepared using with varying heating rate and peak temperature.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

B. Wunderlich, Chapter 3-5, Thermal Analysis, Academic Press Inc., 2012

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 13

1. The subject of the lecture

X RAY DIFFRACTIONS AND CALCULATIONS OF ANALYSIS RESULTS

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

This topic aims to introduce the methods of calculations for the interpretation of results obtained from X Ray diffraction techniques used for the materials analysis. The analysis of crystal structures of metallic and non metallic materials is of great importance for the characterisation however some calculations are needed at least in a secondary level. Following the acquiring the peaks against 2 theta angle or d spacings, the analysis is done automatically by the software to reveal the amount of phases and their crystal structures, retained or retained stresses. However, some calculations can be done without the support of software already installed, it is occasionally more expensive or the source of the X Ray curves may not be possible to track. Students should be given basic equations of d spacing calculations in addition to the advanced treatment of Bragg's law with respect to d spacing transformations to d(hkl) parameters and a, b and c lattice parameters. Students should be given a basic introduction to the crystal systems and their lattice properties such as lattice formations and frequency of occurrence in nature and their common examples with lattice parameters; such examples can be given using well known compounds or everyday substances such as table salt. The calculations of lattice parameters in an unknown X-Ray analysis curve would be interesting to solve by students, which would inflict a feeling of achievement. For this purpose, three or enough examples should be brought upon and distributed to the students. The first calculation is to make a table of 2 theta angle with respect to peak intensities, where students should be shown how to normalise the peak heights, and then d spacings should be calculated based on the table generated by the students. Students should then do further calculations to find a parameters of lattice by which the structures will be revealed if it is cubic or other form of crystal. These include coefficients of multiplication to obtain un-averaged or raw parameters which should be averaged based on normalised peak length. Following the revealing the cubic structure or non cubic structure of the substance, students should be given an information about the use of equations for the determination of type of cubic for example FCC or BCC or simple cubic or any of the 14 crystal formations. It should be emphasized that apart from cubic structure it is not easy to calculate, one needs a computing power for faster results. The second part should include the residual stress measurement techniques and exemplary calculations should be given. The third part of the topic should be on how to calculate the ratios of phases found in the XRD results. The composition of the secondary phase can be done using area ratio with an advanced matching field rationing and curve adjustment methods. Students should be given an example for example solder (electronics solder) and ask to calculate the ratios of phases and students should be asked to comment on why the result is different than that of the composition of solder using phase diagram of Tin-Lead.

3. Learning outcomes

Students can explain the extensive use of Bragg's law and derivatives of it in the use of solving crystal structure and its parameters; differentiate between the different crystal structures by analysing peak structures and positions; calculate the phase ratio by applying the knowledge gained during the lecture based on the areas under the discerning phase peaks; obtain necessary results from an X Ray analysis curve by using appropriate techniques of matching previously known predeposited patterns.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Y. Waseda, E. Matsubara , K. Shinoda, X-Ray Diffraction Crystallography, Introduction, Examples and Solved Problems, Pages 1-20, 107-167.

M. Ladd , R. Palmer, Structure Determination by X-ray Crystallography, Analysis by X-rays and Neutrons, Springer, 2013, Pages 161-186, 439-488

6. Additional notes

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

AVIATIC AND DEFENCE ALLOYS AND SCIENCE OF ARMOURS

Code: NAHSI

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO CONCEPT OF BALLISTICS AND ARMOUR

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

This topic aims to introduce the concepts of ballistics In general and its classification as a science. This topic should start with the definition of subclasses of ballistic science and the definition of armour and its purpose. Ballistics and its working principles as to how it is historically developed in each continent with respect to the type of threat should be elaborated in detail as it is the starting point for armour science. Students should be informed about a realistic kinetic energy calculation of a projectile with an initial velocity of V_{out}, which is also called muzzle velocity or projectile velocity and its impact energy on any substrate with a certain amount of rigidity. The muzzle velocity is classified as V-0 or V-50. Other quantities used to assess performance include ballistic limit, an ambiguous term V-0, the velocity at which there is zero probability of complete penetration (thus, V-0 is lower than V-50); and residual velocity, the velocity of the projectile after a transit through thickness of the target. Students should be also informed about the armour science which is the science of armour of any kind with a velocity which can be a projectile with different shapes, blasted pieces or shrapnel; it also includes specially designed protection to defeat the high velocity projectiles for preventing the projectile with certain velocity of muzzle exit puncture the barrier material. Students should be presented with examples of different shapes and designs of projectiles or ammunitions for standard non standard guns and rifles. The shape and design of projectiles are considered to be the most important part of armour science or rather ballistics, determining the impact force and penetration ratio. Shapes of projectile determine the penetration power of ammunition of all calibres and rounds of rifles or small to medium arms. A part of a movie should be viewed by the students and students later should involve in a discussion regarding what might be the effect of external parameters as velocity and direction of wind, humidity, the effect of weight of ammunition and the grooving inside the muzzle.

3. Learning outcomes

The students can explain the concept of ballistics and its historical development with respect to type of threat in each continent; describe the subclasses of ballistics and some definitions regarding the projectile energy related to kinetics of ammunitions; define the need for armour and armour protection in cases where a penetrating projectile is present; explain the effect of shape and design of ammunitions and projectiles designed for specific purposes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 1-3, D.E. Carlucci and S. S. Jacobson, Ballistics: Theory and Design of Guns and Ammunition, Taylor and Francis, Boca Raton, 2008

6. Additional notes

Topics 2

1. The subject of the lecture

INTERNAL BALLISTICS, TERMINAL BALLISTICS: TERMS AND DEFINITIONS

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

This topic aims to present extended information on the ballistics of ammunitions and projectiles with an introduction of classification of ammunitions used in most of world armies but particularly armies of NATO to date. Students should be particularly presented with the generalised history of ammunitions and projectiles starting right from bow and arrow up to the high altitude missiles. Students should be well versed with the details of internal and terminal ballistics with appropriate videos and images to make students familiar with the subject. In previous topic, ballistics were explained in slightly diminished detail, however, this topic should be more on the cartridge and projectile ammunitions or ammos and their extended types that are used in the field. It is also the aim of this topic to study general terms and their definitions of terminal and internal ballistics. The purpose of ammunitions and their general properties such as travel distance of ammunitions, impact force on the armour at various distances such as 25m, 100m, 150m or 1 km, the aim length, shield or armour piercer or sniper rounds etc… This topic will also cover the classification of internal and terminal ballistics with a purpose of light introduction to subclass of ballistics but slightly more detail to be given to help students realise that these two subclasses are more important and studied for many purposes such as armour design and bullet design. The bullet's design, as well as its impact velocity, plays a huge role in how the kinetic energy is transferred to the target. The type of ammunition and their purpose are more practically determined due to field experience and needs. Therefore, the research on developing new ammunitions or to improvise them to be suited to the purpose should be briefly mentioned with a notion of generalised parameters of purpose, weight, terminal classification 8NATO/the US) such as type I, type IIA and II, type III and Type IV, possibly in the form of tabulated data table.

3. Learning outcomes

The students can elaborate on the ballistics and ammunitions / projectiles and their classification in NATO standards; explain the cartridges and projectile ammunitions produced for commonly known small guns and rifles and they can also define the general terms used in ballistics e.g. terminal and internal ballistics; describe the parameters of terminal and internal ballistics with definitions.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 4-5, D.E. Carlucci and S. S. Jacobson, Ballistics: Theory and Design of Guns and Ammunition, Taylor and Francis, Boca Raton, 2008

6. Additional notes

Topics 3

1. The subject of the lecture

ALLOYING AND PERFORMANCE OF SPECIAL ALLOYS

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

This topic aims to present extensive information on the alloying and alloying rules in most alloy making processes in metallic systems. This topic will also cover the melting and re-melting process in which release of binding energies at the expense of the heat of dissolution prior to solidification will be reviewed to make students accustomed to what happens in liquid state. The interaction between atoms of matrix and alloying atoms should also be reviewed in a graphical form and explained with respect to alloy making and its principles. The alloy making is generally practiced through melting and re-melting by mixing with time due to the interaction between atoms of alloying mixture. This is however not the only method one can prepare alloys of interest but other methods may include extensively diffusion dominant processes such as mechanical alloying. The alloys usually form in a disordered atomic arrangement fashion in crystals. The arrangement of atoms in a crystalline system also involves the precise location of atoms, an important property of intermetallic systems of which most special alloys contain these metallic systems such as superalloys. Order reactions should also be explained by the atomic arrangement where certain properties are presumed to be coming from, such as improved magnetic and mechanical properties. These include the well known yield strength phenomena in Cu-Au, Fe–Al and many other ordered intermetallic structures and alloys. In this topic, some alloy models will also be reviewed in detail with respect to their application in recently studied alloy systems and classical alloy systems. These models will connect the liquid state of atoms under heated and diffusive conditions to initial stage of solidification process and show students how these models are important to construct the atomic arrangement in solidified crystalline systems with ordered or disordered perspectives. The alloys for aviatic applications would require tremendously tight rules of control and these include Xray imaging of alloys and NDT control of casting and final parts as well. High temperature service demands are also closely controlled with a high precision of temperature. Students should be explained why these strictly controlled rules are employed in this sector and the importance of loss of lives such as in planes. A discussion should be initiated with students regarding the importance of alloy composition and mechanical and physical performance. Students should also involve in a discussion on why quality standards of these alloys are written in detail and followed (traced) precisely.

3. Learning outcomes

The students can explain the mechanism of melting and remelting of alloys with a well revised alloy making rules and principles in special alloy making; explain the standards of manufacturing of these alloys are very high and they are strictly controlled and traced to the source for revealing the error and share the responsibility; can explain the need for high mechanical and metallurgical requirements form these alloys.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Relevant Chapters, Alloys and Intermetallic Compounds From Modeling to Engineering

Edited By Cristina Artini, 2021 by CRC Press

6. Additional notes

Topics 4

1. The subject of the lecture

ALUMINIUM BASED ALLOYS FOR AVIATIC AND DEFENSE APPLICATIONS

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

This topic aims to provide advanced knowledge on special aluminium alloys that are increasingly used in the aerospace and defence industries. These alloys are valued for their ability to provide lightweight, robustness, and durability in a single material. Over the years, aluminium alloys have been continuously developed for aerospace applications, such as aircraft material structures and armour shields, due to their high strength-to-weight ratio. Aluminium is a cost-effective alternative to titanium alloys and is considered a high-performance material due to its ease of machining and low manufacturing costs. Reliable data on the properties of industrially significant aluminium alloys is critical for manufacturers and scientists to select the best option from the many available types. This topic should cover recent advances in aluminium-based alloys, including the 2000 series, 7000 series, and Al-Li alloys, which are specifically produced for the aviation sector due to their excellent mechanical and physical properties. The alloy configuration of aluminium-based alloys should be introduced, along with a tabulated list of elements and specific properties such as maximum temperature of use, weldability, and ballistics applications. This text describes and compares the characteristics and effectiveness of new advanced 2000 and 7000 series Al-Li alloys, as well as other aluminium alloys, with currently available ferrous and non-ferrous alloys. The heat treatable alloys contain elements that decrease in solid solubility with decreasing temperature, and in concentrations that exceed their equilibrium solid solubility at room temperature and moderately higher temperatures. The most important alloying elements in this group include copper, lithium, magnesium and zinc. This topic should continue with a brief overview of the historical development of aerospace and ballistically viable aluminium alloys. This should be followed by a listing of a range of current alloys with a description of the wide range of heat treatment tempers with regards to alloy classification system. The weldability issue should also be discussed and generalised definitions should be given to the students. A description should be given on the alloying and precipitation hardening behaviour, which is the principal strengthening mechanism for Al alloys. A survey of the mechanical properties, fatigue behaviour and corrosion resistance of Al alloys is followed by a listing of some of the typical aerospace applications of Al alloys. The production of primary aluminium and some aerospace alloys, and the Type Certification process of Al alloys for aerospace applications should be described at a medium level for students to understand the strict requirements are needed to be met prior to acceptance of any aluminium parts. Finally there is a critical review of some of the gaps in existing aerospace Al alloy technologies. Ballistics properties of aluminium alloys and application fields should also be given to students in the form of images. A discussion on the significance of aluminium alloys for the armour use should be initiated and a reliable solution should be sought at the end of the topic lecture.

3. Learning outcomes

The students can differentiate between the alloys of aluminium based on the composition and mechanical properties; describe the differences in the properties of aluminium alloys based on the requirements such as high temperature applications, ballistics properties; explain the metallurgical differences and their mechanisms in achieving high mechanical and physical properties; suggest aluminium alloy/s based on the requirements from standards and applications using tabulated data given in the topic.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Aluminium Alloys for Aerospace Applications:

(https://link.springer.com/chapter/10.1007/978-981-10-2134-3_2)

Application of aluminum alloys in aviation industry: A review: https://doi.org/10.1063/5.0163002

Application of modern aluminum alloys to aircraft, https://doi.org/10.1016/0376-0421(95)00004-6

6. Additional notes

Topics 5

1. The subject of the lecture

TITANIUM BASED ALLOYS FOR AVIATIC AND DEFENSE APPLICATIONS

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

This topic aims to introduce the titanium alloys which are mostly used in the aerospace industry and ballistics applications. The broad classification of titanium alloys needs to be introduced to students with some properties of alloys of interest such as melting point, maximum temperature of use, mechanical properties should be included in a table. This topic aims also to provide advanced knowledge in titanium alloys that are being increasingly used in the aerospace and defence industry in recent years due, in large part, to its ability to contain the lightweight, robustness and durability with good high temperature corrosion properties. Although Titanium in pure form is still in demand by airplane manufacturers for airframes, Titanium alloys, over the years, have been continuously developed for aerospace applications like aircraft material structures and armour shields due to their lightweight and higher strength to weight ratio. Titanium is relatively more expensive compared to aluminium alloys and considered as having high manufacturing costs despite of its have excellent mechanical and physical properties compared with many industrial alloys. A titanium alloy is mainly used for the fan and the compressor in the fore half section, where the temperature is relatively low (600˚C or lower). For the turbine and the combustion chamber in the rear half section where temperatures are higher, a nickel based alloy or iron-based alloy is used. This topic should also provide the most recent advances in Titanium based alloys, that are specifically used for aviation sector, Ti-Al, Ti-Al-V, Ti-Nb and other intermetallic based alloys and non intermetallic forming alloys with lower limits of Al and Nb. Students should be introduced to alloy configuration of titanium based alloys with a tabulated list of composition elements and also specific properties such as maximum temperature of use, weldability and ballistics applications. The characteristics and effectiveness of new advanced titanium alloys and other Titanium alloys needs to be described and compared to currently available aluminium and ferrous and non ferrous alloys. This topic should continue an overview of the historical development of aerospace and ballistically viable Titanium alloys. It then lists a range of current alloys and describes the wide range of heat treatment tempers with regards to alloy classification system. The mechanical properties, fatigue behaviour and corrosion resistance of Titanium alloys are surveyed, followed by a listing of some typical aerospace applications of Titanium alloys. The text describes the production of primary titanium and some aerospace alloys, as well as the certification process for titanium alloys used in aerospace applications. The language used is clear, concise, and objective, with a formal register and precise word choice. The text is grammatically correct and adheres to formatting guidelines. The text maintains a logical structure with causal connections between statements and avoids biased language. The author also includes a critical review of some of the gaps in existing aerospace titanium alloy technologies and the weldability properties of these alloys. The lecture should provide students with images to illustrate the ballistics properties of Titanium alloys and their application fields. Additionally, a discussion on the weldability of Titanium alloys for use in armour and airframes should be initiated, with the aim of finding a reliable solution by the end of the lecture.

3. Learning outcomes

Students are able to distinguish between titanium alloys based on their composition, mechanical properties, and corrosion resistance. They can also describe the differences in properties of aluminium alloys based on specific requirements, such as high temperature applications, ballistics, and weldability. Additionally, students can explain the metallurgical differences and mechanisms that contribute to achieving high mechanical, corrosive, and physical properties. Using the tabulated data provided in the topic, students can suggest titanium alloys based on the requirements of standards and applications.

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

The course will include a mix of traditional and modern teaching methods using blackboard as well as multimedia tool.

Multimedia presentation - The multimedia aspect of the lecture will be facilitated through platforms like Microsoft PowerPoint, Google Slides, Apple Keynote, Visme, Prezi, or SlideDog. This will enhance the visual presentation of the topics under discussion.

Case study - One part of the course will include students' work on relevant course materials.

Discussion – The students will be encouraged to actively participate in discussions about the case study.

Q and A session – During the lecture, the teacher will ask students questions about the subject.

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

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

I. Inagaki, Y. Shirai, T. Takechi, N. Ariyasu, Application and Features of Titanium for the Aerospace Industry, NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 106 JULY 2014

6. Additional notes

Topics 6

1. The subject of the lecture

IRON BASED BASED ALLOYS FOR AVIATIC AND DEFENSE APPLICATIONS

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

This topic introduces iron-based or ferrous alloys, which are commonly used in ballistics due to their high strength and ballistic impact resistance. The classification of iron-based ballistic alloys is broad and includes steels that are non-ballistic but used in aerospace applications, such as maraging steels, AerMet steels, some stainless steel grades, or similar steels. A list of these steels in tabulated form should be provided to students, including properties of alloys of interest such as melting point and maximum temperature of use, as well as mechanical properties. This topic aims to provide advanced knowledge in iron-based ballistic alloys and aviation alloys, which are used in the aviation and defence industries due to their robustness, durability, and good room temperature impact properties. Ferrous alloys, both with and without high alloying elements, have a wide range of applications across various sectors and industries. However, aerospace manufacturers still demand alloyed ferrous alloys for tubing and fittings applications. Ferrous alloys with high alloying elements have been continuously developed for defense and civilian applications, such as armoured vehicles, vaults, training facilities, security doors, police cars, and security booths. Armour steels are typically more expensive than standard steels. However, they are tough, bendable, long-lasting, and weldable, making them suitable for a wide range of applications. Despite their excellent mechanical and physical properties compared to many industrial alloys, they are considered to have high manufacturing costs. This topic should also cover the latest advances in ballistics and aerospace grades, such as Armox grade ballistic steels. To introduce students to alloy types, a tabulated list of composition elements and specific properties such as maximum temperature of use, weldability, and ballistics applications should be provided. The text should describe and compare the characteristics and effectiveness of ballistics and other ferrous alloys in general with currently available aluminium, ferrous, and non-ferrous alloys. The topic will continue with a brief overview of the historical development of ballistically viable ferrous alloys. This will be followed by a listing of a range of current alloys, along with a description of the various heat treatment regimes used to produce high hardness, in accordance with the alloy classification system. The process of certifying alloys for ballistic applications should be described at a medium level to ensure students understand the strict requirements that must be met prior to acceptance of any products. Additionally, a critical review of existing armour alloy technologies should be provided, including a discussion on the weldability of these alloys and the effect of heat input on the weld metal region.

3. Learning outcomes

Students can differentiate the composition and mechanical properties of iron alloys used for aerospace and ballistics purposes; describe differences in properties between aerospace and ballistic iron alloys based on requirements such as high temperature applications, corrosion requirements, ballistic and weldability properties; explain the metallurgical differences between iron-based ballistic alloys and their mechanisms for achieving high mechanical, ballistic, corrosive, and physical properties; suggest ferrous armour alloys based on the requirements from standards and applications using tabulated data provided in the topic.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Relevant Chapters, Alloys and Intermetallic Compounds From Modeling to Engineering Edited By Cristina Artini, 2021 by CRC Press

Chapter 2, The Science of Armour Materials, I. G. Crouch, Woodhead publishing, 2017, Oxford

Chapter 5, Aerospace Alloys, S. Gialanella, A. Malandrucolo, Springer, 2020

6. Additional notes

Topics 7

1. The subject of the lecture

NOVEL ALLOYS FOR AVIATIC AND DEFENSE APPLICATIONS

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

This topic provides an overview of new generation alloys used in aviation and defence applications, focusing on their properties such as high hardness, strength above 1GPa, corrosion resistance, and magnetic properties. Certain new generation alloys are considered as potential candidates for heavy alloy applications in high temperature and special scenarios. Refractory alloys containing Mo, W, Nb, Cr, Hf, Zr and Ta are a new generation of alloys based on Cr, Mo, W, Nb and Ta. Examples include Mo-1.2Ti-0.25Zr-0.15C, Mo-50Re, Mo-13Re, Nb1Zr-0.005C, Nb-28Ta-10W-1Zr-0.004C, Nb-10Hf-1Ti-0.7Zr-0.015C, Ta-8W-2Hf, W-25Re and W-3Re. This topic covers extensively investigated Nb, Mo, Ta and Ta-based alloys that could potentially replace superalloys. This topic should cover the joinability and ballistics impact of these alloys, as well as their mechanical, physical, and corrosion properties at both elevated and low service temperatures. Students should also be provided with information on the production of these alloys, including vacuum arc melting and ambient-pressure-inert-atmosphere arc melting, as other methods may not be sufficient to melt these elements into the desired shapes. The lecture should mention the physical metallurgy of these alloys, with specific reference to deformation and precipitation mechanisms. Additionally, it aims to introduce some intermetallics with special properties, such as memory shape capacity. Emphasis will be placed on the phase diagrams during the lecture, from a structural pattern point of view, to give students a better understanding of these materials. Students should also be given information on Superalloys that are the materials which have made much of our very-high-temperature engineering technology possible. Nickel-based superalloys are commonly used for high-temperature structural applications, especially when resistance to creep and/or fatigue is required and the risk of degradation due to oxidation and/or corrosion is high. Cobalt-based superalloys are used in aviation and aerospace for manufacturing components such as turbine engines and gas turbines. This topic should also include literature on the defense and aviation applications of these alloys. The topic of discussion should be on the differences between these alloys and their suitability for use as aviation alloys based on their weight-to-strength ratio.

3. Learning outcomes

The students can define the properties of new generation alloys, including high hardness, strength, corrosion resistance, and magnetic properties; determine the production methods, joinability, and ballistics impact of these alloys; differentiate the mechanical, physical, and corrosion properties of the alloys at both elevated and low service temperatures and their advantages and limitations of these new alloy systems.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 6, Aerospace Alloys, S. Gialanella, A. Malandrucolo, Springer, 2020

6. Additional notes

Topics 8

1. The subject of the lecture

MISCELLANEOUS ALLOYS FOR AVIATIC AND DEFENSE APPLICATIONS

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

This topic aims to introduce miscellaneous alloys for aviation and defence applications due to their specific properties such as the weight to strength to ratio, specific strength, high hardness, high temperature mechanical and physical properties or they are simply as an alternative to some of the alloys used for aerospace applications. Students should be introduced to the high entropy alloy concepts and their potential applications in aerospace and defence industries. However, the list may not be long hence a literature survey is sufficient with a list of alloys and possible place of use in a tabulated form of table. General characteristics of these alloys such as high strength and high corrosion resistance should be emphasized with a reference to their crystallographic properties and atomic level mechanisms of strengthening. This topic should briefly cover the physical chemistry of high entropy alloys from the perspective of atomic construction and entropic energy. Later, physical metallurgy will discuss the general properties of these proposed alloys. The topic will also address the advantages and limitations of these new alloy systems in relation to their applications. Designing high-entropy alloys (HEAs) poses several challenges due to the large number of elements involved and the complexity of their interactions. The study of high-entropy (HE) alloys has experienced significant growth in recent years due to their exceptional properties, such as enhanced oxidation resistance, superior mechanical properties, and desirable magnetic properties. Students should be made aware that bulk metallic glasses are also new types of alloys and there is a growing need for metals that are tougher, lighter, more formable, and machinable, and that can be used in a wider range of applications at higher temperatures. Multicomponent advanced metals, such as multicomponent bulk metallic glasses and advanced high-entropy alloys, have shown potential in meeting these requirements. High-performance computing, high-resolution microscopy, and advanced spectroscopy methods, including neutrons and synchrotron x-rays, have contributed to the development of these metals. The topic should also discuss the development of new experimental approaches that relate the bulk properties and associated optimized properties. With the development of space technology, there is an urgent need to reduce the weight of structural materials to improve the carrying capacity of payloads and the overall performance of spacecraft. Magnesium (Mg) alloys offer significant advantages, including low density, high specific strength, good biocompatibility, and excellent electromagnetic shielding. Therefore, they are an ideal metal structure material for weight reduction in aerospace applications. Students should be explained of manufacturing magnesium alloys and various alloying techniques with advantages and disadvantages listed in a tabulated form. In this topic, the effect of alloying additions on HEAs and BMGs on the mechanical and physical properties should also be thought and given in the form of table template and categorical development over the years. The variation of the properties of these alloys should be discussed in the classroom and the effect of each element on the specific properties should also be summarised for the purpose of discussion.

3. Learning outcomes

Students can explain the importance of BMGs, HEAs and Magnesium alloys as new types of alloys in the context of growing need for metals that are tougher, lighter, more formable, and machinable; discuss the variation of the properties of these alloys and the effect of each element on the specific properties; address the advantages and limitations of these new alloy systems in relation to their applications and also briefly explain the physical chemistry of high entropy alloys from the perspective of atomic construction and entropic energy; elaborate on the miscellaneous alloys with their specific properties such as weight to strength ratio, specific strength, high hardness, high temperature mechanical and physical properties, or as an alternative to some of the alloys used for aerospace applications

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 9, Aerospace Alloys, S. Gialanella, A. Malandrucolo, Springer, 2020

6. Additional notes

Topics 9

1. The subject of the lecture

COMPOSITES APPLICATIONS IN DEFENCE AND AVIATION

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

This topic presents an advanced treatment of composite applications in defence and aerospace industries. Composites are commonly used due to their lightweight properties, low absorption of radio waves, high strength to weight ratio, formability, and corrosion resistance. Introduce students to simple definitions of composite materials, including metal matrix, polymer matrix, and FRC (fibre-reinforced composites such as carbon fibre and glass fibre-based composites). Students should be introduced to the way in which composites are manufactured. Composites are generally easier to form at low temperatures than metal alloys, making them versatile materials. To help students understand the advantages of composites, particularly CFRC and GFRC materials, a brief introduction to the procedure for materials selection on the airframe can be provided. However, it is important to note that the selection of materials for each part of the airframe must be carefully analyzed based on the operating environment and loads that the component will experience throughout the airframe's lifespan. For example, aluminium is sensitive to tension loads but performs well under compression. On the other hand, composites are not efficient at handling compression loads but it is a best choice at handling tension. The use of composites, especially in high-tension environments such as the fuselage, significantly reduces maintenance requirements due to fatigue when compared to an aluminium structure. The historical background of composites can be established, followed by an explanation of their gradual use in various industries due to necessity. For example, composites were initially used in military vehicles before being applied to commercial planes. Originally, composites were used in radomes, then it became more common in applications such as tensile loading secondary structures. It was not until carbon reinforcements were introduced that primary composite structures were developed. Composites are now widely used, as metal components have gradually been replaced by integrated composite designs due to their density as opposed to reducing the total weight of airframe. Students should be given examples of composite applications in real applications such as the Airbus 320 which utilises a variety of composite components, such as the fin and tailplane and the use of composites in missiles, leading to the development of primary structures for space vehicles. Students should be introduced to the criteria of space vehicles such as high dynamic pressures during take-off and equidirectional load sharing by the body of satellite due to low gravity and high rotation speeds etc.. Another area of use for composites materials is the space applications that are very well suited for the use of these composites. Moreover, in many cases, no other material is suitable for technical reasons. Students should be given a tabulated data from literature with respect to different types of composites and their effective area of use and the reasoning of the use in the particular area. Students should be involved in a discussion regarding the efficiency of the use of fillers in metal matrix and polymer matrix composites in order to obtain a certain property with a view of final product formability or coatability.

3. Learning outcomes

The students can explain the advantages of composites, particularly CFRC and GFRC materials for the use of many military and commercial applications; provide examples of composite applications in real cases such as the Airbus 320 and the use of composites in missilies and primary structures for aerospace vehicles; identfy the problem with weight reduction in aerospace applications and suggest from various composites in order to meet the specifications; explain how these composites are generally produced and shaped.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 1-6, The Science of Armour Materials, I. G. Crouch, Woodhead publishing, 2017, Oxford

6. Additional notes

Topics 10

1. The subject of the lecture

PENETRATION MECHANICS AND FAILURE MODES

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

This topic aims to introduce armour threats that are defined as penetrative objects, failure mechanisms of armours structures or armour plates with a penetrating projectile. Body armour is designed to protect individuals from various threats, including weapons and ammunition. Some key issues in body armour include threats, materials, and design. The most common threats to body armor can be categorized into several types, including firearms, explosives, and blunt trauma. Typical threats to body armour and the corresponding armoured types used to defeat. Body armour can be made from various materials, such as ceramic, steel, or composites, to withstand different types of threats. The projectiles that are fired from guns and rifles and also free flying non directional particles from explosives may behave differently in thin, thick and infinite armour plates that are designed specifically to defeat the threat. Students should be informed about the specific projectile threats and their resultant effect on the body plate. Various visuals are available in literature and internet resources to present the failing non failing armour plates etc… There should be an in depth analysis of projectiles and armour interactions during the impact moment and a mathematical relationship that defines the materials and projectile behaviour should be given in time. Students should be made aware of penetrating effect of specifically designed projectiles with respect to their calibre sizes or form of tip of ammunitions and their related failure results. Failure mechanisms of these ammunitions should also be explained to the students with a light reference to various impact related materials behaviour relationships as given in previous lecture topics. Modelling studies of penetrating ammunitions or small projectiles with tip forms of oblique and normal, should be shown to students in order for them visualise the energy involved and penetration principles into thick and infinite plates. Literature offers many modelling studies of such studies as well as rod type ammunitions or projectiles failing the armour plates with different materials or structures. Students should be given the failure modes i.e. compressive, tensile and bending failures, based on analytical models that are proposed to guide the design of the penetration projectile. Students should be mentioned on the penetration resistance from a rigid projectile to estimate the forces applied on the projectile during penetration. Projectile nose erosion and the projectile tail attachment failure are also part of this topic. A discussion on the effectiveness of composite and single layer but thick armour plates against the penetrating rods, large calibre and small calibres ammunitions should be initiated and questions relevant to the topic should be directed to the students at the end of the topic.

3. Learning outcomes

Students can state the definition of armour threats, which are defined as penetrative objects, and their impact on body armour and also identify the common threats to body armour, including firearms, explosives, and blunt trauma; analyse the projectiles and armour interactions during the impact moment, including the mathematical relationship between materials and projectile behavior; describe the penetrating effect of specifically designed projectiles with respect to their caliber sizes or form of tip of ammunitions and their related failure results; define the failure mechanisms of these ammunitions and their impact on various materials and materials behavior relationships and also the penetration resistance from a rigid projectile to estimate the forces applied on the projectile during penetration.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 14-15, D.E. Carlucci and S. S. Jacobson, Ballistics: Theory and Design of Guns and Ammunition, Taylor and Francis, Boca Raton, 2008

6. Additional notes

Topics 11

1. The subject of the lecture

DESIGN OF ARMOUR SYSTEMS VIA MATERIALS PROPERTIES

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

This topic aims to introduce the armour systems that are designed for the impact effect from high velocity projectile or free flying objects using various materials available in industry. These materials include polymers based composites, ceramics and metallic armour alloys etc… The design of armour plates should be recalled with a specific intention of teaching how each type of armour material behaves under the impact force or pressure and then how different mixed design would affect the defeat mechanism on the armour plate. The instructor should be actively attentive to mention the importance of collective benefit of armour design by giving examples from the industrial applications and literature studies. It is also important that by understanding the threats from external sources and designing armour plates by using appropriate armour materials, body armour (plate) can provide effective protection for law enforcement and military personnel. The materials design should include the explanation of elastic and plastic behaviour materials in short and detailed information on how materials behave under impact with well known models of failure. Students should be given a well rehearsed explanation of these models as they address different problems arising from the impact forces and material behaviours. It is also necessary to relate these models to classical failure modes of materials and show students the difference between these models and failure using visual examples. Strain hardening is the most important starting point for metallic material design for armour plates, thus, should be well emphasized in the classroom. In additions, other parameters for the design, apart from the models proposed, practically contain of major projectile defeat mechanisms considered in the design a) a hard top surface layer (hard metallic compound such as boride or nitrides, or ceramic (f.e. B_4C) or ceramic based spray coating) against initial impact of the projectile, b) optimally shaped mostly ceramic based pellets or armour alloys to disperse the impact force from the projectile to the surrounding areas, c) a proper bonding material for either CFRC or GFRC materials as well as bonding the pellets to absorb impact energy on the armour and to limit crack propagation on the interlayer and on pellets, d) a network of connecting reinforcements to increase the integrity and reduce the impact force. A discussion on the applicability of damage models with the parameters of design should be initiated with students and how efficient design and efficient model outcome should intertwined may be discussed at the end of topic.

3. Learning outcomes

Students can emphasize the importance of understanding the threats from external sources and designing armor plates using appropriate materials to provide effective protection for law enforcement and military personnel; describe the elastic and plastic behavior of materials, well-known models of failure, and classical failure modes of materials; analyse the design issue in armour plates by considering major projectile defeat mechanisms, including a hard top surface layer, optimally shaped pellets, proper bonding material, and a network of connecting reinforcements.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 1, 9 and 10, The Science of Armour Materials, I. G. Crouch, Woodhead publishing, 2017, Oxford

6. Additional notes

Topics 12

1. The subject of the lecture

HUMAN VULNERABILITY

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

Shock waves, ballistics loading and body-projectile interactions, blast loading, survivability of humans under debris and behind armour, vapour effect from the impact of projectile (3 hr).

The aim of this topic is to present the issue of human vulnerability, which is mainly concerned with the human body exposed to external ballistic impact force resulting in injury, and also with the mechanism by which injury occurs during interaction with high velocity projectiles. The topic should begin with an explanation of the basics of post-impact shock waves and their evolution in and around the human body. A historical development of the ballistic effect on the human body or animals as such examples of such data was not complete until the First World War when improved blast effect was used extensively to deter the opposing forces by demolishing the factories and structures. Prior to development, many tests were carried out on animals and effective testing was carried out on corps in the battlefield. Human vulnerability in ballistics refers to the susceptibility of the human body to injury and death caused by ballistic penetration, such as gunshot wounds. Specific aspects of human vulnerability in ballistics are armour plates, ballistic injuries from which body armour systems are designed to provide protection against ballistic penetration threats, reducing the risk of injury or death. These systems are analysed using modelling and simulation techniques to assess their effectiveness in different scenarios. Ballistic injuries can result from direct or indirect penetration to the human body. The severity of these injuries should be mentioned and the factors involved must be defined before the final effect on humans can be explained. These factors include the type of weapon, the velocity of the projectile and the angle of impact. A list of injuries can be tabulated and classified from minor to life-threatening and may include soft tissue damage, fractures, pulmonary haemorrhage, rupture of lungs, edema and infections. Fatalities from ballistic injuries can be caused by blood loss, tissue damage and other complications. In the case of ballistic loads and blast loads resulting in ballistic penetration, blast injuries occur as a result of the interaction between the blast wave and the human body. These injuries can result in primary, secondary and tertiary damage depending on the nature of the blast and the proximity of the individual to the blast. Students should be provided with information on the basic treatment of ballistic injuries and the various protective measures to be taken in the event of such events. This knowledge can also help in the design of body armour systems that are tailored to the human body and provide optimum protection against ballistic penetration. For example, soft body armour is effective against low and medium velocity handgun projectiles, but may not be sufficient against high velocity projectiles such as those from rifles. Several parametric factors such as weight and cost, multi-hit and fragmentation properties can be mentioned in the classroom. A discussion on the importance of ballistic impact force on humans and animals can be initiated with a view to body shape and armour design.

3. Learning outcomes

The students can explain the basics of shock waves occurring after the blast and after impact, and their development in and around the human body; define and derive conclusions about ballistic loading and its impact on human bodies, including direct and indirect penetration, and the factors that influence the severity of injuries (type of weapon, velocity of the projectile, and angle of impact); explain different types of ballistic injuries, their classification (ranging from minor to life-threatening), and their potential causes (soft-tissue damage, fractures, and infections); relate the concept of ballistic and blast loading, and how they result in ballistic penetration and blast injuries and also suggest the basic treatment of ballistic injuries and the importance of protective measures in case of such events.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Liu S, Xu C, Wen Y, Li G, Zhou J. Assessment of bullet effectiveness based on a human vulnerability model. J R Army Med Corps. 2018 Jul;164(3):172-178.

United States Army Medical Department. *Wound Ballistics*. Washington DC: Office of the Surgeon General, Department of the Army, 1962.

6. Additional notes

Topics 13

1. The subject of the lecture

BALLISTICS STANDARDS

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

Ballistic testing techniques, blast and fragmentation techniques, perforation tests, NIJ standards, STANAG standards (3 hr)

This topic aims to present the standards in ballistics testing and procedures for the validation of either product or damage that will be caused by the firearm or projectile. The topic should begin with explaining the needs for standardisation and number of standards exists in NATO contraries and other countries. A historical development on the ballistic testing can be introduced to the students with perspective of adapting ammunitions and common production of such items. Students should be given information NATO standards collections i.e. STANAG and one of the most used standard, NIJ. The National Institute of Justice (NIJ) establishes and updates voluntary minimum performance standards for body armour, conducts testing against these standards, and sponsors research to improve body armour. Ballistic standards are used to assess the performance of body armor in providing protection against gunfire. These standards rate body armor based on its ability to resist penetration and blunt trauma protection. The NIJ Standard-0101.06, for example, sets performance standards for law enforcement body armor. It rates vests on a scale against penetration and blunt trauma protection. The most widely used ballistic standards for bulletproof vests include the NIJ standard. The UL 752 and NIJ's 0108.01 are common ballistic standards used for bullet-resistant glass. These standards consider factors such as the type of ammunition and the number of hits the armor should withstand. It's important to specify the required level of ballistic protection when ordering products to ensure they meet the necessary standards. Despite there being a multitude of standards, only several standards are used extensively. Two examples of widely-accepted standards include the U.S. National Institute of Justice stab and ballistic documents. STANAG (Standardisation Agreement) is a declaration that sets the standards of NATO member countries in the military field. All military equipment produced by NATO member countries must comply with these standards. This is done through technology/knowledge transfer rather than direct material transfer. An example of STANAG is the STANAG magazine standard, which determines the bullet size of weapons. Many such standardisations have been introduced and they are called STANAG's (STANAGs). Ballistic testing is a process used to evaluate the protection, safety, and performance of various materials and systems, such as armor, firearms, and munitions. The techniques employed in ballistic testing can vary depending on the specific needs and requirements of the test. Many tests are available but in general, vulnerability of armour tests, threat tests, low velocity and fragmentation tests, small- and medium-caliber threats, spiked and edged-weapon threat tests, blast testing, and Ballistic testing exist in defence industry. Of these, ballistic testing is extensively used which involves state-of-the-art indoor testing ranges that can be climate-controlled to ensure accurate results. The ballistic testing process involves using NIJ- and CAST-approved equipment to measure and record the results of the tests. A discussion on the stance of countries on the standardisation of large scale firing power and self making their ammunitions can be initiated with a perspective of arms exports and imports issues.

3. Learning outcomes

The students can explain the basics understanding of the need for standardization in ballistics testing and the existence of various standards in NATO countries and other nations; define the prominent ballistic standards such as NIJ (National Institute of Justice) and NATO standards collections like STANAG, which are used to assess the performance of body armor in providing protection against gunfire; recognise the importance of specifying the required level of ballistic protection when ordering products to ensure they meet the necessary standards; explain the widespread use of ballistic testing in evaluating the protection, safety, and performance of various materials and systems in the defense industry, including armor, firearms, and munitions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 11, The Science of Armour Materials, I. G. Crouch, Woodhead publishing, 2017, Oxford

https://www.bodyarmornews.com/ballistic-standards/

6. Additional notes

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

FAILURE ANALYSIS

Code: FA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO FAILURE AND CAUSES

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

This topic aims to introduce definitons of failure concept and general views on the causes of the failure observed in industrial and special applications. Students should be given a definition of failure from the perspective of strength of materials and atomistic deformation or dislocation theories. Student should be mentioned of the consequences of failure that is encountered in all machine parts or sturtcural parts at some point, which which is preventable and can be delayed with appropriate measures. Failure analysis, or root cause analysis of structural failures, is a comprehensive interdisciplinary science that investigates to determine the failure mechanism of machine parts in service and root causes of these failures in the event of a component or equipment failure. Common failures and corresponding solutions should also be provided to the students in the forms of tabulated data. Students should be given information about a typical failure analysis procedure that is composed of collecting data using standardised methods of investigation and analysing collected data or existing data obtained from failed parts or structures with the help of metallographic, visual and / or metallurgical analysis. Failure analysis procedures should involve a human factor that is prone to error and hence necessary precautions such as statistically determined number of sampling and sampling locations should be taken care of during investigation. A short introduction to these basic rules of investigation can be given to students to remind them how these details affect the results. Students should be made aware of the fact that some failures are commercially very important and hence meticulous explorations of evidences are needed with strict rules. Many examples can be given on the style of failure analysis; many different examples of materials and structures are also to be given to students. Students should be involved a discussion regarding the failures of more specific or non common applications such as nuclear power plants or electronics devices that are employed to measure distance etc… in order to make them understand that generalised procedure is always useful for even non stardard cases. Students may involve in a discussion regarding the need for failure analysis for non materials related subjects.

3. Learning outcomes

Students can explain the failure modes from mechanistic and materials point of view to explain how the failure may have occurred; describe the procedures for failure analysis of failed part or structures with the help of knowledge obtained in this class; explain the procedures of analysis in detail; interpret the failure procedure and suggest a routine to investigate the failed part based on the evidences to be obtained and procedures to be followed.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

Additional, optional literature:

- ASHBY, M. F., and JONES, D. R. H., Engineering Materials, Pergamon Press, Oxford, 1980

-CADDELL, R. M., Deformation and Fracture of Solids, Prentice-Hall, Inc., New Jersey, 1980

6. Additional notes

Topics 2

1. The subject of the lecture

FAILURE IN CASTINGS AND MELTING RELATED PROCESSES

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

This topic aims to introduce the failure types and solution in castings and melting related processes such as induction melting, classical crucible melting and alloy making remelting. Alloy making procedures are needed to be introduced to the students and possible methods of melting procedures can be given separately to introduce them to various procedures that may be being used in industry. Casting procedure also varies with type of industry such as, arc and induction remelting are more common for the casting of large sections or in order to produce good quality heat. A summary of these procedures or methods of production should be given to students. Students should be introduced a quality control procedures for a casting factory and how it is doneduring the production of casting i.e. regular quality control checks and inspections during the melting and casting processes. Casting technology has davnaced dramatically by the implementation of advanced technologies, such as computer simulations, to optimize casting designs and predict potential issues. Continuous training and skill development for personnel involved in casting operations are needed and this eventually leads to the reduced rejection rate and less number of improperly cast parts. The knowledge on how defects form in castings are important for workers as to solve problems during the pouring stage, such as turbulence or improper pouring temperature, can result in defects like misruns or cold shuts. Optimizing pouring techniques and ensuring a controlled solidification process help prevent such casting failures. Inadequate heat treatment after casting can lead to insufficient mechanical properties or dimensional instability. Proper post-casting heat treatment processes, such as annealing or quenching, are necessary to enhance the material's properties. Students should be extensively given information about casting operations and fabrication routes for remelting and casting defects and their prevention with a knowledge on typical problems of solidification and proposed design problems. Students should be involved in a discussion regarding the role of inclusions and their size in typical steel castings.

3. Learning outcomes

Students can explain the casting processes that are available in industry and present the problems associated with castings and melting related processes; describe the defects that are formed during the casting and melting and analyse them to decide if they are resourced from design of the casting mold or other parameters such as pouring temperature, pouring rate etc…; elaborate on the prevention of defects of casting and remelting processes employed in steel making and no ferrous casting procedures.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.

Additional, optional literature:

- Ashby, M. F., and Jones, D. R. H., Engineering Materials, Pergamon Press, Oxford, 1980
-Caddell, R. M., Deformation and Fracture of Solids, Prentice-Hall, Inc., New Jersey, 1980

6. Additional notes

Topics 3

1. The subject of the lecture

HYDROGEN CRACKING

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

This topic aims to introduce one of the critical problems that are sourced back to high alloying element and hard microstructures observed mostly in steels. Hydrogen cracking, also known as hydrogen-induced cracking (HIC), is a metallurgical phenomenon that poses a significant challenge in various industries, particularly those using high-strength steels and alloys. This type of cracking occurs when hydrogen interacts with the metal surface and travel to the inner part of the specimen, leading to the formation of cracks that can compromise the structural integrity of the material. Hydrogen cracking manifests in different forms, with hydrogen-induced cracking (HIC) and hydrogen-induced stress cracking (HISC) being notable types. HIC involves the formation of small, blister-like cracks oriented parallel to the material's surface, leading to reduced toughness and strength. On the other hand, HISC occurs under sustained tensile stresses and is associated with prolonged exposure to hydrogen-containing environments, with cracks exhibiting intergranular or transgranular characteristics. Working principle of hydrogen cracking should be given to students because it is vital for industries where reliability and safety are paramount in structural engineering. One of the primary factors contributing to hydrogen cracking is the susceptibility of certain materials, especially high-strength steels, to hydrogen embrittlement. This vulnerability arises during various stages of the material's life cycle, such as welding, heat treatment, or exposure to environments containing hydrogen. The mechanisms of hydrogen breakdown from various sources can be given to students in visual forms in order to make them understand the procedure. Sources of hydrogen may include the breakdown of moisture, hydrocarbons, or other hydrogen-containing compounds. The presence of residual stresses within the material, induced by welding or fabrication processes, acts as a catalyst for hydrogen cracking. These stresses create conditions favorable for crack initiation and propagation. Additionally, the microstructure of the material plays a crucial role, with certain characteristics, such as coarse grains or high impurity levels, increasing susceptibility to cracking. Inclusions or precipitates within the material can also serve as initiation sites for internal cracks. Prevention of HIC or HISC require Careful material selection, stress management, Hydrogen removal strategies, such as minimizing hydrogen exposure during welding and fabrication and employing preheating and post-weld heat treatment help reduce residual stresses and promote hydrogen diffusion. Students should be involved in a discussion regarding the hydrogen cracking in non ferrous metals.

3. Learning outcomes

Students can explain the mechanism of formation of hydrogen cracking phenomena in high strength steels and highly alloyed steels; elaborate on the prevention of hydrogen cracking based on the hydrogen removal procedures and materials selection routine; analyse the hydrogen cracking in steel by the appearance of broken surface and crack propagation.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.

6. Additional notes

Topics 4

1. The subject of the lecture

LIQUID METAL CRACKING/ SOLIDIFICATION CRACKING

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

This topic aims to give detailed information on liquid metal cracking and or solidification cracking problems observed in castings. Liquid metal cracking and solidification cracking are two distinct but related phenomena that can compromise the structural integrity of metallic materials, particularly during welding and casting processes. Students should be informed that these types of cracking are critical in various industries, including manufacturing, construction, and aerospace. Eliminating working mechanisms and implementing industry proof preventive measures are essential for liquid metal cracking which occurs during the solidification phase of metal alloys when the material is in a partially molten state. This phenomenon is particularly prevalent in alloys with low melting ranges or narrow freezing temperature ranges. As the metal cools and solidifies, the contraction can induce cracking, especially in areas with high thermal gradients. One common scenario for liquid metal cracking is in the weld fusion zone. Rapid cooling during welding can lead to the formation of cracks, often perpendicular to the fusion line. These cracks are typically associated with high levels of restraint and are more likely to occur in materials with high thermal expansion coefficients. Solidification cracking, also known as hot cracking or centerline cracking, is another type of cracking that occurs during the cooling and solidification of molten metal. The key contributing factors to solidification cracking include high levels of sulfur and phosphorous, which can lower the material's ductility. Additionally, a high cooling rate during solidification, often encountered in thin sections or when welding thick joints, can exacerbate the likelihood of cracking. Preventing liquid metal cracking and solidification cracking involve a combination of material selection, welding techniques, and process control. Alloy compositions should be carefully chosen to minimize susceptibility to cracking, with attention to the levels of impurities that can affect ductility. Controlling the cooling rate during welding or casting is crucial for mitigating both types of cracking through preheating, post-weld heat treatment, or adjusting welding parameters to ensure a more gradual cooling process. Proper weld joint design, minimizing welding restraint, and selecting appropriate filler materials are also essential to prevent cracking. Students should involve in a discussion regarding the use of external sources to prevent solidification cracking such as high frequency sound (ultrasound) etc…

3. Learning outcomes

Students can give detailed information about the mechanism of solidification cracking occurring in welding and casting processes; elaborate the preventive measures that need to be taken during the casting and welding and suggect an appropriate measure for a given case; elaborate on the effect of some alloying elements that inhibits the theo formation of crack free joints.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

6. Additional notes

Topics 5

1. The subject of the lecture

PLASTIC DEFORMATION PROCESSES AND DEFECTS

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

This topic aims to present the problems associated with the plastic deformation or shaping and forming of metals i.e. the rolling of metal sheet using external forces and, the formation defects resulting from the improper deformation. Students should be given a detailed treatment of plastic deformation processes observed in industry such as sheet metal making, shaping etc… Students should also be aware of deformation capacity of materials in the form of limit diagrams for shaping of metal sheets and how they are interpreted in industry. The effect of temperature on the forming ability and following size stability of products are important aspect of shaping; low temperature shaping as well as new type of steels (DP series) would result in spring back problem, too. Plastic deformation processes play a pivotal role in the manufacturing of various components across industries where most of the automotive and white goods need sheet metal produced with size precision and achieve desired mechanical properties. These processes, such as forging, rolling, extrusion, and drawing, involve the application of controlled forces to alter the shape of a material permanently. However, like any manufacturing technique, plastic deformation is not without its challenges, and defects can arise during these processes. Excessive force, uneven surface or inadequate temperature control can lead to cracks and fractures in the material during plastic deformation. Proper process parameters and material preparation are critical to avoiding these defects. Surface defects, such as laps, folds, or wrinkles, can occur due to uneven deformation or improper die design, which would be prevented by uniform stress distribution and optimizing tooling design. Insufficient material cleanliness can result in internal defects like voids or inclusions, increasing the chance of having dimple surface defects. Residual stresses can arise during plastic deformation by which post-deformation heat treatments may be employed to relieve these stresses and enhance material performance. Careful control of process parameters, including temperature, strain rate, and deformation rate, ensures that the material undergoes plastic deformation without exceeding its limits. Well-designed dies and tooling with appropriate clearances and radii help prevent surface defects and ensure uniform deformation. While defects may arise, adopting preventive measures and meticulous process control can significantly enhance the quality of the final products and this ensures formed components meet the desired specifications and performance standards. Students should involve in a discussion on the use of rollers with different design that may exceed the capacity of limit of shaping and precautions to thin a metal to make a folio.

3. Learning outcomes

Students can describe plastic deformation processes employed in industry to produce sheet metals with high size precision; explain how defects form in metal sheet or perform and elaborate the main reasons for defect formation; explain the preventive measures to avoid defects froming in sheet metals during and after the rolling and forging processes.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

6. Additional notes

Topics 6

1. The subject of the lecture

CORROSION DEFECTS

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

This topic aims to present a collection of defects and solutions to problems eminating from corrosion and failures that are partly involving corrosion. This topic also presents the types of corrosion defects, their causes, and implementing effective prevention measures. Students should be given a list of failures that are related to corrosion and preventive measures that are proven to be useful. Students should also be mentioned of a tabulated list of corrosion resistant materials and their limits for corrosion with respect to operational temperature, molarity of chemicals and special conditions. This tabulated form of data should also contain the efficacy of certain coatings generated using various techniques based on literature studies. Corrosion, a natural electrochemical process that leads to the deterioration of materials, is an insidious challenge in various industries. This electrochemical reaction between materials and their environment results in the formation of corrosion defects and compromises the integrity of structures and components.

Uniform corrosion is the most common type, characterized by a relatively even removal of material across the exposed surface. Localized corrosion includes pitting, crevice corrosion, and galvanic corrosion. Pitting involves the formation of small pits on the material's surface, while crevice corrosion occurs in confined spaces. Galvanic corrosion arises from the interaction of dissimilar metals. Filiform corrosion is specific to coatings on metals; it forms beneath the protective coating. It is commonly observed in outdoor environments with high humidity. Intergranular corrosion occurs along grain boundaries, weakening the material at the microscopic level, which is often associated with certain alloys and heat treatment processes. Exposure to aggressive chemicals in the environment, such as acids, salts, or pollutants, can accelerate the corrosion process, initially leading to the formation of surface defects. The interaction of metals with moisture and oxygen initiates electrochemical reactions that contribute to corrosion. Elevated temperatures and high humidity levels create favorable conditions for corrosion defects. Microorganisms, including bacteria and fungi, can contribute to corrosion defects in certain environments. Microbial activity produces corrosive byproducts that accelerate material deterioration. A collection of images of corrosive defects observed on industrial materials and under special conditions should be presented in the classroom. Applying protective coatings, such as paints or corrosion resistant coatings, creates a barrier between the material and the corrosive environment. Cathodic protection involves the use of sacrificial anodes or impressed current systems to control the electrochemical reactions responsible for corrosion, particularly in structures like pipelines or offshore platforms. Stainless steels, aluminum, and corrosion-resistant alloys are examples of materials with enhanced resistance. Regular monitoring of environmental conditions and corrosion rates enables early detection of potential defects. Students should involve in a discussion regarding the corrosion in the sea and prevention based on the type of material.

3. Learning outcomes

Students can describe the main corrosion types observed commonly in industrial applications and also specific corrosion process with underlying mechanisms; recognise the defects from corrosive processes and suggests a plausible preventive measure based on the type of corrosion; differentiate between the corrosion types based on the images and actual parts that are corroded naturally or unnaturally.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.
- Mondal, B.C. and Dhar, A. S., Interaction of multiple corrosion defects on burst pressure of pipelines, Canadian Journal of Civil Engineering, 2017, https://doi.org/10.1139/cjce-2016-060

6. Additional notes

Topics 7

1. The subject of the lecture

WELDING AND WELD DEFECTS

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

This topic aims to present welding related defects that form during various welding processes. A short introduction of welding processes and general properties of weld metals such as mechanical and microstructural differences compared to base metal should be given to students prior to going deeper into defect formation. It should be born in mind that welding is a fundamental process in manufacturing and construction, which enable the joining of materials to create strong and / or robust joints. However, like any manufacturing process, welding is also susceptible to the formation of various defects that can compromise its the structural integrity and mechanical properties. Common weld defects can be prevented by implementing quality control measures that are crucial in ensuring the reliability and safety of welded components. Common welding methods include arc welding, gas welding, and resistance welding, each with its specific applications and characteristics. Porosity in welds occurs due to the entrapment of gases, such as hydrogen or nitrogen, during the welding process. This defect weakens the weld and may lead to premature failure. Cracks can manifest in various forms, including hot cracks, cold cracks, and solidification cracks. These defects often result from improper welding parameters, high residual stresses, or inadequate preheating. Incomplete fusion or penetration occurs when the weld fails to fully join the base materials. This defect can weaken the weld joint and compromise its load-bearing capacity. Undercutting is a groove-like defect along the weld's toe, often caused by excessive heat or incorrect welding techniques. Spatter refers to the expulsion of molten metal droplets during welding, which can result in surface irregularities and compromise the aesthetics of the weld; it can happen in many weld techniques specifically spot welding and arc welding. Adhering to proper welding procedures, including selecting appropriate welding parameters, maintaining correct electrode angles, and using suitable filler materials, is fundamental in preventing weld defects. Regular quality control through non-destructive testing methods, such as X-ray or ultrasonic testing, helps detect hidden defects and ensures the integrity of the weld zone. Proper cleaning and preparation of base materials, as well as adequate preheating, contribute to successful welding and minimize the risk of defects. In some cases, post-weld heat treatment can relieve residual stresses and reduce the likelihood of defects like cracking, enhancing the overall integrity of the weld. Students should involve in a discussion regarding the quality control of spot welds in car chassiss.

3. Learning outcomes

Students can explain the importance of welding for the industry and also types of welding techniques that are heavily used in many sectors of industry; describe the formation of common defects in weld metals and suggest a proper solution to the given problem; analyse the problem related to the welding defects from visual sources and suggest a preventive measures for the given problem.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.
- https://testbook.com/mechanical-engineering/welding-defects-types-and-causes

6. Additional notes

Topics 8

1. The subject of the lecture

HEAT TREATMENT OF METALS AND RELATED DEFECTS

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

This topic aims to present an extensive treatment on defects and their formation mechanisms in heat treatment processes. Students should be given an introduction to basic heat treatment processes applied in industry. Students should be informed about the definitions of various phase and time temperature transformation diagrams that are related to the processing of steels. A list heat treatment processes for steels and for some commercial alloys can be given in a tabulated form with respect to treatment temperatures and properties to be achieved following the heat treatment. Heat treatment is a critical process in metallurgy and materials related industries that involve the controlled heating and cooling of metals to alter their physical and mechanical properties. This technique is widely employed in various industries to enhance the strength, hardness, toughness, and other characteristics of metallic materials. However, like any manufacturing process, heat treatment is not immune to defects, and understanding these issues is essential for achieving optimal results. Cracking can occur during the heating or cooling stages of heat treatment due to metallurgical or design reasons such as thin sections. Hence, the fast or uneven cooling, excessive internal stresses, or material impurities can contribute to crack formation. Decarburization is the loss of carbon from the surface of the steel during heating, which can reduce hardness and strength. However, the loss of certain elements such as Cr and Mn are also observed in steels passing through heating and holding stage. In processes susceptible to surface reactions, such as decarburization, maintaining a controlled atmosphere is essential. This prevents the loss of alloying elements and maintains the desired material properties. Shape distortion, or shape change in extreme degrees can occur due to uneven heating or cooling during quenching or imporper furnace locations. One of the most observed defects in heat treatment is excessive grain growth during heat treatment which can lead to reduced mechanical properties. Students should be given extended treatment on excessive grain growth mechanism and its prevention in most steels. A list of problems related to heat treatment and respective solutions can be given to students in a tabulated form in addition to mechanisms active in the formation of such defects. Students should be informed that the most important solution most of the problems are proper temperature control and holding times to prevent abnormal grain growth and cracking through intergranular manner. Controlling the cooling rate, especially during quenching, helps prevent cracking and distortion. Quenching mediums and techniques are selected based on the material's composition and properties. Heat treatment is a versatile tool for tailoring the properties of metals to meet specific application requirements. Students should involve in a discussion regarding the use of heat treatment for critical applications such as induction heating of band saws and possible defect formation such processes.

3. Learning outcomes

Students can describe the heat treatment processes and their possible applications in various industries; explain the mechanisms behind the defect formation due to heat treatment in steels and some other commercial alloys; visually recognise the defects after heat treatment and suggest plausible solutions to such problems.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

6. Additional notes

Topics 9

1. The subject of the lecture

WEAR

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

This topic aims to present the types of wear and resulting defects forming on the surface or sinde of machine parts. Wear is an inevitable aspect of material interactions, but with a thorough understanding of wear mechanisms and the implementation of effective improvement strategies, its impact on the materials loss and labour costs can be effectively minimized. It needs proper material selection, surface treatments, lubrication, and maintenance to warrant the longevity and performance of materials and mechanical systems in many industrial applications. Students should be given a list of applications where wear is dominant failure mechanism. Wear is a natural and inevitable process that occurs when two surfaces come into contact and experience relative motion. This phenomenon, prevalent in various industries and everyday activities, leads to the gradual loss of material and changes in surface properties. Students should be given information about the types of wear, the factors influencing wear mechanisms, and employing effective prevention strategies that are essential for enhancing the longevity and performance of materials and mechanical components. Students should be given a list of wear types and their final effect on the surface of materials in a tabulated form in order to make them familiar to the defects from wear process. A list of preventive measures can also be given with respect to type of wear for common materials and specific applications. Main parameters such as the hardness, strength, and toughness of materials should be mentioned to the students and clearly state that these influence resistance to wear. Harder materials generally exhibit better resistance to abrasive wear. A smooth surface with proper machining and finishing processes reduces the likelihood of abrasive wear, which contribute to improved wear resistance. Lubrication plays a crucial role in reducing the wear by minimizing friction between surfaces. High loads and pressures can accelerate wear as elevated temperatures can exacerbate wear by influencing material properties and promoting oxidation. The best method of preventing wear is through choosing materials with superior wear resistance for specific applications. Hardened alloys, ceramics, and composite materials are often selected for their enhanced wear properties. Applying wear - resistant coatings, such as hard chrome, nitriding, or ceramic coatings, provides an additional layer of protection to surfaces, reducing wear rates. Students should have a discussion on the efficiency of coatings compared to hardened surfaces and decide which one is suitable for the industrial applications.

3. Learning outcomes

Students can explain the wear types and mechanisms involving in the failure of machine parts; analyse the wear condition through images and suggest a proper solution to the source of problem and a method to amend the worn surface to improve the friction and resulting wear;

analyse the machine part and weigh the conditions of working and suggest a coating that will reduce the wear during the service.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

6. Additional notes

Topics 10

1. The subject of the lecture

MILLING AND MACHINING DEFECTS OF METALS AND ALLOYS

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

This topic aims to introduce a process which Milling and machining are fundamental processes in the manufacturing industry, enabling the precise shaping of metals and alloys to meet specific design requirements. However, machining and removal of excessive metal present a high level of dimensional accuracy, they are also prone to defects that can affect the quality and integrity of the finished components. Some common defects associated with milling and machining can be overcome by implementing effective preventive measures. Surface roughness with high depth is a common defect resulting from milling and machining processes. It manifests itself as asperity irregularities on the surface of the machined part and can be influenced by factors such as feed rate, tool wear, and cutting speed. Other issue with milling and machining is the tool wear which is a significant concern in milling and machining. As tools work with metal surfaces, they undergo gradual wear of the tip and affect the precision and quality of the machined components. Students should be given many examples from industry related to the worn surfaces of both tool and machined surfaces. Chatter occurs when vibrations are transmitted to the tool during machining, leading to irregularities on the machined surface. It often results from improper tool selection, unstable machining conditions, or inadequate machine rigidity. Built-up edge is the accumulation of workpiece material on the cutting tool during machining. Intensive machining operations, especially in the case of thin-walled or intricate components, can induce deformation and residual stresses in the material. Adjusting cutting parameters, such as cutting speed, feed rate, and depth of cut, helps optimize machining conditions. Finding the right balance minimizes tool wear, reduces surface roughness, and enhances overall machining quality. The appropriate cutting tool material and geometry is crucial for smooth operation and surface finish. Proper coolant and lubrication systems aid in dissipating heat generated during machining, reducing tool wear and built-up edge formation. They also contribute to improved surface finish. Employing post-machining treatments, such as stress relieving or heat treatment, helps lessen residual stresses and deformation induced during machining, ensuring the dimensional stability of the final part. A discussion on the behaviour tool materials at excessive temperature should be initiated with students and a proper solution should be seeked to mend the condition of such case.

3. Learning outcomes

Students can recognise the milling and machining defects formed during the process of excessive metal removal and analyse the case based on parameters given in the lectures; describe the milling parameters and explain the mechanisms with which defects occur; suggest a methodology that will help tool wear is lessened and surface finish is improved.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.
- Tangjitsitcharoen, S., Pongsathornwiwat, N. Development of chatter detection in milling processes. *Int J Adv Manuf Technol* **65**, 919–927 (2013).

6. Additional notes

Topics 11

1. The subject of the lecture

DEFECTS IN ROLLERS AND EXTRUSION PROCESSES

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

This topic aims to present plastic deformation process specific to rollers and rolling of sheet metals with a focus on cracks and surface defects on rollers. It is also aim of this topic to mention the defect formation in extrusion processes such as aluminium and plastic extrusion processes. Extrusion is a simple process in which metal or plastic is forced to extrude from a predefined orifice with a specific shape in this way, the shape of extruded product takes the form of predefined extrusion dies or orifice, resulting in simple shapes such as cylindrical rods and pipes, rectangular solid and hollow bars, and long plates. Students should be given a short introduction of extrusion and main parameters should be mentioned with a possible result on the surface. The parameters such as the temperature of the billet, the shape of orifice of die for extrusion and pressure of ram should be mentioned to students. Rollers and rolling processes play a pivotal role in various industries, providing efficient means of shaping and forming materials. These processes are fundamental in metalworking, paper production, textiles, and numerous other manufacturing sectors. The formation of defects on the roller requires the understanding of principles of rolling, the types of rollers, and the diverse applications of rolling processes which is essential for achieving precision, consistency, and efficiency in material shaping. Flat rollers are the most common type and are used for simple flat rolling processes. They impart a consistent thickness to the material and are crucial in the production of sheet metal. Grooved rollers have patterns or grooves on their surfaces, allowing for the production of specific profiles or shapes in the material. This type is essential in the manufacturing of rails, rods, and various structural components. Thread rollers are designed to produce threads on rods, bolts, or screws. This type of rolling process is widely used in the production of fasteners and threaded components. Ring rollers are specialized for shaping materials into circular or curved profiles. They are employed in the production of seamless rings, bearings, and cylindrical components. Rolling processes are extensively used in metal forming industries to produce sheets, plates, bars, and profiles with precise dimensions and mechanical properties. Rollers are also crucial in paper production, where they contribute to calendering and smoothing processes. In textiles, rollers play a role in the manufacturing of fabrics and especially printing a motive on the fabric. Rolling processes are integral in the automotive industry for manufacturing components like chassis parts and engine components. In aerospace, they contribute to the production of aircraft components with tight tolerances. Each application introduced a different defects formation on the rollers and hence it requires special attention. Students should be aware of the working conditions of rollers and make a specific analysis on each case. Students should discuss what differences rollers should have in case of paper milling and sheet metal rolling.

3. Learning outcomes

Students can describe the process of rolling in many industrial fields and recognise the defects on the rollers with respect to place where the rollers are used; define the extrusion processes and possible surface and in body defect during and after extrusion processes of aluminium and plastic materials; analyse rolling processes in different applications and suggest a preventive measures in order for rollers and extrusion dies work smoothly with less wear.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.
- Patel SP, Upadhyay SH. Influence of roller defect and coupled roller–inner–outer race defects on the performance of cylindrical roller bearing. Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics. 2019; 233(3):731-746. doi:10.1177/1464419318819332
- Wei Shao, Peng Peng, Yunqiu Shao, Awei Zhou, "A Method for Identifying Defects on Highly Reflective Roller Surface Based on Image Library Matching", *Mathematical Problems in Engineering*, vol. 2020, Article ID 1837528, 9 pages, 2020. https://doi.org/10.1155/2020/1837528

6. Additional notes

Topics 12

1. The subject of the lecture

SHAPING AND FORGING LIMIT DIAGRAMS

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

This topic aims to further the shaping, forging and forming limit diagrams used in sheet metal and deformation processes in general. Although briefly introduced in week 5 under the topic of plastic deformation processes and defect formation, a more in-depth treatment of shaping limit diagrams would be useful in understanding defect mechanisms and their application to various shaping and forming processes. Shaping limit diagrams, also referred to as forming limit diagrams (FLD), illustrate the strain limits beyond which sheet metal undergoes localized necking or tearing during forming processes. Shaping limit diagrams are essential for predicting defects and optimizing forming conditions to prevent failures. Engineers use them to ensure uniform deformation of the material without reaching critical strain levels that cause fractures or wrinkles by understanding the material's behavior under different stress conditions, the feasibility and parameters of shaping operations. Forging limit diagrams focus on the forging process, which involves applying compressive forces to shape and deform materials. These diagrams provide a visual representation of the material's formability limits during forging, considering factors such as temperature, strain rate, and material properties. They help identify the conditions under which the material is susceptible to defects like laps, folds, or cracks. Manufacturers can utilise this information to adjust forging parameters, such as temperature and pressure, to enhance the material's plasticity and prevent unwanted deformations. Shaping and forging limit diagrams are widely used in the automotive industry to design and optimise processes for producing body panels, chassis components, and engine parts. Shaping and forging limit diagrams are useful in developing efficient manufacturing processes for aircraft components in aerospace engineering, where lightweight and high-strength materials are prevalent. The construction industry also utilizes these diagrams to shape structural components and ensure the integrity and durability of materials used in buildings and infrastructure projects. Shaping and forging limit diagrams are essential tools for engineers and manufacturers who want to optimize material forming processes. These diagrams guide the design and execution of shaping operations by considering material properties, temperature, strain rate, and other factors. It is important to discuss in detail the specific industry for which these diagrams are being applied. Additionally, students should also consider the parameters under which these diagrams can be applied, such as ballistics.

3. Learning outcomes

Students can explain the use of shaping or forming limit diagrams and forging limit diagrams in especially sheet metal forming industry; describe the defect mechanisms in forming and shaping processes and suggest a plausible solution; recognise the defects by the visual examination and from images obtained from various shaping and forming processes.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- Colangelo, V. J., Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, New York, 1974.
- Handbook of Case Histories in Failure Analysis, ASM International, 1992.
- Charlie R.B., Ashok C., Failure Analysis of Engineering Materials, McGraw-Hill, New York, 2002.

6. Additional notes

Topics 13

1. The subject of the lecture

DEFECT FORMATION DURING METAL POURING

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

This topic aims to present the metal pouring and solidification in foundaries and defects forming related to this process. Students should be given brief information about the furnaces and melting cupolas with various purposes; some of them are good for non ferrous metals and alloys and some are good for high alloyed steels and cast irons. Lining of the cupolas should also be mentioned for the proper definition of melting pots. Metal pouring is a critical stage in metallurgical processes and it involves transferring molten metal from a furnace to molds or other casting structures and defects can occur during metal pouring, impacting the quality of the final product. Students should be informed to be familiar with the potential defects, their causes, and implementing preventive measures that are essential for ensuring the success of metallurgical processes. Alloying of melts should be introduced to students with a special interest to prealloyed ferro alloys that are used to reduce the loss during the alloying process. Shrinkage defects occur when the molten metal contracts upon solidification, leading to voids or cavities in the cast structure. These defects are often influenced by factors such as cooling rate, alloy composition, and mold design. Porosity is the presence of small voids or gas pockets within the cast metal and it can have detrimental effect on the strength of billet. It results from gases escaping from the non killed molten metal during pouring or inadequate venting in the mold. Non-metallic particles or inclusions become trapped in the cast metal which originate from the raw materials, melting process, or inadequate filtration of the molten metal. Cold shut defects occur when the molten metal does not properly fuse with other end during pouring, leading to a partially filled cavity. This defect is often associated with improper pouring techniques or inadequate gating systems. Misruns and short pours happen when the molten metal fails to completely fill the mold, resulting in incomplete castings. Inconsistent pouring practices, such as improper pouring speed or angle, can lead to defects like misruns, cold shuts, and uneven filling of molds. Contaminations in raw materials, such as impurities or moisture, can lead to inclusions and porosity in the cast metal. A careful attention to pouring practices, mold design, material quality, and temperature control can prevent most of the defects forming during the melt pouring. A discussion can be intitiated on how the lining of melting pots and resulting products are related i.e. basic or acidic linings are important for the final product.

3. Learning outcomes

Students can recognise the defects resulting from improper melt pouring practice; explain the formation mechanisms of most defects formed during melt pouring; analyse the defects and suggest a plausible solution to the given problem; explain each parameters of metal pouring process and describe the resulting effect on the final products.

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

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Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**.

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

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- Handbook of Case Histories in Failure Analysis, ASM International, 1992.

6. Additional notes

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).

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

MATERIALS SELECTION AND PRINCIPLES

Code: MSP

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

MATERIALS AND CLASSIFICATION BASED ON THE USE IN INDUSTRY

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

This topic aims to introduce the materials classfication that are used in the industry. Students should be given information about the classification of materials based on their usage and their properteis. The classification of materials for specific purposes involves grouping them into categories such as metals, ceramics, polymers, and composites, based on their chemical makeup and atomic structure. Students can be introduced to common crystal structres that are found in industrial materials. The steps for selecting the appropriate material include identifying material properties, considering costs, and using tools like material indices or performance indices. Factors to consider during the selection process encompass mechanical properties, design requirements, availability, manufacturability, and cost. The responsibility of the selection process lies with designers and engineers, who must choose materials that meet performance goals at the lowest cost. The selection principles involve considering factors such as material availability, mechanical properties, and the impact of manufacturing processes and heat treatments on material properties During the lecture, as an introduction to the issue of sustainable nanotechnology, the most important features of nanotechnology will be presented, which indicate that it is considered the technology of the future. The reasons for which it is of great interest in various fields will be indicated by appropriate didactic materials. Students should be reminded about the knowledge that they have gained about the unique properties of nanomaterials that enable their innovative applications in various aspects of everyday life of people and the world of technology, such as: food, various fields of manufacturing of metallics, nonmetallic, organic and inorganic materials, mechanics, optics, medicine, chemical industry, electronics, energy, catalysis, optoelectronics and photoelectrochemical applications and non-linear optical devices. During the lecture, students will learn that despite such a rich contribution to the development of science and various applications, nanotechnology unfortunately has a negative impact on our environment and human health. Students should involve in discussions regarding the importance of materials classification in various industries.

3. Learning outcomes

Students can explain the classification of materials based on their usage and properties, such as metals, ceramics, polymers, and composites, considering their chemical makeup and atomic structure; define the understanding of the steps involved in selecting appropriate materials, including identifying material properties, considering costs, and using tools like material indices or performance indices; define the factors to consider during the selection process, such as mechanical properties, design requirements, availability, manufacturability, and cost and emphasize the responsibility of designers and engineers in choosing materials that meet performance goals at the lowest cost; present the important features of nanotechnology as the technology of the future and its applications in various fields such as food, production, mechanics, optics, medicine, chemical industry, electronics, energy, catalysis, optoelectronics, and photoelectrochemical applications.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)
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Students are expected to read below texts related to the lecture:

- *Materials Science: A Field of Diverse Industrial Applications.* Edited by Arti Srivastava, Mridula Tripathi, Kalpana Awasthi, Subhash Banerjee, Bentham Books 2023, DOI:10.2174/97898150512471230101.

- Industrial Materials 2nd Edition, Larry David Helsel (Author), Peter P. Liu (Author), Goodheart-Willcox Pub 2007.

6. Additional notes

Topics 2

1. The subject of the lecture

MATERIALS SELECTION CRITERIA AND TABULATED DATA

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

This topic aims to introduce the criteria of materials selection for various applications and its sicentific procedures for the given application. The important part of this topic is to introduce the tabulated data regarding the selection based on various properties in the form of tabulated data obatined from various sources of literature study and books available in this field. In this topic, the coin production can be given as an example for the materials selection and using come tabulated data available in books or literature. Students may be asked to show the coins in their pockets and can be asked what sort requirements can be thought of when using coins in a regular day. Availability, economics, manufacturability, joinability, corrosion, and wear are all important criteria in the selection of alloys for coin production. Availability refers to the accessibility of the raw materials, while economics involves the cost of the materials and the overall production process. Students will learn how easily the material can be processed into coins, and joinability refers to the ability to join the material through processes like welding or soldering. Corrosion and wear resistance are crucial for the durability of coins. For instance, aluminum alloys are often selected for coin production due to their availability, low cost, and good corrosion resistance. Students should also be given information about the other sources for the selection of alloys used for machines such as pumps, machine parts such as pipes or external surfaces of boats which are used in saline environment. The selection of materials for these environments involves a careful consideration of these factors to ensure the quality and longevity of the products in certain mediums. Students should involve a discussion regarding the use of industrial alloys and new type of alloys such as high entropy alloys to be used in such environments in terms of advantages and disadvantages as the new alloys are not tested sufficiently in such environments.

3. Learning outcomes

Students can analyze the suitability of different alloys for coin production based on the given criteria; explain the rationale behind the selection of specific alloys for coins; identify the potential challenges associated with using different materials in coin production; develop critical thinking skills by weighing the various factors involved in material selection; appreciate the importance of careful material selection in ensuring the quality and durability of products; develop an understanding of the economic and practical considerations involved in engineering design; gain a sense of the trade-offs and compromises often necessary when selecting materials for specific applications.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-*Handbook of Materials Selection.* Edited by Myer Kutz, John Wiley & Sons, Inc. 2002, DOI:10.1002/9780470172551

6.	Additional notes

Topics 3

1. The subject of the lecture

MATERIALS SELECTION FOR STRENGTH PURPOSE

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

This topic aims to present materials selection processes and examples for selection for strength needed for a given application. Students should be given an introductory information regarding what types of strength requiremens available for materials selection such as tensile srength, flow stress, compression stress or strength, bending strength etc… Other properties that are obtained thorugh a testing procesures can also be given as additional information, making sure that related calculations for obtaining these derivatives is given appropriately. A classification of strength properties or types of concepts of strength should be emphasized based on mostly tensile strength but other concepts regarding the determination of strength can also be used for classification. Depending on industry, strength may be interpreted differently and may not be compatible with academic definition; hence, these should be explained to students. Some help may be seeked form the students who have work experience or already working. During the lecture, students will learn that the determination of strength and evaluation process for materials and alloys involves various mechanical tests to assess their performance. For instance, a study on glass fiber reinforced and elastomer filled polyamide composites used tests such as tensile, impact, and bending tests to determine properties like tensile modulus, elongation at break, impact strength, flexural strength, and flexural modulus. Additionally, a mathematical model was developed to calculate the tensile strength of thermoplastic composites reinforced with long glass fibers. Students will also learn the analysis of mechanical properties and structural analysis of self reinforced composite materials involved tensile property analysis using a universal testing machine. These methods are essential for understanding the strength characteristics of materials, including low strength, medium strength, high strength, and ultrahigh strength materials, as well as the strength of thermoplastics, fiber-reinforced materials, and hybrid composites, aiding in the selection of materials for static and dynamic strength requirements.

3. Learning outcomes

Students can differentiate between different strength levels (low, medium, high, ultrahigh) and their characteristics; analyze mechanical properties of materials using data from various tests; conduct tensile property analysis using a universal testing machine; select appropriate materials based on their strength characteristics and application requirements; identify the unique strengths and weaknesses of thermoplastics, fiber-reinforced materials, and hybrid composites; understand the importance of various mechanical tests (tensile, impact, bending) in determining material properties like tensile strength, elongation, and flexural strength; recognize the role of mathematical models in predicting the tensile strength of specific composite materials; appreciate the impact of material selection on static and dynamic strength requirements.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Mechanical Behavior of Materials 2nd Edition.* Thomas H. Courtney (Author), Waveland Pr Inc. 2005.

-*Materials Selection in Mechanical Design 4th Edition.* Michael F. Ashby (Author), Butterworth-Heinemann 2010.

-*Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4.

6. Additional notes

Topics 4

1. The subject of the lecture

MATERIALS SELECTION FOR TOUGHNESS PURPOSE

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

This topic aims to introduce and present toughness concept in materials selection for certain applications where toughness is required. Toughness is a material property that measures the ability of a material to absorb energy and deform plastically before fracturing. Students will learn toughness can be calculated through experimental routes and fracture mechanics principles. The experimental approaches to fracture toughness evaluation at the micro scale involve the preparation of miniature specimens containing micro to nano scale features. One of the important concepts in the definition of fracture toughness is the presence of cracks and its physical effect in the fracture toughness. The fracture toughness of a material determines how large a crack the material in question can tolerate under static and dynamic stresses or load. The type of loading is also important for the determination of toughness and classifiy the toughness with respect to loading direction; however, there is usually one type of loading used in general. Students should be given information tabulated data about the toughness versus other properties of materials such as density of material, size of the specimen, hardness, tensile strength or flow stress and also type of alloy can also be attempted using literature sources. It would be interesting to start a discussion regarding the definition of toughness with respect to certain objects that are available in classroom or students may choose an application and define the toughness and required materials to endure for a given strength levels. Materials selection for toughness is important in applications where the material is subjected to high stress and impact loads. Students will also learn that tabulated data of toughness for some materials and systems are available, and they provide a measure perceived at certain dimensional scales of the energy dissipation. Toughness determination must be carried out using specimens and tests of corresponding dimensions.

3. Learning outcomes

Students can define toughness as a material property related to energy absorption and plastic deformation efore fracture; describe how toughness can be measured in terms of energy per unit volume; explain the basic principles of fracture mechanics and their role in toughness evaluation; recognize the importance of micro-scale experimental methods for evaluating toughness in specific materials; explain the limitations of experimental methods due to dimensional scaling effects; analyze how material selection based on toughness is crucial for high-stress and impact applications; provide examples of materials with high and low toughness and their suitable applications; understand the limitations of using tabulated data for toughness across different dimensional scales.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Mechanical Behavior of Materials 2nd Edition.* Thomas H. Courtney (Author), Waveland Pr Inc. 2005.

- *Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4

6. Additional notes

Topics 5

1. The subject of the lecture

MATERIALS SELECTION FOR FATIGUE PURPOSE

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

This topic aims to present the concept of fatigue in structures under varying types of loads and extend this concept to materials used for such applications. Fatigue in metallic materials refers to the progressive weakening of a material due to repeated loading, leading to localized structural damage. During the lecture students will learn how to evaluate fatigue, the fatigue resistance or fatigue life of metals is crucial and can be determined through various testing methods such as the Wöhler curve and diagram, which help calculate the number of cycles until failure. Factors affecting fatigue in metals include stress levels, material defects, surface finish, and environmental conditions. Students will also learn that the calculation of fatigue life involves the use of S-N curves, which plot stress versus the number of cycles to failure, and is determined through standard laboratory tests using various methods for applying cyclic loads. When selecting materials for fatigue strength, factors such as the material's fatigue limit, endurance limit, and the specific application's loading scenarios and environmental performance should be considered. Students should be informed of the fatigue effect on working parts and components and most importantly how they eventually fail through this effect by showing actual examples from practice or experiment. Some comments should be seeked from students for the parts shown in the classroom and possible solutions should also be given to students using examples. An example of fatigue testing should be introduced in the classroom by introducing different methods of testing and test machines and their general specifications. Students should be initially introduced to the fatigue effect on materials and given detailed parametric definititons as they matter for structural parts or components working in low and high rotational speeds with and without extensive loading conditions. There should a discussion regarding the prevention of fatigue based on the machining of surfaces and their final effect on different metallic and non metallic materials such as carbon fibres, titanium alloys and steels.

3. Learning outcomes

Students can define and explain fatigue in metallic materials; describe the process of fatigue damage accumulation and its consequences; explain the concept of fatigue resistance and fatigue life; identify various testing methods for evaluating fatigue life, including the Wöhler curve and diagram; list several factors affecting fatigue in metals, such as stress levels, material defects, surface finish, and environmental conditions; define and differentiate between fatigue limit and endurance limit; apply knowledge of fatigue factors to select appropriate materials for different loading scenarios; estimate fatigue life using appropriate testing methods and data analysis; critically evaluate the impact of various factors on fatigue performance of metallic material; recognize the potential dangers of fatigue-related failures and the need for preventative measures; develop a critical thinking approach to analyzing and solving fatigue-related problems.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Mechanical Behavior of Materials 2nd Edition.* Thomas H. Courtney (Author), Waveland Pr Inc. 2005.

- *Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4

6.	**Additional notes**

Topics 6

1. The subject of the lecture

MATERIALS SELECTION FOR CREEP PURPOSE

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

This aim of this topic is to introduce creep behaviour of materials that are used for the purpose of structural and specific applications and operated at high temperatures. Creep is a time-dependent deformation that occurs in solid materials when they are exposed to high levels of stress at high temperatures. It is a slow and progressive deformation that can lead to permanent deformation and failure of the material. Students will learn the creep rate is a function of the material's properties, exposure time, exposure temperature, and the applied structural load. In selecting the best material for a system that will experience creeping, creep resistance is an important parameter to consider. The evaluation procedure for creeping and experimental setup involves creep testing, which is similar to tensile or compression tests, but with high-temperature conditions maintained. The factors affecting creeping in other material systems include temperature, stress, and time. Students will also learn the calculation of creeping and predicting the creep life involves the use of creep curves, which show the relationship between creep strain and time. Materials selection for creeping systems involves a design-led procedure that considers the material's creep resistance, creep fracture, creep relaxation, and creep buckling. The creep behaviour is not usually pertinent to structural materials working at low or room temperatures but this property is eminent at high er temperatures, however, the long term exposure to the static loads may trigger this effect on some materials that are not clearly crystalline such as window glasses, as it may appear in historical places and ornaments that are made of glasses for years and ages to come. Student should be made aware that this effect is not limited to high temperatures and given examples of such. Students should be informed about the parameters and possible solutions to the problems being faced at industry and typical applications. A discussion regarding the effect of creep for composites should be started and a possible outcome should be reached.

3. Learning outcomes

Students can recognize the influence of material properties, exposure time, temperature, and applied load on creep rate; appreciate the significance of creep resistance in material selection for systems experiencing creep; understand the role of creep testing in evaluating creep behavior and designing experimental setups; describe factors affecting creep across systems: Recognize the general influence of temperature, stress, and time on creep in diverse materials; show how to calculate creep strain using creep curves and predict creep life; interpret creep curves and data obtained from creep testing; develop the ability to select materials based on their creep resistance for systems susceptible to creep; define creep resistance, creep fracture, creep relaxation, and creep buckling into the design process.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Mechanical Behavior of Materials 2nd Edition.* Thomas H. Courtney (Author), Waveland Pr Inc. 2005.

- *Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4

6. Additional notes

Topics 7

1. The subject of the lecture

CORROSION AND PREVENTION

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

This topic aims to give a detailed insight and subjects and sub topics related to corrosion of various types, especially the ones relevant to the industry and application thereof. There are many types of corrosion such as atmospheric corrosion, high temperature corrosion, galvanic and combined corrosion, fluid-related corrosion, and polymeric materials and their corrosion are also important considerations in materials selection for various applications. During the lecture students will learn that atmospheric corrosion, which occurs in the presence of water as a surface film on the metal, is influenced by factors such as relative humidity and temperature. High temperature corrosion, on the other hand, occurs in the absence of moisture on the metal surface and is influenced by the specific operating conditions and materials involved. Soil and corrosion factors, as well as fluid-related corrosion, are significant in the context of infrastructure and industrial equipment, with soil composition and fluid characteristics impacting the corrosion behavior of materials. Student will also learn that polymeric materials and corrosion present unique challenges, as the interaction between polymers and corrosive environments requires careful consideration in material selection. In the context of a chemical factory, comprehensive materials selection procedures should be employed, taking into account the specific corrosion types present in the various operating environments and selecting materials that offer the necessary corrosion resistance and longevity. This process typically involves a thorough understanding of the corrosion mechanisms at play, as well as the performance characteristics of different materials in specific corrosive conditions. Students should be involves in a discussion reagarding the prevention of various types of corrosion in working parts and parts that have been produced using new types of alloys. A great detail on the use of sacrifice alloys for sea and liquid corrosion in various liquid media. A list of corrosion and prevention measures should also be given to students for guidance for later use as a reference.

3. Learning outcomes

Students can understand the different types of corrosion: atmospheric, high temperature, soil, fluid-related, and polymer-related; recognize the influence of environmental factors like humidity, temperature, soil composition, and fluid characteristics on corrosion behavior; identify the importance of comprehensive materials selection procedures in chemical factories, considering the specific types of corrosion present in different environments; gain knowledge of the relationship between corrosion mechanisms and material performance; analyze the various factors contributing to different types of corrosion; select appropriate materials for specific applications based on their corrosion resistance and longevity; apply knowledge of corrosion mechanisms to predict material behavior in different environments;

evaluate the performance of different materials in corrosive conditions; appreciate the importance of material selection in preventing corrosion and ensuring the longevity of infrastructure and equipment; develop a critical approach to selecting materials based on scientific understanding and performance data.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4.

6. Additional notes

Topics 8

1. The subject of the lecture

WEAR AND MATERIALS BEHAVIOUR

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

This topic aims to study the effect of wear and its greater definition in applications related to industrial applications and with respect to types of wear in different conditions. A detailed tour of wear types will be given to students and corresponding solutions will be introduced with examples. Tribology, the study of friction, wear, and lubrication, has a rich historical background and significant economic implications. During the lecture students will learn the field encompasses the study of various types of wear, including abrasive, adhesive, and fatigue wear, and the development of wear measuring devices and principles. Materials selection for wear resistance is a crucial aspect, involving factors such as hardness, toughness, and the economic considerations of component manufacture. The role that material properties play in determining wear behaviour is still ill defined. In wear theory hardness remains the term most commonly used to express the relation between material properties and wear rates although it has often been shown to be inadequate for this purpose, particularly when dissimilar materials are under consideration. Students will also gain knowledge of that various methods and approaches have been developed to improve wear resistance, including the selection of wear-resistant materials for specific industries such as the petrochemical industry. Oils and lubrication play a vital role in reducing wear, and the design and selection of materials for tribological applications are essential for enhancing the resistance to abrasive wear and improving the lifespan of machine components and parts. Materials loss due to wear is accounted for more than expected in industrial applications. A series of tests necessary for the use to describe and define the type of wear will also be introduced and various calculations techniques will be given with examples. Modelling studies about the wear and their effects on the mechanical and surface properties can also be introduced to students with an insight of how to control the basic and advanced parameters. Studies on wear modeling have been developed taking into account the classical wear theory put forward by Archard, which should be introduced to students with theory and application. Students can be involved in a discussion regarding the use of lubricants and their composition for the different applications such as non metallic surfaces and highly soft surfaces.

3. Learning outcomes

Students can define and explain the key concepts of tribology: friction, wear, and lubrication; identify and describe different types of wear, including abrasive, adhesive, and fatigue wear; explain the importance of material selection for wear resistance, considering factors like hardness, toughness, and cost; understand the various methods and approaches used to improve wear resistance, such as selecting industry-specific materials; describe the role of oils and lubrication in reducing wear; explain the impact of material design and selection on tribological applications, particularly abrasive wear resistance and lifespan; apply knowledge of tribology principles to analyze real-world problems; select appropriate wear-resistant materials based on specific applications and constraints; evaluate the effectiveness of different lubrication methods in reducing wear; design materials and components for improved tribological performance and lifespan; appreciate the historical importance and economic significance of tribology; recognize the interconnectedness of various engineering disciplines within tribology.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Engineering Materials 1 An Introduction to Properties, Applications and Design. 4th Edition.* Authors: Michael F. Ashby and David R.H. Jones, Elsevier Ltd. 2012, DOI: 10.1016/C2009-0-64288-4.

6. Additional notes

Topics 9

1. The subject of the lecture

MATERIAL SELECTION DIAGRAMS

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

The purpose of this topic is to present the material selection diagrams used in many applications. The main objective of material selection is to minimise costs while meeting product performance requirements, and the systematic selection of the best material for a given application begins with the properties and costs of candidate materials. Young's modulus, strength, density, fracture toughness, stiffness, thermal conductivity, thermal expansion and thermal diffusivity are all important mechanical and thermal properties of materials. During the lecture, students will learn that Young's modulus is a measure of the stiffness of a material and its ability to resist deformation under stress. Strength is the maximum stress a material can withstand before failure. Density is the mass per unit volume of a material. Fracture toughness is a measure of a material's ability to resist crack propagation. Rigidity is a measure of a material's resistance to deformation under load. Thermal conductivity is a measure of a material's ability to conduct heat. Thermal expansion is a measure of a material's tendency to expand or contract with changes in temperature. Thermal diffusivity is a measure of a material's ability to conduct heat relative to its ability to store heat energy. Students will also learn that these properties are often plotted against each other in material charts to help engineers select the best material for a given application. There is another aspect to material selection in applications such as piping and structural material selection and this will be illustrated in class following the explanation of normal material selection diagrams. A Material Selection Diagram (MSD) is an engineering drawing that shows the material selection information and specification of the piping and equipment in the process and utility facility that is a step in the process of designing any physical object of the material. A Material Selection Diagram (MSD) is an engineering drawing that shows the material selection information and specification of the piping and equipment in the process and utility facility that is a step in the process of designing any physical object of the material. An MSD is usually developed from simplified process flow diagrams (PFDs) by the process engineer, materials engineer and metallurgist on a project. The material engineer uses the material selection diagram to assign a line class and specification to each line on the Piping and Instrumentation Diagram (P&ID) (or Process Engineering Flow Scheme (PEFS)).

3. Learning outcomes

Students can define the mechanical and thermal properties of materials; show the relationship between these properties and how they affect the behavior of materials; explain how these properties are measured and characterized; interpret and analyze materials charts that plot these properties against each other; apply their understanding of these properties to select the best material for a given application; communicate their understanding of these

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properties clearly and concisely; appreciate the importance of material selection in engineering design.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Materials Selection in Mechanical Design 4th Edition.* Michael F. Ashby (Author), Butterworth-Heinemann 2010.

6. Additional notes

Topics 10

1. The subject of the lecture

DESIGN ISSUES AND MATERIALS SELECTION

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

The aim of this topic is to present the designs and design issues related to the material selection process, particularly important for corrosion and mechanical properties of products. Although the design of a component requires a thorough and detailed study of the capabilities of the materials to be selected and the working conditions, the real question is how long the service life should be from the manufacturer's point of view, which in turn defines the cost and quality of the product. The relationship between design and material selection is a crucial aspect of product development, influencing performance, functionality, cost and sustainability. Moreover, the impact of materials selection on machining processes is essential for small, complex components. Factors like corrosion resistance, exposure to chemicals, temperature resistance, and cost influence the choice of materials for components, especially in critical industries like the chemical process industries. Students will learn that material selection is not just a step in the manufacturing process, but an art requiring attention to detail, knowledge and expertise. It involves choosing the right material to meet design requirements, taking into account attributes such as chemical, electrical, physical and mechanical properties, as well as cost and sustainability. The process aims to optimise performance objectives such as cost minimisation and environmental impact. Material selection is fundamental to engineering as it determines the sustainability and cost-effectiveness of the final product, influencing its performance, longevity and commercial viability. Students will also learn that design engineers must carefully consider various factors to ensure that the selected material meets the performance, cost and sustainability requirements of the product. Material selection is a multidisciplinary decision-making process that evaluates mechanical properties, availability, cost and sustainability considerations to arrive at the most suitable material for a given application. Effective collaboration between designers, engineers and scientists is often required to achieve optimal material selection.

3. Learning outcomes

Students can explain the relationship between design and material selection; show that material selection is not just a technical process, but also requires creativity and judgment; identify and analyze the different factors that need to be considered when choosing a material; evaluate different materials based on their properties, cost, and sustainability; explain the importance of collaboration between different disciplines for successful material selection.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Materials Selection in Mechanical Design 4th Edition.* Michael F. Ashby (Author), Butterworth-Heinemann 2010.

6. Additional notes

Topics 11

1. The subject of the lecture

MATERIALS SELECTION IN AUTOMOTIVE INDUSTRY

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

This topic introduces materials selection and related procedures for automotives and manufacturing industries. Materials selection in the automotive industry plays a crucial role in achieving fuel economy, weight minimisation and performance. To meet these requirements, different materials are used for different automotive parts. Students will learn that steel, aluminium, magnesium and high strength steels are commonly used for various components, while plastics and polymer composites are increasingly being used for parts such as bumper beams to reduce weight and improve fuel efficiency. In addition, safety is a paramount consideration when selecting materials for automotive applications. Materials such as carbon-fibre epoxy composites are increasingly used in racing cars due to their high strength-to-weight ratio. Glass fibre composites are also popular for sports cars because they are lightweight, easy to form, corrosion resistant and cost effective. Throughout the automotive industry's history, new materials have been introduced, such as the use of powder metal engine bearing caps to reduce weight and improve efficiency. Students will also learn that research is ongoing to explore advanced lightweight materials, including biocomposites, for applications in automotive parts such as bumper beams. This continuous evolution in material selection is driven by the need for increased fuel efficiency, environmental regulations and customer demand for more sustainable and fuel efficient vehicles. In general, material selection in the automotive industry is a multifaceted process that involves the evaluation of properties such as lightweighting, economics, safety considerations and innovative solutions to meet the evolving demands for vehicle performance and sustainability. Students should be given a detailed list of parts that are classified into metallic and non metallic groups and their safety category with respect to where it is being used to make sure that such materials has a specific purpose. Students should involve a discussion on how new materials can improve the performance as well as weight reduction of automotive from the perspective of new alloys and carbon based materials and also the role of design problems including joining procedures.

3. Learning outcomes

Students can show the importance of material selection in achieving fuel economy, weight minimization, and performance in automobiles; identify the different materials commonly used in automotive parts and their properties (steel, aluminum, magnesium, high-strength steels, plastics, polymer composites, bio-composites); explain the benefits and drawbacks of different materials for specific automotive applications; recognize the historical and ongoing evolution of materials used in the automotive industry, including examples like powder metal engine bearing caps; show the factors driving the continuous improvement of materials selection in the automotive industry (fuel efficiency, environmental regulations, customer demand); analyze the suitability of different materials for specific automotive applications based on their properties and requirements; apply knowledge of materials science and engineering principles to make informed decisions about material selection in automotive design; communicate effectively about the technical aspects of materials selection and their impact on automotive performance and sustainability; appreciate the importance of innovation and continuous improvement in materials technology for the automotive industry; present the need for sustainable and environmentally responsible materials selection in the automotive industry.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Materials Selection in Mechanical Design 4th Edition.* Michael F. Ashby (Author), Butterworth-Heinemann 2010.

- New Trends and Developments in Automotive Industry (Chapter 20). Edited by Marcello Chiaberge, Intercohen 2011, DOI: 10.5772/1821.

- Advanced Materials in Automotive Engineering 1st Edition. Edited by by Jason Rowe, Woodhead Publishing 2012.

6. Additional notes

Topics 12

1. The subject of the lecture

MATERIALS SELECTION IN AVIATION INDUSTRY

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

This topic aims to present general principles of materials selection in aviation and aerospace industry, specifically projected on the lightweight and high temperature materials including low strength and high strength groups. The specifications for aviation-related structures require a systematic consideration of production related issues to facilitate the manufacture and assembly of product components. Emphasis should be placed on designs that facilitate production, and material selection should be made accordingly. Material selection is a crucial step in the design process for the aviation industry. The aviation industry's material selection has evolved to prioritise lightweight components for improved safety, performance, fuel efficiency, and range. This shift has moved away from traditional materials like aluminium towards newer alternatives that offer better durability and performance characteristics. These materials are commonly used in aerospace structures, including aircraft, spacecraft; aricracft launch vehicles, and jet or rocket propulsion and their power systems. The selection of materials is based on the requirement for lightweight, high-strength materials to improve performance and fuel efficiency. The course will cover the significant advancements in materials selection for high-speed air vehicle applications, including supersonic aircraft. The emphasis is on using high-strength, low-weight materials to meet the demands of such applications. The aviation industry relies on carefully selected iron-based and non-ferrous materials to meet the specific requirements of high-speed air vehicles. The process of materials selection is crucial for ensuring the safety, efficiency, and sustainability of aircraft manufacturing. It involves balancing various factors to meet the demanding requirements of modern aerospace applications. Students should be involved in a discussion regarding the use of lightweight materials and alloys in aircraft system with a perspective of design of aircraft. Another issue that can be brought forward to emphasize is that how different the design of aviation systems and materials compared to automotive or structural material systems. The rockets firing systems and related ceramic and high temperature resistant materials can be mentioned with visual presentation of rockets firing videos.

3. Learning outcomes

Students can present the importance of considering production-related issues during the design process for aviation structures; recognize the crucial role of materials selection in the design process of aircraft, spacecraft, launch vehicles, and propulsion systems; identify the key drivers for materials selection in the aviation industry, including high strength, lightweight materials for performance and fuel efficiency; explain the specific challenges of materials selection for high-speed air vehicles, including supersonic aircraft; define different materials used in the aviation industry, such as iron-based and non-ferrous alloys; analyze the impact of material properties on the performance and efficiency of aircraft components; evaluate specific materials based on their suitability for different aviation applications; Identify new and emerging materials that could be used in the future of aviation; develop an appreciation for the complex considerations involved in designing and building safe and efficient aircraft.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-*Materials, Structures and Manufacturing for Aircraft 1st Edition.* Edited by Melih Cemal Kuşhan, Selim Gürgen, Mehmet Alper Sofuoğlu, Springer 2022.

- *Introduction to Aerospace Materials.* Edited by Adrian P. Mouritz, Woodhead Publishing 2012.

6. Additional notes

Topics 13

1. The subject of the lecture

MATERIALS SELECTION IN GEAR AND SHIPPING INDUSTRY

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

This topic aims to present material selection processes in shipbuilfing and gear manufacturing. A list of candidate materials for shipbuilding should be given in the form tabulated data i.e. codes, compositions and the location within the ships. Another list of materials for the manufacturing of gears should be given to the students with compositions and codes of the steels from which gears are made. The materials used in shipbuilding, walls, hulls, beams and columns, should be designed for the structural integrity and performance of the vessels, to prevent deformation when passing through rough waters and also to carry the load that may collide the walls of the ship. During the lecture, students will learn that steel and aluminium alloys are the primary materials used in shipbuilding, chosen for their ability to withstand compressive, tensile and shear stresses, as well as hardness, brittleness and strength values. Steel, a very versatile and widely used material in the shipbuilding industry, offers excellent mechanical properties but can be heavier even with thin walls, whereas aluminium can be used with thicker walls, so a compromise has to be made to prioritise the properties. On the other hand, aluminium alloys are preferred for their lightness, making them suitable for small vessels. Students will also learn that wood, concrete and glass fibre reinforced plastics are also used in shipbuilding, particularly for smaller vessels. The choice of materials is based on the specific requirements of the different areas of the ship to ensure watertightness, safety and durability. For beams and columns, materials must be selected to address vibration issues and ensure the structural stability of the ship. In addition, in the manufacture of gears, material selection is an important part of the manufacturing process to ensure surface hardening with sufficient depth to prevent surface defects and wear, and to improve the overall performance of the gears. A discussion should be initiated with students on the use of soft and hard materials on the efficiency of gear performance and surface properties.

3. Learning outcomes

Students can identify the primary materials used for gear manufacturing and ship construction (steel and aluminum alloys); explain the key properties of these materials (strength, hardness, brittleness, etc.) and their impact on gear and ship performance; recognize the advantages and disadvantages of different materials (e.g., steel's strength vs. weight, aluminum's lightness); show the use of other materials like wood, concrete, and fiber-reinforced plastics in specific applications; appreciate the importance of selecting the right material for different parts of the ship based on specific requirements (waterproofing, safety, durability); explain challenges of vibration in beams and columns and how material selection can address them; recognize the importance of material selection in gear making for factors like surface hardening and defect prevention.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- *Gear Materials, Properties, and Manufacture.* Edited by J.R. Davis, ASM International 2005, DOI: 10.31399/asm.tb.gmpm.9781627083454

-*Selection of Gear Materials in Machine Design: An Optimization Door.* Author: Prithwiraj Jana, LAP LAMBERT Academic Publishing 2017.

-*The Selection of Materials for Ship Structures*, Stuart Cannon, Brian Ralph, D. W. Chalmers and G. Victory, Philosophical Transactions: Physical Sciences and Engineering 1991, 334, 1634, 357; http://www.jstor.org/stable/53777.

6. Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

SINTERING TECHNOLOGIES

Code: SN

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

SINTERING PROCESSES, THERMODYNAMICS OF THE INTERFACE

2. Thematic scope of the lecture

This lecture will concentrate on the sintering processes and thermodynamics of interfaces in materials science, emphasizing powders and their transformation into engineered shapes. The class will cover the fundamental principles of sintering, including the mechanisms involved in powder consolidation, the thermodynamics governing the process, and the behavior of interfaces between powder particles. The class will explore the techniques used to analyze sintering behavior and the properties of sintered materials. It will also examine the factors affecting powder-to-powder interfaces during the sintering process.

This in-depth exploration seeks to unravel the intricacies of sintering, a pivotal technique in materials engineering. Sintering involves the consolidation of powder particles through controlled heat and pressure, resulting in the creation of dense and well-formed structures.

To gain a detailed understanding of sintering, it is crucial to examine its fundamental principles. Sintering is a process wherein powder particles are subjected to elevated temperatures, allowing them to coalesce and form a solid mass. The driving force behind this phenomenon lies in minimizing the overall free energy of the system. Categories of sintering can be broadly classified into solid-state sintering, liquid-phase sintering, and transient liquid-phase sintering, each exhibiting unique characteristics and applications.

The lecture will thoroughly cover the driving forces and basic phenomena governing sintering. The thermodynamics of interfaces, particularly surface energy and adsorption, play a crucial role in the sintering process. Surface energy, a foundational concept in materials science, influences the behavior of powder-to-powder interfaces during consolidation. Understanding the relative adsorption of atoms on powder surfaces is essential for a comprehensive understanding of sintering behavior.

To keep up with the factors affecting powder-to-powder interfaces, the class will clarify the thermodynamics of curved interfaces. Surface tension and surface energy, intricately linked to the thermodynamic potential, are explored in detail. The application of capillarity and atom activity to sintering, both in condensed and dispersed phases, will be discussed, shedding light on the energy changes associated with curved interfaces.

In summary, this lecture provides a thorough examination of sintering processes, covering the fundamental principles, categories, driving forces, and thermodynamics of interfaces. By gaining a comprehensive understanding of these concepts, students will acquire the knowledge necessary to analyze sintering behavior, properties of sintered materials, and the intricacies of powder-to-powder interfaces during this transformative process.

3. Learning outcomes

Students can demonstrate a deep understanding of the fundamental principles of sintering, including the mechanisms involved in powder consolidation, the thermodynamics governing the process, and the behavior of interfaces between powder particles; categorize different types of sintering processes, such as solid-state sintering, liquid-phase sintering, and transient liquid-phase sintering, and understand their unique characteristics and applications in materials engineering; develop the skills to analyze and interpret sintering behavior using various techniques, gaining proficiency in assessing the properties of sintered materials; explore the implications of surface tension and surface energy on powder-to-powder interfaces, gaining insight into the thermodynamics of curved interfaces; integrate the concepts of capillarity and atom activity into the context of sintering, both in condensed and dispersed phases.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

- ...

6. Additional notes

Topics 2

1. The subject of the lecture

POWDER PRODUCTION AND CHARACTERIZATION

2. Thematic scope of the lecture

This class will concentrate on the exploration of powder production and characterization, providing an in-depth examination of various methods for producing powders and the techniques involved in analyzing and classifying them based on their unique properties. The fundamental principles of powder production, encompassing both traditional and modern methods, will be thoroughly covered to equip students with a comprehensive understanding of the diverse approaches employed in materials science.

A key aspect of the course is the detailed exploration of powder characterization, with a specific emphasis on distinguishing between nano-sized and micron-sized powders. The significance of this differentiation lies in the pivotal role that powder properties play in influencing the performance and application of materials in various industries. Students will develop a comprehensive understanding of the desirable characteristics of powders, including particle size, morphology, and surface area, and their implications for material behavior.

Synthesis of powders will be a central focus, and students will investigate the various methods employed to create powders with specific properties. The class will clarify the desirable characteristics that make a powder suitable for particular applications, taking into account the intricate interplay between synthesis methods and the intended use of the material.

The synthesis of powders involves both mechanical and chemical methods. Students will explore powder preparation through mechanical methods, which may include processes such as milling, grinding, and crushing. Additionally, they will gain insight into powder synthesis through chemical methods, which may involve precipitation, sol-gel processes, or other chemical reactions tailored to produce powders with controlled properties.

Throughout the course, students will engage in a thorough exploration of the synthesis techniques, allowing them to comprehend the intricacies involved in tailoring powder properties to meet specific requirements. Concluding remarks will provide a comprehensive summary of the key concepts covered, reinforcing the paramount importance of powder production and characterization in materials science and various industries.

In summary, this class offers a focused journey into the world of powder production and characterization. Through a detailed exploration of synthesis methods, desirable characteristics, and analytical techniques, students will acquire the knowledge and skills necessary to navigate the complex landscape of powder materials in diverse applications.

3. Learning outcomes

Students can acquire a comprehensive understanding of various powder production methods, including both traditional and modern approaches, and the ability to differentiate between them based on their principles and applications; develop the skills to analyze and classify powders based on their unique properties, such as particle size, morphology, and surface area; gain proficiency in the synthesis of powders, exploring both mechanical and chemical methods; apply their knowledge of powder properties to assess their suitability for particular uses; cultivate critical thinking skills in the context of powder production and characterization.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 3

1. The subject of the lecture

PRE SINTERING PROCESSES

2. Thematic scope of the lecture

This course will center on the theoretical underpinnings of the pre-sintering processes integral to powder metallurgy and ceramics manufacturing. It will specifically address the complexities involved in powder compaction and shaping, the pre-sintering densification process, and related considerations that profoundly influence the outcome of these manufacturing processes. The course aims to provide an in-depth exploration of the techniques and methods employed when working with both ceramic and metallic powders. Special emphasis will be placed on understanding the pivotal roles played by lubricants and binders in the formation of powder compacts, as well as the overarching process of achieving the desired densification crucial for subsequent final sintering stages.

A fundamental focus of this theoretical class involves an exploration of the mechanics of unsaturated bodies. This encompasses a thorough examination of the concept of effective stress, a foundational consideration for comprehending the behavior of unsaturated bodies during compaction. The class will provide a nuanced elucidation of particle interactions within the powder compact, emphasizing factors such as interparticle friction and the crucial role of lubrication in facilitating optimal densification. Furthermore, an extensive analysis of stress-strain behavior during compression will be undertaken, enabling students to grasp the mechanical responses of powder compacts under varying pressures.

A critical aspect that will be meticulously addressed is the strength of agglomerates and compacts. Students will delve into the factors influencing the strength of these structures, considering the interplay of various elements such as particle morphology, size distribution, and the effectiveness of binders and lubricants. This thorough exploration aims to provide a detailed understanding of the mechanisms that govern the structural integrity of powder compacts, forming the bedrock for informed decision-making in advanced manufacturing processes.

Throughout the theoretical class, there will be a deliberate effort to cultivate a profound comprehension of the theoretical aspects of working with powder materials. Students will engage in discussions and analyses related to shaping these materials into well-defined compacts, recognizing the theoretical intricacies involved in achieving optimal pre-sintering densification. This theoretical foundation will equip students with the knowledge necessary to critically evaluate and contribute to advancements in the field of powder metallurgy and ceramics manufacturing.

3. Learning outcomes

Students can attain a comprehensive understanding of the theoretical principles underlying pre-sintering processes in powder metallurgy and ceramics manufacturing, including powder compaction, shaping, and pre-sintering densification; acquire specialized knowledge in the theoretical aspects of working with ceramic and metallic powders, exploring the nuances of techniques and methods employed in powder compaction, as well as the roles played by lubricants and binders in forming powder compacts; gain a conceptual grasp of the mechanics of unsaturated bodies, including the concept of effective stress; develop the ability to critically analyze the theoretical factors influencing the strength of agglomerates and compacts; apply their theoretical knowledge to make informed decisions in advanced manufacturing processes.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 4

1. The subject of the lecture

SINTERING PROCESSES AND POLYCRYSTALLINE MICROSTRUCTURES

2. Thematic scope of the lecture

This course will extensively explore the intricate realm of sintering processes within the domain of materials science, with a particular focus on solid-state sintering models. The exploration will encompass a spectrum of modern techniques, notably examining the realm of microwave sintering, a contemporary approach that has garnered increasing attention in recent research. The course's overarching objective is to facilitate an in-depth understanding of the fundamental principles of sintering, emphasizing the nuanced distinctions between liquid and solid-state sintering processes. Additionally, it will shed light on both the advantages and challenges associated with microwave sintering, a crucial aspect in the evolution of materials synthesis methodologies. Importantly, the course will underscore the significant significance of microstructural characteristics in sintered materials, unraveling the interplay between sintering processes and the resulting polycrystalline microstructures.

A crucial aspect of this exploration involves a detailed analysis of the impact of sintering processes on polycrystalline microstructures. The course will elucidate the role of interfacial tension in shaping microstructures, unraveling the dynamics that govern the interactions at grain boundaries during sintering. Wetting angle, a nuanced parameter, will be explored to understand its influence on the formation of microstructural features, providing insights into the wetting behavior of materials during the sintering process. The exploration will extend to the distinctions between single-phase and multiphase microstructures, emphasizing the complexities involved in achieving specific material configurations during sintering.

In the context of sintering processes, the course will provide a comprehensive exploration of the interplay between process parameters and resulting microstructures. This will include an in-depth examination of the pivotal role played by interfacial tension in influencing the grain boundary migration and coarsening phenomena during sintering. The explanation of wetting angle dynamics will contribute to an understanding of how material properties and surface energies impact the evolution of microstructures. The course will also address the challenges and advantages associated with microwave sintering, considering its role in influencing sintering kinetics and, consequently, the resulting microstructures.

In summary, this course aims to foster a profound understanding of sintering processes in materials science, focusing on solid-state sintering models and exploring modern techniques such as microwave sintering. The emphasis on microstructural characteristics, including the impact of interfacial tension, wetting angle, and the distinctions between single-phase and multiphase microstructures, will equip students with a comprehensive toolkit for advanced research and innovation in the field of materials synthesis.

3. Learning outcomes

Students can develop a comprehensive understanding of the fundamental principles of sintering, with a focus on both solid-state sintering models and modern techniques like microwave sintering; gain proficiency in analyzing the impact of sintering processes on polycrystalline microstructures; apply the concept of interfacial tension to elucidate and comprehend the dynamics governing interactions at grain boundaries during sintering; evaluate the influence of wetting angle dynamics on microstructural features, gaining insights into the wetting behavior of materials during the sintering process; critically assess the advantages and challenges associated with microwave sintering, recognizing its pivotal role in influencing sintering kinetics and the resulting microstructures.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 5

1. The subject of the lecture

INITIAL, INTERMEDIATE & FINAL STAGE SINTERING

2. Thematic scope of the lecture

This course will facilitate an in-depth exploration of the various stages inherent in the intricate process of sintering, covering the initial, intermediate, and final stages. The primary focus will be on unraveling the mechanisms and phenomena associated with each stage, providing students with a profound understanding of grain growth, interface formation, diffusion kinetics, void growth, and closure mechanisms. Additionally, the class will thoroughly examine the transition from curved to straight boundaries, shedding light on the evolving nature of interfaces during the sintering process. The lecture aims to illuminate the details of sintering kinetics, explaining the microstructural changes that occur at different stages of this complex process.

A significant portion of the course will be dedicated to a detailed exploration of solid-state sintering models and densification, with a specific focus on the initial stage of sintering. Within this context, the Two-Particle Model will be thoroughly examined, unraveling its geometrical relationships, driving forces, and underlying mechanisms. Atom diffusion and diffusion equations will be explored to provide a detailed understanding of the fundamental processes at play during the initial stage of sintering. The class will critically assess the general features of the Two-Particle Model and highlight its limitations, ensuring that students develop a nuanced comprehension of the theoretical foundation underpinning this sintering model.

Sintering kinetics will be a crucial aspect of the course, covering lattice diffusion from grain boundaries, grain boundary diffusion from grain boundaries, viscous flow, surface diffusion from particle surfaces, lattice diffusion from particle surfaces, evaporation/condensation, and gas diffusion. Sintering diagrams will be used to visualize the complex relationships between variables during the sintering process. The course will further investigate the effect of sintering variables, including particle size, temperature, pressure, and chemical composition, on sintering kinetics. This exploration will provide students with a comprehensive understanding of how these variables influence the rate and success of sintering.

The course will conclude with a critical examination of the usefulness and limitations of the initial stage sintering theory. By fostering a deep understanding of the intricacies of sintering at its various stages, students will be well-equipped to contribute to advancements in materials synthesis and processing. In summary, this course offers a comprehensive journey through the diverse stages of sintering, providing students with the theoretical foundation and analytical tools necessary to navigate the complexities of this fundamental process in materials science.

3. Learning outcomes

Students can gain comprehensive knowledge of the various stages in the sintering process, including the initial, intermediate, and final stages; acquire an in-depth understanding of solid-state sintering models, particularly focusing on the initial stage of sintering; critically assess the general features and limitations of this model; develop proficiency in understanding sintering kinetics, covering various processes such as lattice diffusion from grain boundaries, grain boundary diffusion, viscous flow, surface diffusion, and gas diffusion; use sintering diagrams to visualize and interpret complex relationships between variables during the sintering process; analyze the impact of sintering variables, including particle size, temperature, pressure, and chemical composition, on sintering kinetics; develop the ability to critically evaluate the usefulness and limitations of the initial stage sintering theory.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 6

1. The subject of the lecture

NORMAL GRAIN GROWTH & SECOND PHASE PARTICLES

2. Thematic scope of the lecture

Normal grain growth and the presence of second-phase particles represent fundamental aspects in the complex process of sintering, significantly influencing the final characteristics of sintered materials. Normal grain growth, a core phenomenon, involves the enlargement of grains during the sintering process. In the context of adjacent powder particles, this process is driven by the reduction of total grain boundary energy. As sintering progresses, grains with higher energy boundaries tend to shrink, while those with lower energy boundaries grow, leading to coalescence and an overall increase in grain size.

Understanding the mechanisms behind normal grain growth is crucial for tailoring material properties. Factors such as temperature, time, and impurities intricately affect the kinetics of normal grain growth. This knowledge is vital for optimizing sintering conditions, ensuring the desired microstructure, and subsequently, the material's performance.

Complementing the discussion on normal grain growth, the role of second-phase particles emerges as a central point in material science. These particles play a multifaceted role in shaping the microstructure of sintered materials. Parameters governing the manufacturing of sinters with controlled second-phase particles require careful attention. Achieving a uniform dispersion of these particles is imperative, involving considerations such as particle size, distribution, and volume fraction. This control is crucial for tailoring the mechanical and thermal properties of the sintered material to meet specific engineering requirements.

The effects of second-phase particles extend beyond their spatial distribution. They act as influential factors in dictating the mechanical behavior of sintered materials. Strengthening mechanisms come into play during sintering, where the presence of second-phase particles can impede grain boundary movement, hinder dislocation motion, or induce precipitation hardening. This intricate interplay contributes to the overall performance of the material in real-world applications.

In conclusion, this class offers an in-depth exploration of normal grain growth and the role of second-phase particles in the sintering process. Students will gain a nuanced understanding of the mechanisms driving normal grain growth, the parameters crucial for controlling second-phase particles, and the intricate effects of these particles on material properties. This comprehensive knowledge equips individuals with the skills needed to navigate the complexities of sintering, ensuring the production of materials tailored to specific engineering requirements.

3. Learning outcomes

Students can develop a thorough understanding of the mechanisms governing normal grain growth during the sintering process, including the intricate factors influencing grain boundary energy, the nuanced impact of temperature, time, and impurities, and the essential role these mechanisms play in determining the final microstructure; acquire proficiency in managing the parameters associated with second-phase particles in sintered materials; acquire the ability to analyze and comprehend the effects of second-phase particles on the properties and behavior of sintered materials; apply their knowledge of normal grain growth mechanisms to optimize sintering conditions; develop the ability to critically evaluate microstructural outcomes in sintered materials, considering the interplay of normal grain growth and second-phase particles.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 7

1. The subject of the lecture

GRAIN BOUNDARY SEGREGATION & GRAIN BOUNDARY MIGRATION

2. Thematic scope of the lecture

The lecture's thematic scope delves into the intricate aspects of grain boundary segregation and grain boundary migration, pivotal phenomena for understanding the behavior and properties of sintered materials. Grain boundary segregation, an involved process within the sintering mechanism, entails the preferential accumulation of metallic and non-metallic segregates along grain boundaries. The exploration of the kinetics of segregate formation provides valuable insights into the dynamics of the sintering process, elucidating how impurities or alloying elements influence the grain boundary structure.

A significant consideration in grain boundary segregation involves the impact of Ellingham reactions. These reactions, which characterize the thermodynamic stability of metal oxides, can influence the segregation process during sintering. Understanding the interplay between Ellingham reactions and segregation is paramount for predicting and controlling the distribution of segregates along grain boundaries, ultimately shaping the material's microstructure and properties.

The class will further extend its exploration to grain boundary migration, a phenomenon propelled by heat energy. The kinetics and mechanisms involved in the migration of grain boundaries during sintering will be meticulously examined. This includes an in-depth analysis of how heat energy facilitates the movement of grain boundaries, influencing the overall structure of the sintered material.

In the context of grain boundary migration, the lecture will also shed light on interface migration under chemical inequilibrium. This process involves the migration of interfaces within the material to balance chemical potential gradients. Understanding the nuances of interface migration is crucial for predicting and controlling the final microstructure, adding a layer of complexity to the broader understanding of grain boundary processes.

An additional facet to be addressed is abnormal grain growth, a phenomenon that can deviate from the typical grain growth behavior during sintering. Abnormal grain growth results in the formation of unusually large grains, significantly impacting the material's properties. Recognizing the conditions that lead to abnormal grain growth is paramount for steering clear of undesirable microstructural outcomes in sintered materials.

In conclusion, this comprehensive class will navigate through the intricacies of grain boundary segregation and grain boundary migration. By examining the kinetics of segregate formation, understanding the influence of Ellingham reactions, and scrutinizing the mechanisms of grain boundary migration, students will gain a comprehensive perspective on the processes shaping the microstructure of sintered materials. The inclusion of interface migration under chemical inequilibrium and a consideration of abnormal grain growth adds layers of depth to the exploration, providing a detailed understanding of how these phenomena collectively influence material properties. This knowledge will empower students to critically analyze and control the microstructural outcomes of sintering processes, advancing their capabilities in materials science and engineering.

3. Learning outcomes

Students can develop a thorough understanding of the mechanisms governing grain boundary segregation during the sintering process, including the kinetics of segregate formation and the nuanced influence of impurities or alloying elements on grain boundary structures; acquire competence in analyzing the role of Ellingham reactions in grain boundary segregation; delve deeply into the kinetics and mechanisms involved in grain boundary migration under the influence of heat energy; acquire a nuanced understanding of interface migration under chemical inequilibrium; develop the ability to recognize conditions leading to abnormal grain growth during sintering.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 8

1. The subject of the lecture

SOLID STATE SINTERING : SPS AND HIP ASSISTED SINTERING

2. Thematic scope of the lecture

This class is designed to thoroughly explore the domain of solid-state sintering processes, with a specific emphasis on advanced methods such as Spark Plasma Sintering (SPS), Hot Isostatic Pressing (HIP), extrusion sintering, and pulsed electric current sintering. The focus will be on achieving a deep understanding of the principles, mechanisms, and applications associated with these sophisticated sintering techniques. Additionally, the class aims to identify the various factors that influence the outcomes of sintering, elucidate the advantages of field-assisted sintering methods, and clarify the roles of extrusion and pulsed electric current in enhancing the efficiency and quality of the sintering process.

Spark Plasma Sintering (SPS) is a central aspect of this discussion, wherein the application of pulsed direct current and uniaxial pressure is explored to augment the sintering process. This class will discuss the principles and mechanisms of SPS, its applications across materials and industries. A comprehensive understanding of the factors influencing sintering outcomes, such as temperature, pressure, and heating rate, is deemed essential for optimizing material properties through SPS.

Hot Isostatic Pressing (HIP) represents another crucial facet of this lecture. This technique involves the simultaneous application of high pressure and temperature to achieve densification and enhance material properties. The class will thoroughly explore the underlying principles of HIP, its mechanisms, and the varied applications in industries spanning from aerospace to medical devices. An examination of the factors influencing HIP outcomes, including pressure, temperature, and dwell time, is an effective implementation.

Extrusion sintering, a technique involving the compaction and shaping of powders through an extrusion process, will also be covered. The class will elucidate the principles governing extrusion sintering, examining its advantages in achieving complex shapes and structures. Students will gain insights into the parameters influencing extrusion sintering, such as die design, temperature, and pressure, ensuring a comprehensive understanding of this versatile technique.

Pulsed electric current sintering, with its unique approach of applying short pulses of electric current during sintering, will be a focal point. The class will explore the mechanisms behind pulsed electric current sintering, its applications, and the benefits it offers in terms of enhanced densification and reduced processing times. An analysis of the factors influencing pulsed electric current sintering outcomes, including pulse frequency and duration, will be integral to understanding the intricacies of this innovative method.

In conclusion, this class provides a meticulous exploration of solid-state sintering, with a focus on advanced techniques like SPS, HIP, extrusion sintering, and pulsed electric current sintering. By covering the principles, mechanisms, and applications of these methods, students will not only develop a comprehensive understanding of each technique but also be equipped to identify optimal conditions for sintering efficiency and product quality. The class aims to foster a deep appreciation for the nuanced interplay of factors in these advanced sintering processes, empowering students to apply this knowledge in engineering and materials science contexts.

3. Learning outcomes

Students can acquire an advanced understanding of the principles and mechanisms underlying Spark Plasma Sintering (SPS), encompassing the application of pulsed direct current and uniaxial pressure. This knowledge will enable them to critically analyze and optimize SPS conditions for specific materials and applications; develop proficiency in the principles and techniques associated with Hot Isostatic Pressing (HIP), gaining insights into the simultaneous application of high pressure and temperature for densification; achieve a comprehensive grasp of the principles governing extrusion sintering, including factors such as die design, temperature, and pressure; develop expertise in the mechanisms behind pulsed electric current sintering, understanding how short pulses of electric current enhance densification and reduce processing times; gain the ability to evaluate and optimize sintering outcomes across different techniques, considering factors such as temperature, pressure, heating rate, die design, and pulse parameters.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 9

1. The subject of the lecture

SOLID STATE SINTERING: MECHANICAL ALLOYING

2. Thematic scope of the lecture

This class will thoroughly explore the solid-state sintering process known as mechanical alloying, specifically involving the utilization of powders to fabricate alloyed materials. The class will extensively cover the principles of mechanical alloying, encompassing its production and synthesis methods. It will delve into the effects of powder size, shape, and density on the mechanical alloying process. Additionally, the class will scrutinize the role of compaction in achieving desired alloying outcomes during mechanical alloying.

Mechanical alloying stands as a central focus of this class, providing a profound understanding of the manipulation of powders to create alloyed materials. The principles, production methods, and synthesis techniques associated with mechanical alloying will be systematically elucidated, offering a foundational understanding of this intricate process. This knowledge is crucial for engineers and scientists aiming to harness the full potential of mechanical alloying in shaping material properties.

The production and synthesis of alloyed materials through mechanical alloying are intricate processes that demand a detailed comprehension of the underlying mechanisms. The class will shed light on the principles governing mechanical alloying, unraveling how mechanical forces induce structural changes at the atomic level, resulting in the creation of finely alloyed powders. This insightful analysis of synthesis methods is paramount for professionals seeking to optimize mechanical alloying for specific material properties.

In the context of mechanical alloying, the class will meticulously analyze the impact of powder characteristics on the overall process. Powder size, shape, and density are pivotal factors influencing the success of mechanical alloying, and the class will systematically examine how variations in these characteristics affect alloying outcomes. This understanding is vital for optimizing the mechanical alloying process, ensuring the uniform distribution of alloys and the attainment of desired material properties.

Furthermore, the class will scrutinize the role of compaction in the mechanical alloying process. Compaction, as a fundamental step in powder preparation for sintering, plays a crucial role in influencing the packing density and structure of the powder bed. A thorough exploration of compaction processes and techniques is essential for achieving homogeneity in the mechanical alloying precursor, laying a solid foundation for subsequent sintering steps. The analysis of compaction parameters, including pressure and dwell time, is vital for controlling the density and porosity of the compacted powder.

In conclusion, this class provides an extensive exploration of solid-state sintering through the lens of mechanical alloying. By focusing on the principles, production methods, and synthesis techniques associated with mechanical alloying, students will gain a comprehensive understanding of how to manipulate powder particles effectively for alloy creation. The meticulous analysis of powder size, shape, and density, along with a nuanced examination of compaction's role, equips learners with the knowledge needed to optimize the mechanical alloying process. This comprehensive education is fundamental for professionals seeking to harness the capabilities of mechanical alloying for tailored material properties in various applications.

3. Learning outcomes

Students can develop an advanced understanding of the principles governing mechanical alloying, including the manipulation of powders to create finely alloyed materials; gain proficiency in the production and synthesis techniques associated with mechanical alloying; acquire analytical skills to assess the impact of powder characteristics, such as size, shape, and density, on the mechanical alloying process; develop a comprehensive understanding of the role of compaction in the mechanical alloying process; apply their knowledge of mechanical alloying principles, production techniques, and powder characteristics to design materials with tailored properties.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 10

1. The subject of the lecture

ALLOYING IN POWDER METALLURGY: DIFFUSION ALLOYING

2. Thematic scope of the lecture

This class will thoroughly explore the thematic scope of alloying within the domain of powder metallurgy, with a specific emphasis on diffusion alloying as a mechanism for achieving desired material compositions. The class aims to provide a comprehensive understanding of the principles governing mass transfer through diffusion and its application to sintering processes. It will cover the mechanisms of elemental transport through both surface and volume diffusion for alloying purposes. Additionally, the class will examine the thermodynamics of alloying via sintering, considering the role of diffusion in achieving homogenized compositions.

The focus of the class is on alloying within the context of powder metallurgy, with diffusion alloying being a central aspect. This particular method serves as a foundational process within powder metallurgy, offering a pathway to achieve precisely tailored material compositions. The core objective is to enable students to comprehend the intricate principles governing mass transfer through diffusion and its practical application to sintering processes.

Understanding the principles of mass transfer through diffusion is crucial for grasping the intricacies of diffusion alloying. The class will systematically elucidate the mechanisms involved in elemental transport, highlighting both surface and volume diffusion. Surface diffusion involves the movement of atoms along the material's surface, while volume diffusion occurs within the material's bulk. A nuanced understanding of these distinct modes of diffusion is vital for professionals aiming to optimize alloying processes and achieve specific material compositions.

The class will further explore how diffusion, both at the surface and within the volume of powder particles, contributes to the alloying process. Elemental transport through surface diffusion and volume diffusion plays a crucial role in achieving a homogenized distribution of alloying elements. This nuanced understanding of diffusion mechanisms is essential for controlling the alloying process and tailoring material properties to meet specific engineering requirements.

Additionally, the class will extend its exploration into the thermodynamics of alloying via sintering, delving into the underlying principles that govern alloy formation during the sintering process. The interplay between diffusion and thermodynamics is critical for understanding the driving forces that lead to alloy homogenization. This comprehensive approach enables students to comprehend not only the kinetic aspects of diffusion but also the thermodynamic foundations, providing a thorough framework for alloying via sintering.

The examination of the thermodynamics of alloying through sintering also involves considering factors such as temperature, pressure, and time. The class will analyze how these parameters influence the diffusion-driven alloying process, ensuring that students develop a nuanced understanding of the conditions necessary for achieving the desired material compositions.

In conclusion, this class offers a comprehensive exploration of alloying within powder metallurgy, with a specific focus on diffusion alloying. By elucidating the principles of mass transfer through diffusion and its application to sintering processes, students will gain a profound understanding of the mechanisms driving elemental transport. The in-depth exploration of surface and volume diffusion, coupled with an examination of the thermodynamics of alloying, equips learners with the knowledge needed to control and optimize alloy formation during sintering. This extensive education is instrumental for professionals seeking to leverage diffusion alloying for the tailored development of materials in diverse engineering applications.

3. Learning outcomes

Students can develop an advanced understanding of diffusion alloying mechanisms, including the principles governing mass transfer through diffusion and its application in achieving specific material compositions; gain proficiency in analyzing elemental transport through both surface and volume diffusion; apply thermodynamic principles to understand alloying via sintering; develop the ability to evaluate and analyze factors such as temperature, pressure, and time that influence diffusion-driven alloying processes; acquire the knowledge and skills necessary for strategically controlling alloy formation during sintering.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 11

1. The subject of the lecture

LIQUID PHASE SINTERING

2. Thematic scope of the lecture

This class is dedicated to the in-depth exploration of liquid phase sintering, aiming to provide a comprehensive understanding of the intricacies of this phenomenon and its diverse applications in materials science and engineering. The focus will encompass various facets of liquid phase sintering, including transient liquid phase sintering, eutectic-assisted sintering, third body melting sintering, and reactive liquid formation. The class aims to offer detailed insights into the principles, mechanisms, and the broad field of application for each type of liquid phase sintering.

Understanding the foundational principles that underpin the liquid phase sintering process is crucial for engineers and materials scientists. This knowledge is essential for comprehending the intricacies of subsequent liquid phase sintering variations.

Exploring the dynamics of liquid infiltration into porous structures and its influence on the consolidation of powder particles is crucial for optimizing liquid phase sintering processes. A nuanced understanding of capillary phenomena is vital for tailoring materials with specific characteristics.

Analyzing how the presence of a liquid phase influences the shape and growth of grains within the material is pivotal for predicting and controlling microstructural outcomes. This exploration is crucial for ensuring the development of materials with desired properties.

Unraveling the Lifshitz–Slyozov–Wagner (LSW) theory provides insight into the coarsening process of particles in a liquid matrix. Understanding the dynamics of particle size evolution during liquid phase sintering is paramount for predicting the material's final microstructure and properties.

The class will explore how the characteristics of the liquid phase influence grain morphology and the occurrence of abnormal grain growth. This knowledge is indispensable for tailoring materials with specific structural features and properties.

In addition to the theoretical aspects, the class will discuss practical considerations, advantages, and challenges associated with different types of liquid phase sintering. This discussion will provide students with insights into the real-world applications and limitations of these processes.

In conclusion, this class offers a detailed exploration of liquid phase sintering, covering the principles, mechanisms, and applications of various types of liquid phase sintering. By examining specific aspects such as capillary phenomena, grain shape, and abnormal grain growth, students will gain a profound understanding of the intricacies involved in achieving desired material properties through liquid phase sintering. This comprehensive education equips learners with the knowledge needed to navigate the advantages and challenges associated with these processes in diverse engineering applications.

3. Learning outcomes

Students will develop an advanced understanding of the principles governing liquid phase sintering, including the foundational aspects of transient liquid phase sintering, eutectic-assisted sintering, third body melting sintering, and reactive liquid formation; acquire proficiency in analyzing capillary phenomena in a binary two-phase system, understanding the dynamics of liquid infiltration into porous structures; acquire the ability to analyze how the presence of a liquid phase influences grain shape and growth within the material; apply the Lifshitz–Slyozov–Wagner (LSW) theory to gain insights into the coarsening process of particles in a liquid matrix develop the ability to strategically consider practical advantages and challenges associated with different types of liquid phase sintering.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 12

1. The subject of the lecture

REACTIVE SINTERING PROCESS AND HARDENING OF SINTERS

2. Thematic scope of the lecture

This class will center on the reactive sintering process and the subsequent hardening of sintered materials, aiming to provide students with a thorough understanding of the principles, applications, and complexities involved in these advanced metallurgical techniques. The focus will be on exploring the mechanisms and applications of reactive sintering, shedding light on the chemical reactions that occur during the sintering process and their profound influence on material properties.

Reactive sintering is a key focus, and students will gain insights into the principles governing this process. The class will systematically cover the reactions that take place during sintering, examining how the chemical transformations at the atomic and molecular levels contribute to the enhancement of material properties. Understanding the intricacies of reactive sintering is essential for engineers and materials scientists seeking to optimize the synthesis of advanced materials with tailored characteristics.

The subsequent discussion will revolve around the hardenability process for sintered parts. This includes a detailed exploration of furnace design, a crucial element in the hardening process. The class will delve into the factors influencing the design of furnaces used in reactive sintering, considering parameters such as temperature control, atmosphere regulation, and heating efficiency. A careful examination of furnace design is crucial for achieving uniform heat distribution and ensuring the overall success of the hardening process.

Cooling mediums for hardening and tempering will also be examined, providing students with a comprehensive understanding of the post-sintering treatments. The choice of cooling medium plays a pivotal role in determining the final material properties, and the class will explore how different mediums influence the hardening and tempering processes. This knowledge is indispensable for tailoring material characteristics to meet specific engineering requirements.

Furthermore, the class will delve into the effects of alloying elements on material properties during the reactive sintering process. A thorough analysis of how different alloying elements interact with the base materials, alter the microstructure, and influence mechanical properties will be presented. This exploration is crucial for materials engineers aiming to design alloys with enhanced performance in specific applications.

Throughout the class, a multitude of materials properties influenced by reactive sintering and subsequent hardening will be discussed. These properties may include hardness, strength, wear resistance, and thermal conductivity. Understanding the correlation between processing parameters and material properties is pivotal for engineers aiming to tailor materials for diverse applications, from automotive components to cutting tools.

In conclusion, this class offers a comprehensive exploration of reactive sintering and the subsequent hardening of sintered materials. By examining the principles, applications, and effects of alloying elements, students will gain a profound understanding of the complex interplay between reactive sintering processes and the resulting material properties. This extensive education equips learners with the knowledge needed to strategically design and engineer advanced materials with enhanced performance characteristics for diverse applications in the field of materials science and engineering.

3. Learning outcomes

Students will develop a comprehensive understanding of the mechanisms involved in reactive sintering, including the chemical reactions occurring during the process; gain proficiency in analyzing and influencing furnace design for the hardenability process in reactive sintering; acquire a thorough knowledge of the selection and influence of cooling mediums for hardening and tempering; show how different mediums impact the final material properties is essential for tailoring materials with specific characteristics to meet engineering requirements; develop the ability to analyze the effects of alloying elements on material properties during reactive sintering; apply their knowledge of materials properties, influenced by reactive sintering and subsequent hardening, in diverse engineering contexts.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

Topics 13

1. The subject of the lecture

MACHINING AND TESTING OF SINTERED PRODUCTS

2. Thematic scope of the lecture

This class will concentrate on the processes of machining and testing of sintered products, covering practical examples and case studies. The class will explore the techniques and methods used to machine sintered products, including cutting, grinding, and finishing. It will also encompass various testing procedures and characterization techniques employed to evaluate the mechanical, physical, and functional properties of sintered products. The lecture will highlight real-world applications and case studies to illustrate the importance of machining and testing in ensuring product quality and performance.

Machining sintered products is a crucial aspect of this class, and students will gain insights into the intricacies of processes such as cutting, which involves the removal of excess material to achieve the desired shape and dimensions. Grinding, on the other hand, plays a critical role in refining the surface finish and achieving tight tolerances. The class will meticulously explain these techniques, exploring the complexities involved in ensuring precision and quality in the final machined product. Understanding the detailed relationship between machining processes and the inherent characteristics of sintered materials is essential for engineers and manufacturers aiming to optimize the production of components with specific design requirements.

The second major component of this class is the exploration of testing procedures and characterization techniques. The class will cover a range of testing methods, from mechanical tests assessing properties like hardness and tensile strength to physical tests evaluating density and porosity. Functional tests, examining properties relevant to the application, will also be discussed. The incorporation of characterization techniques, such as microscopy and spectroscopy, adds depth to the evaluation process by providing insights into the microstructure and composition of sintered products. Students will gain a comprehensive understanding of how these tests collectively contribute to assessing the quality and performance of sintered components.

Real-world applications and case studies will be a pivotal aspect of the class, illustrating the practical implications of machining and testing in ensuring product quality. Exemplary studies will showcase how these processes play a vital role in diverse industries, from automotive manufacturing to medical device production. The class will draw on these case studies to highlight the importance of careful machining and thorough testing in meeting stringent industry standards and customer expectations.

In conclusion, this class offers a thorough exploration of machining and testing of sintered products, combining theoretical knowledge with practical insights from exemplary studies. By exploring machining techniques, testing procedures, and real-world applications, students will gain a profound understanding of the crucial role played by these processes in ensuring the quality and performance of sintered components across various industries. This extensive education equips learners with the knowledge needed to navigate the intricacies of manufacturing and testing in the realm of sintered materials.

3. Learning outcomes

Students can develop proficiency in applying various machining techniques, including cutting, grinding, and finishing, to sintered products; gain a comprehensive understanding of a range of testing methods, encompassing mechanical, physical, and functional tests for evaluating the properties of sintered products; acquire competency in employing characterization techniques such as microscopy and spectroscopy to analyze the microstructure and composition of sintered products; apply testing results to quality assurance processes; strategically utilize case studies and real-world applications to gain practical insights into the importance of machining and testing in ensuring product quality.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

UNIVERSITY OF SILESIA IN KATOWICE
UNIVERSITY OF ŽILINA

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

THEORY OF ALLOYS AND PHASE EQUILIBRIA IN MATERIALS

Code: TAPEM

Course content – lecture

Topics 1

1. The subject of the lecture

BASIC THERMODYNAMICS AND ITS APPLICATION

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

This topic aims to give students a detailed overview of thermodynamics topics that are relevant to the phase transformations in metals and alloys. Thermodynamics of materials, which is specific to materials engineering and chemical engineering, generally help to understand the mechanisms lying under the structural transformations and phase diagrams of metallic systems. Although, the other systems such as ceramic compounds and ceramic + ceramic or metal + ceramic mixtures do also benefit from the rules of thermodynamics, especially metal based and ceramic based composites that are regularly used in industrial applications. It is imperative to state that phase transformations are only and collectively possible outcome that are results of operational temperature and the composition effect on many materials properties such as hardness, corrosion and mechanical properties and hence it is conclusive for the microstructural properties that play important role many other properties including the ones mentioned above. Thermodynamics laws and topics such as entropy and enthalpy will help students to understand the energy to microstructural changes in micro and macro scales. This topic will also introduce the concept of free energy concept in microstructural context and its compositional dependence in dominantly metallic alloy systems. The equilibrium concept and its types will also be explained to the students in the context of alloy formation and chemical imbalance and their effect on the resultant microstructures. The alloy formation and various mechanisms that are active in the process will be linked to the thermodynamics of alloy systems via atomic interactions and free energy of quasi chemical models. These quasi chemical models are related to the solution formation with binary types of atoms however single component systems need to be introduced in order to fortify the concept of solution of metallic atoms at high temperatures and room temperatures, too. The phase diagrams of temperature to chemical composition in atomic percentage or mol percentage are very popular in metallurgy and materials applications but it is sometimes important to deduce relevant information from pressure to temperature diagrams to specifically reveal the vapour phase of one or more of the constituents and their liquid phase stabilities. Such information will also be given to the students by using common phase diagrams available in literature and practical examples. The melting of metallic systems is also important step in the formation of alloy but different mechanisms such as the effect of pre melting grain shape and curvature are to be integrated into the melting efficiency in terms of theoretical point of view.

3. Learning outcomes

Students can relate the concept of free energy of formation of solution to microstructural changes and related variations in the phase diagrams in metals and alloys; define the alloy formation in detail in atomistic way and relate them to the various models with which some concepts can be explained in binary and alloy systems; relate phase diagrams and thermodynamic definitions to their practical use via the knowledge that student obtained in this topic.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

J. Manec, Structural thermodynamics of alloys, D. Riedel Publ. Co.Boston USA, 1973

6. Additional notes

Topics 2

1. The subject of the lecture

ALLOY MAKING FROM MELT AND ATOMIC INTERACTIONS IN CRYSTALLINE MATTER

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

This topic is interested in the alloy making rules in metallic systems and their application rules in crystalline matter. This topic will also cover the process in which atomic relaxation and release of binding energies at the expense of heat of dissolution prior to solidification. In general the thermodynamics rules and thermochemical rules will be reviewed to make students accustomed to what happens in liquid state. The interaction between the atoms of interest and alloying atoms are also to be explained in a graphical form and it is possible to show interactive gifs and short videos to make it clear for students in classroom. The alloy making is generally applied through melting and mixing in time due to interaction between atoms of mixture in alloy systems that are being prepared in crucible. This is however not the only method where one can prepare alloys of interest but the easiest method which can be used to form the alloy into desired shape of interest. Other methods may include extensively diffusion dominant processes. The alloys are thought to be formed in a disordered fashion as to clarify the atomic arrangement in crystals. This is an important step for many calculations as they are the measure of entropy of alloy systems to allow the calculation of entropy of atomic mixtures regarding their atomic configuration. The arrangement of atoms in a crystalline system also involves the precise location of atoms that are considered as ordered atomic positions and very important property of intermetallic systems in general. Order reactions will also explain the atomic arrangement where certain properties are presumed to be coming from, such as improved magnetic and mechanical properties. However, the source of new problems also stems from these arrangements as to how they behave differently under transition conditions during varying heat experiment. These include the well known yield strength phenomena in Cu - Au, Fe – Al and many other ordered intermetallic structures and alloys. This topic will also be briefly mentioned but extensive treatment will be given in another topic related to intermetallic alloys. In this topic, some alloy models will also be reviewed in detail with respect to their application in recently studied alloy systems and classical alloy systems. These models will connect the liquid state of atoms under heated and diffusive conditions to initial stage of solidification process and show students how these models are important to construct the atomic arrangement in solidified crystalline systems with ordered or disordered perspectives. This topic will finally present a theoretical explanation of solidification with a short introduction the thermodynamics and thermochemical processes to reveal the elemental distribution changes in solid state to relate the final form of composition and initial stage of composition also what determines them to be precisely conclusive in their behaviour. There are some exemplary studies to visualise these concepts to make students learn conceptually rather than pure theory. The driving forces for solidification from the liquid state will also be briefly mentioned to explain how such a reaction moves.

3. Learning outcomes

The students can explain the models in alloy formation and theoretical background of alloying at atomic level and their working mechanisms in many metallic alloy systems. Students can elaborate on how atoms are arranged in both liquid state and crystalline state with regards to their arrangement from the thermodynamical / thermochemical point of view. Students can relate driving forces needed for the rearrangement of atoms to their final state of equilibrium.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Reading materials will be given to the student in the classroom.

6. Additional notes

Topics 3

1. The subject of the lecture

SOLID STATE REACTIONS AND ALLOYING MECHANISMS

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

This topic is aimed to give a detailed view into the reactions in solid state with regards to atomic arrangement mechanisms within the matrix of (mostly) metallic atoms with the help of heat (insertion and extraction rate) and the principles of extended Hume-Rothery rule of alloying. Students should be reminded of Hume Rothary rules of alloying in the form of table listing the important points; the Hume-Rothery rules are a set of basic rules that describe the conditions under which an element could dissolve in a metallic substrate, forming a solid solution. These rules are considered for the prediction of possibility of two elements will mix into a substitutional solid solution alloy initially in molten state and then later in solid state. Students should also be acquainted with interstitial alloys and their broad perspective in making the alloy stronger as oppose to substitutional alloys. Some basic rules can be put forward about the interstitial alloys but instructor should elaborate on the outcomes of the alloying with this kind by bringing examples from structural alloys. Apart from the geometrical rule of Hume Rothery, phase diagram rule and free energy diagrams provide equilibrium phases and their compositions and insights into the driving forces for phase transformations in an alloy system, respectively. In summary, solid-state reactions and mechanisms in alloy systems encompass various processes, including sintering, mechanical alloying, self-propagating reactions, interdiffusion, and composition-dependent reactions. These solid state manufacturing processes can lead to the formation of a wide range of materials that are different to conventional materials such high entropy alloys, dispersion-strengthened materials, amorphous alloys, and nanocomposites. It is also within the context of this course to critically discuss the effect of these alloy formation rules with regards to what happens in melt state to reveal the mechanisms active during in each condition of heat insertion and extraction. The students should also be expected to read course materials and reference materials prior to this lecture to critically asses the rules by which the mechanisms are based on. This topic will also cover the interactions regarding the atoms in regular crystal systems and accompanying reaction processes such as interdiffusion with a specific interest of calculations atomic distance in binary and multinary atomic compositions.

3. Learning outcomes

Students can explain the Hume Rothery rules of mixing of atoms in solid state in alloy systems. Students can elaborate on substitutional solid solutions and interstitial solid solution formation and discuss the difference between these two alloy systems. Students can explain the role of diffusion and solubility in alloy making process and can extend his/her views on new coming materials such as nanomaterials, metallic glasses and amorphous alloys. Students can describe interstitial alloys and their broad perspective in making the alloy stronger as oppose to substitutional alloys.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Solid State Chemistry and its Applications", Anthony R. West, Wiley and Sons, 2005

Chapter 8, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 4

1. The subject of the lecture

ISOMORPHOUS SYSTEMS-BINARY SYSTEMS

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

This topic picks up with an overview of isomorphous binary systems with their phase diagrams and related calculations using basic thermodynamics and kinetics as they pertain to the processing of crystalline materials. The first module deals with phase diagrams - charts that tell us how a material will behave given a certain set of variables such as temperature, pressure, and composition. Isomorphous binary systems are two component systems that are completely soluble in each other both in the liquid and solid states in all proportions. Students will learn how to interpret common and less complex phase diagrams and how to extract useful information from them using lever rule and graphical rules of phase diagrams. The short definition of solidification will be provided with types of solidification such as equilibrium solidification and microstructures. Such definitions will be useful in interpreting the outcomes of any alloy solution passing through solidification process. Non equilibrium cooling and resultant solidification products are extremely important for the application of phase transformations and they are not represented by the phase diagrams available to practitioners. However, this topic will introduce the definitions of solidification such as coring, zone refining and supercooling with microstructures related consecutive process. Free energy curves for the formation of phase stabilities will be shortly introduced together with a relation to the solute redistribution of alloying elements within the matrix of metallic systems. The solidification process imposes a chemical driving force for the phase transformation in such a way that dendrite formation is supercritical for the practical and industrial processes related to the solidification and solute partitioning in solution. These include zone refining of a bar of which its undesired solute atoms which may be large in atomic size or have low solubility in the matrix crystal structure is swept off by the driving force of chemical changes. Finally, this topic will end with the practical applications of solidification and solution treatment by heat treatment and consequences in real life materials available to engineers.

3. Learning outcomes

The students can make sensible calculations using the basics of phase rules and thermodynamics laws by considering the free energy and kinetic concepts in the solidification of isomorphous binary systems. Students can analyse the solidification process with respect to the cooling routes by the formation of certain parts of the microstructure. They can put forward some suggestions regarding the mechanism of solute partitioning in solution and redistribution that leads to coring, zone refining and supercooling occurring during the solidification process.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Isomorphous alloy systems, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 5

1. The subject of the lecture

BINARY EUTECTIC, PERITECTIC AND METATECTIC SYSTEMS

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

This lecture aims to give an advanced understanding of eutectic and peritectic and metatectic systems phase diagram formations that are available in many industrial metals and alloys. Initially, the eutectic systems will be introduced to the students with real and prospective applications. It is important to mention the fact that the well known eutectic system is found in Pb – Sn system and eutectoid systems is found in steel which known as pearlite that is a mixture of Fe3C and Fe phases. The majority of the eutectic or eutectoid systems are microstructural systems and are formed of two different chemically and crystallographically different phases, which is mostly intermediate phase that melts incongruently. Following the short introduction to eutectic systems, the mechanism is in which the eutectic reaction takes place will be explained in much detail. The eutectic reaction will take place where the driving force for the change will have the similar level of free energy of formation with respect to application temperature. The microstructures of eutectic reactions are to be explained by the help of phase separation rules and thermodynamics of free energy from which the phases are formed. The formation of two different phases will require two different energy levels that are chemically driven to form during the phase separation however in eutectic systems, phases are cleverly formed due to the solubility and activity of one alloying element in the matrix i.e. the carbon would act as high activity alloying element within the matrix of Fe. The eutectic system will later be categorized as hypo and hyper eutectic systems, that is, low amount of alloying additions deviating from the stoichiometric composition. Hence the modification of a eutectic structure may be possible in different ways in hypo and hyper eutectic systems via temperature modified systems or chemically and mechanically induced processing routes. These include, heat treatment process in which a transformation temperature is reached and the diffusion of one of the alloying elements are happened to occur in the matrix, which is aimed to simultaneously equalize the alloying additions or segregate them to form a specific compound, or even, cause a non stoichiometric formation of microstructures and secondary phases within the matrix. The isothermal diffusion of alloying elements hence determines the phase separation but the growth of these phases are important in many industrial applications to obtain certain properties such as hardened surface via quenching process, and also softening of the alloy to ease the manufacturing by turning, shaping and forming by rollers. Following the eutectic systems, peritectic systems in alloy systems will be introduced to the students. The application of peritectic systems is usually less known and industrially important than those of eutectic systems. The important concept on equilibrium solidification of peritectic systems will be given to the students by using lab based experimental results, additionally, hypo and hyper peritectic structures are to be introduced and detailed as in eutectic systems. Metatectic systems will also be introduced and detailed using again experimental and lab based results.

3. Learning outcomes

The students can explain how the eutectic, peritectic and metatectic structures are formed and analysed on the alloy systems observed in most metallic industrial materials. Students can analyse these alloy systems both via metallographically prepared optical images and various thermal analysis techniques. The student can offer a process by which the modification of microstructures are possible and the specific needs for industrial use using these three systems on the industrial applications that will also be conveyed with a specific reference to the atomic mechanisms.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 2-7, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 6

1. The subject of the lecture

BINARY MONOTECTIC AND SYNTECTIC SYSTEMS

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

This topic aims to introduce the monotectic and syntactic reaction systems that are also part of binary systems. The applications of such systems can be found in Cu-Fe, Pb-Zn, Al-Bi and Al-Sb alloy systems. Certain potentially useful alloy systems are difficult to synthesize because of large differences in specific gravity or density values in molten state which give rise to undesirable buoyancy influences upon the process of solidification. In such systems, two liquid phases are formed with a characterized by the large miscibility gap. In some alloy systems, two liquid solutions are seen to be immiscible (insoluble) only over a certain composition range, and in most cases (there are some exceptions), the mutual miscibility is found to increase with the rise of temperature. To obtain 100% solid by the reaction, the amounts of both the liquids is fixed. If one of the liquids is in greater proportion, then extra part of this liquid remains unreacted alongwith the product solid after the syntectic reaction. All those alloys which fall in the composition range of the syntectic horizontal undergo the syntectic reaction. Any such molten alloy that is falling in the syntectic range of compositions, must be present as two different layers of liquids above the syntectic temperature. Hence the solidification of these alloys behaves practically different than those of with miscibility properties as in Cu-Ni systems. The monotectic systems may be obtained more frequently than that of syntactic reaction systems but in both reaction systems hypo and hyper composition ranges are obtained with relatively different properties depending on the amount and level of heating regime or temperature. Hypo monotectic or syntactic systems are less likely to proceed with strong phase separation as it may start the interdiffusion as it gets close to the soluble single phase region on both terminal phases. It is interesting that free energy of phase curves behaves little different and can be expressed as two different phases with large compositional difference. Free energy composition diagrams are therefore provide a plausible mechanism in order to explain phase separation during solidification. Equilibrium solidification is more prominent in these systems as they are less likely to generate commonly diffused systems e.g. interface composition difference as the solidification does usually occur at different temperatures. Following the introduction of monotectic and syntactic reaction systems and their general properties and applications in some systems, forced and natural cooling in these systems will be discussed with a relation the immiscibility gap and gravity forces that are effective in the phase diagrams. However, students will be given information regarding the microstructures and thermal curves obtained from these reaction systems and will be able to relate the resulting conclusions with the alloy systems. The segregation during the natural and forced cooling systems will also be discussed upon the solidification of these reaction systems at the end of the lecture.

3. Learning outcomes

The students can determine the type of monotectic and syntactic systems in a phase diagram and determine the required methods of analysis for phase volume determination and composition analysis using classical method of tie line calculation. Students can explain the differences in these monotectic and syntactic systems and their sequence of formation during the solidification process. Students can make substantially detailed comments on the microstructures and segregation behaviours of these reaction systems.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 2-7, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 7

1. The subject of the lecture

INTERMEDIATE PHASES

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

This topic aims to introduce the intermetallics with the brief definition of intermediate phases and categorical classification of intermediate phases in alloy systems. The definition of intermetallic phases and their properties in short will also be explained to the students. It is part of this lecture to explain how these phases are formed and their short mechanisms will be introduced to the students. During the lecture, the phase diagrams will be emphasized from the structural pattern point of view which will give students more understanding of zones of different behaviour, in addition to the topics previously mentioned in other lectures in this topic. As is known well, phase diagrams are often quite complex in terms of their appearance and phase zones, with a number of different reactions occurring at different composition ranges and temperatures. In most cases, the appearance of several reactions in a binary phase diagram is the result of the presence of intermediate phases. These are phases whose chemical compositions are intermediate between the two pure metals, and whose crystalline structures are different from those of the pure metals. The structural classification of intermediate phases will also be given to the students in detail and the rules that are governing their formation will also be introduced. The difference in crystalline structure distinguishes intermediate phases from primary solid solutions, which are based on pure metals. Some intermediate phases can accurately be called intermetallic compounds, when, like Mg2Pb, they have a fixed simple ratio of the two kinds of atoms. However, many intermediate phases that exist over a range of compositions are considered to be intermediate or secondary solid solutions. Intermediate phases can be classified based on their melting behaviour, either congruent or incongruent melting phases. On heating, an incongruent melting phase decomposes into two different phases, usually one solid and one liquid, such as a peritectic transformation. A congruent melting phase melts in the same manner as a pure metal. In this case, the phase diagram is divided into essentially independent sections. The congruent melting of an intermetallic phase divides the binary phase diagram into two separate eutectic reactions that can be analyzed separately. The intermetallic compound Mg2Pb has a simple fixed ratio of the two kinds of metal atoms. Stoichiometric and non stoichiometric intermetallic compound concepts and their structural difference are to be provided with the help of graphical definitions. Stoichiometric formations of intermetallics are based on the perfect crystallographic orientation of atoms whereas non stoichiometric compositions in intermetallic systems are more profound with several defect types and the non equilibrium solidification will also be playing a significant role in such formations. The lecture will finally be proceeding with how non equilibrium transformations are observed and will also be supported by the microstructural images obtained from literature.

3. Learning outcomes

The students can define the intermetallic phases and classify them with their structural difference by using crystallographic notations. They can also easily determine the how intermediate phases are defined in phase diagrams and show different variations of them with respect to their solubility and alloy formation basics in phase diagrams, based on their knowledge from the previous lectures. Students can also differentiate between the equilibrium and non equilibrium microstructures of intermetallics in different alloy systems using optical or electron images.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 9, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 8

1. The subject of the lecture

BINARY EUTECTIC AND EUTECTOID SYSTEMS: Fe-C phase transformation systems (Carbon steels)

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

This lecture aims to introduce the binary eutectic system with a reference to carbon steels defined by the phase diagram of Fe – C or Fe – Fe3C system that is significantly important in many industrial applications such as ship building and construction in general, automotive industry and spare parts sectors. The most important part of this topic is to cover the eutectic systems in short and later the phase transformations in Fe – C or Fe3C system to help students relate them into industrial applications. Eutectic transformation and eutectoid phase transformations as given in previous topic lecture, both reactions are based on the principle of lowering the transformation temperature by which the constituents melt at lower temperature than those of starting metals. Eutectoid transformation is also same eutectic transformation but happens in solid state hence the dynamics of transformations are very complicated compared to liquid state transformation that is eutectic one. The transformation in eutectic systems are based on cast iron however, this system is to be thought in next topic lecture. The transformations in Fe – C system will be given initially and later on the phase transformations in the eutectoid transformation systems will be deeply introduced to the students. The importance of cooling rate will also be introduced with a great detail as it is one of the most important parameters of eutectoid reactions that lead to the formation of different microstructures. The microstructural changes are necessary to produce a great variety of properties in carbon steel with a determining factor on the diffusion characteristics and hence the intragranular diversity of sub grain formations. The eutectoid transformations produce equilibrium phases by slowly cooling at a rate that is sufficiently long to allow carbon atoms in the γ phase to diffuse to the Fe3C and iron atoms to diffuse to the α phase. The definitions of phases forming in eutectoid Fe – Fe3C systems are Ferrite (α-iron), Austenite (γ-iron), Cementite (iron carbide, Fe3C), Pearlite (88wt% ferrite, 12wt% cementite, or 99.2wt% iron, 0.8wt% carbon), Bainite, Martensite, Ledeburite (ferrite-cementite eutectic, 4.3% carbon). These products of phase transformation in Fe – Fe3C eutectoid system can be classified equilibrium and non equilibrium products. Equilibrium transformation products are ferrite (bcc iron), ledeburite, cementite (fcc iron) and pearlite phases whereas non equilibrium phases can be classified as martensite (bct structure), bainite (two different variants: bcc iron + finely distributed fe3C precipitates within the bcc iron plates or situated along the iron plates). In the final stage, the microstructures of Bainite, Martensite, Pearlite and other variations of these formations and the mixtures of these phases will be given to the students using images from the industrial applications and also the modification of these microstructures using heat treatment e.g. tempering and normalisation heat treatments, and changing the cooling rate e.g. water and oil quenching etc... Finally, as the last step in this topic, students are expected to carry out analysis based on given optical microscopy images and prepare a report using their analysis results as an essay.

3. Learning outcomes

The students can classify the phase transformations that are relevant to carbon steels based on Fe – Fe3C phase diagram and analyse the methodical route that modify the final microstructures of carbon steels with respect to their composition range. Students can determine the microstructures that form in equilibrium and non equilibrium cooling paths and classify them according to their appearance and explain how they form in detail.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**.

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

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

Section 1, Phase Transformations in Steels, Diffusionless Transformations, High Strength Steels, Modelling and Advanced Analytical Techniques, Woodhead Publishing Series in Metals and Surface Engineering (Vol 2), 2012

6. Additional notes

Topics 9

1. The subject of the lecture

BINARY EUTECTIC SYSTEMS: Cast iron systems

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

This topic is aimed to introduce the generalized knowledge about the cast iron systems that are important to widely practiced industrial applications in casting sector especially in foundries where large amount of steel and cast iron is produced apart from non ferrous metals. Foundry or casting sector is the oldest sector in metal industry as we need the steel and cast iron to make machine bodies as well as steel bars to make buildings. However, the cast iron differs from the steels with the high amount of C, P, S and Si present in the composition with microstructures and variety of intragrain features encountered in chemically different and conditionally treated systems. One example of cast iron with different composition and applications is nodular cast iron or ductile iron containing spherical graphite structure. The common defining characteristic of this group of materials is the shape of the graphite. In ductile irons, graphite is in the form of *nodules* rather than flakes as in grey iron. Whereas sharp graphite flakes create stress concentration points within the metal matrix, rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy its name. Nodule formation is achieved by adding *nodulizing elements*, most commonly magnesium (magnesium boils at 1100 °C and iron melts at 1500 °C) and, less often now, cerium (usually in the form of mischmetal). Tellurium has also been used. Yttrium, often a component of mischmetal, has also been studied as a *possible nodulizer*. During solidification, the major proportion of the carbon precipitates in the form of graphite or cementite in cast irons. Following the solidification is just complete, the precipitated phase is embedded in a matrix of austenite which has an equilibrium carbon concentration of about 2 wt %. On further cooling, the carbon concentration of the austenite decreases as more cementite or graphite precipitates from carbon rich solid solution. For conventional cast irons with lower C than eutectic composition (solidifies at approximately 1147 C), the austenite then decomposes into pearlite at the eutectoid temperature, which is around 723 C. However, in grey cast irons, if the cooling rate through the eutectoid temperature is sufficiently slow, then a completely ferritic matrix is obtained with the excess carbon being deposited on the already existing graphite. Alloy cast irons are already being used for special applications such as die steel for large scale applications in place of their steel replacements. Finally the topic will be end with the binary peritectic and peritectoid systems and their analysis in cast iron systems, in addition to calculation of type and amount of phases present in the microstructures of these systems. There will be a short explanation of other phases present in the Fe – C system as an addition.

3. Learning outcomes

The students can differentiate the types of cast irons based on their microstructures and also their formation properties such as melting temperature depending on the amount of carbon using Fe - C phase diagram. Students can explain the mechanisms of carbon rich phase and graphite formation in general cast irons, and also the formation of nodular cast iron in addition to binary eutectic and eutectoid systems that are dominating the solidification of cast irons.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters: Fe–C System. Stable and Metastable Equilibrium Diagrams, Stable Eutectic—Graphite Morphologies and General Properties of Non-alloyed Grey Cast Irons (or Low Alloy) and Flake Graphite, In: Physical Metallurgy of Cast Irons, by J. A. Pero-Sanz Elorz , D. F. González , L. F. Verdeja, Springer books, 2018

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 10

1. The subject of the lecture

BINARY PHASE DIAGRAMS CALCULATIONS

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

This lecture aims to introduce the calculation of binary phase diagrams with an example featuring the well-known Fe-C binary system. This topic will start with the calculation basis for binary isomorphous systems, maximum and minimum in the solidus and liquidus curves and continue with general calculation principles for constructing phase diagram. A phase diagram consists of a number of phase-boundaries separating regions of temperature- and composition-space in which different phases are stable at equilibrium. This topic will cover the calculation results of of binary eutectic / peritectic / monotectic and syntectic systems using various calculation softwares. Published equilibrium diagrams for the Fe-C system often show equilibria between Fe-rich phases and both C (in the form of graphite) and cementite (Fe_3C). Graphite is the more stable of these two phases, and forms readily in cast irons (2-4 wt.% C), but usually with great difficulty in steels (up to 1.5 wt.% C). In the latter, it is more practically useful to consider metastable equilibria involving Fe_3C. In this tutorial, phase diagrams for both Fe-C and Fe-Fe_3C will be calculated. The phase diagram is made up of a number of phase boundaries. A phase diagram represents the domains of stable phases under a given condition of composition and pressure. Till the fifties, phase diagrams were approached mainly through experimental measurements which did not involve thermodynamics, using either direct phase estimation methods or indirect methods. The indirect methods involve measurement of a physical property or rather a change thereof like dilation, resistivity etc or thermal analysis. The thermodynamics of phase equilibria represented, till about the riffles, a parallel activity with few bridges or connections with the former approach. As the stable state of a phase is associated with the minimum of free energy, it should be possible to link up thermodynamics with phase diagram, provided of course that an adequate representation of thermodynamic data is available. The situation has changed considerably during the last twenty five years and more and more phase diagrams are being generated from thermodynamic data. Not only does it provide considerable saving of labour but the exercise gives a deeper insight to the systematic of phase diagrams. The calculations have become feasible with the availability of computers and appropriate numerical methods. Further, with the availability of sophisticated instruments, it has become possible to generate more precise and reliable thermodynamic data. Phase diagrams are visual representations of the equilibrium phases in a material temperature, pressure and concentrations of the constituent components and are frequently used as a function of as basic blueprints for materials research and development. Under typical experimental conditions of constant pressure and temperature and a closed system, calculated phase equilibria are obtained via minimization of the total Gibbs energy of a system by adjusting the compositions and amounts of all individual phases in the system. The topic will end with the examples of Fe – C system and other important systems their calculated diagrams obtained from various calculation programs and presented in the literature.

3. Learning outcomes

The students can explain how the phase diagram calculations are carried out using various calculations software and differentiate between the analysis of phase diagram sections such as liquid phase formations and various systems such as eutectic and peritectic melting processes. The student can elaborate on the basic measurement methods for the determination of phase diagrams for binary systems, these include Fe – C system and other systems such as Al – Si phase diagram. Students can describe various analytical calculation methods for overall formation of phase diagrams which will also be introduced to the students to derive possible applications.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 12 and 13, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 11

1. The subject of the lecture

TERNARY SYSTEMS: GENERAL

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

The lecture aims to give an extensive introduction to ternary systems in mostly metallic systems and application rules of phase calculations in such diagrams including representation of ternary systems in well known commercial and studied ternaries. The lever rule or tie line rules are to be shown to the students and applied to these ternary systems with extensive examples found n many systems. Ternary systems are those having three components. It is not possible to describe the composition of a ternary alloy with a single number or fraction, as was done with binary alloys, but the statement of two independent values is sufficient to form a ternary phase diagram with many phases. For example, the composition of an Fe - Cr - Ni alloy can be implemented on a ternary phase diagrams as it is studied in detail because of its industrial importance. But the requirement that two parameters must be stated to describe ternary composition means that two dimensions must be used to represent composition on a complete phase diagram. The external variables that must be considered in ternary constitution are temperature, pressure, composition X, and composition Y. To represent completely the phase equilibria at constant pressure in a ternary system, a 3-D model, commonly termed a space model, is required; the representation of composition requires two dimensions, and that of temperature, a third dimension. The model used is a triangular prism, in which the temperature is plotted on the vertical axis, and the composition is represented on the base of the prism, which may be conveniently taken as an equilateral triangle. A hypothetical ternary phase space diagram made up of metals A, B, and C. The liquidus plots contain temperatures that are plotted as isothermal contours in a 3D diagrams. This presentation is helpful in predicting the freezing temperature of an alloy for any three metal and non metal systems. The liquidus plot also gives the identity of the primary phase that will form during solidification for any given alloy composition. Similar plots, known as solidus plots, showing solidus freezing are also to be presented during the course. This kind of phase diagrams is mostly used for the casting professionals to predict the energy consumption as well. An isothermal plot shows the phases present in any alloy at a particular temperature and is useful in predicting the phases and their amounts and compositions at that temperature. Certain groups of alloys can be plotted as vertical sections, also called isopleths. These sections often represent a fixed composition of one of the elements, while the amounts of the other two elements are allowed to vary. These plots show how the phases and structures change when the temperature varies and when two of the elements present change their respective amounts. This topic will also be introducing many examples regarding the different types of phase calculation and the application of the lever rule-tie lines and tie triangles.

3. Learning outcomes

The students can explain the rules that are important to calculate the phase composition and their formation in ternary systems. In addition to the general rule of application of ternary systems in industrial alloys, the students can derive conclusions how ternary phase systems are constructed and calculations are made in such complex systems using predetermined coefficients and thermodynamic rules and values. The student can analyze and explain the parts of zones in phase diagrams of ternary systems.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 109, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 12

1. The subject of the lecture

EXEMPLARY STUDIES IN PHASE DIAGRAMS

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

The topic aims to give extensive exemplary studies on binary fully soluble, binary eutectic, binary peritectic, binary monotectic and basic and complex ternary systems in mostly metallic systems and application rules of phase calculations in some industrially important applications including graphical representation of alloy systems in well known commercial and literature studied ternaries. This topic continues on the short introduction on the subject of solution thermodynamics for multi-component systems to emphasize the importance and help students understand the underlying basics, but the emphasis is mostly with its role in the stability of multi-component phase equilibria. The situation of phase and resulting microstructural stability of phase equilibria in temperature - composition variants at constant pressure (1 atm) is known classically in materials as the phase diagram derived mostly from the experimental works, however, recent years have drastically witnessed the developments in computer based calculations using many techniques as given previous lectures in this course. With these techniques, a thermodynamic model assumed for the behaviour of each solution phase, coupled with the free energy differences among the various phases of the pure components, the full phase diagram can be calculated, both for complete equilibrium and for meta - stable equilibrium in many systems whether it is metallic or ceramic or even composite systems. The calculated equilibria can be compared to the measured equilibria where amenable to experimentation. The model is not just useful to interpolate and extrapolate among data, but is also immensely helpful in interpreting notable features of the phase diagram for a particular system. Up to five components of metal and oxides are considered in this exemplary study and essay reporting topic. Alloy systems that are selected for this topic are stressed over alloy systems such as Fe – C, Fe – Cr – Ni, or famously known as stainless steel system, high entropy systems that are known as Cantor alloys containing Fe-Cr-Ni-Cu-Co + X metallic alloys, also oxide systems, which differ in that the vertices are usually compounds, rather than the pure components. This topic will also be introducing many examples regarding the different types of phase diagrams with the calculation and the application of the phase diagrams during the presentation, based on the images that will be provided using Thermo-Calc or similar softwares such as Pandat, FACT-SAGE and SOLGASMIX and nd most recently through public software libraries such as gibbs, pycalphad and OpenCalphad. At the end of this topic, students are to be requested to write a report on the development of phase diagrams and calculation methods by which phase diagrams are produced using academic software databases as given in previous paragraph. The students will also have an opportunity to strengthen their knowledge on phase diagrams and its calculation during the course.

3. Learning outcomes

The students can explain and analysis the phase diagrams and their types on the phase diagrams given using various phase diagram calculation programs and is content with the the way which these software are operated. The students can derive conclusions from the phase diagrams that are important to calculate the phase composition and their formation in binary and ternary systems presented during the topic and can elaborate on how interpretations are made using basic rules of application.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 14, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

Topics 13

1. The subject of the lecture

NON EQUILIBRIUM REACTIONS: MARTENSITIC, BAINITIC AND PRECIPITATION HARDENING

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

The topic aims to give extensive examination of non equilibrium reactions that are very important in the metallurgical applications. In fact, most of the metallurgical reactions are determined by their capacity to form non equilibrium reactions as part of their use in industry. This section will be divided into two sections i.e. martensitic and bainitic reactions and also precipitation reactions and related hardening mechanisms available alloy systems. The first section examines two important strengthening mechanisms in metallic alloys with binary compositions, that is, martensitic and bainitic transformations, both of which occur under nonequilibrium cooling conditions in C containing iron alloys. The martensitic reactions are result of a specific type of phase transformation that produces the structure known as martensite which was first observed and described in steels although they occur also in many other materials, such as e.g. in Fe-Ni and Titanium alloys. The topic will later proceed with the practical understanding of how time temperature transformation diagrams (TTT) and continuous cooling transformation diagrams (CCT) are generally constructed in practical way and how they are used to understand and control the formation of martensite and bainite in steel and some other martensite producing alloys. Many examples of TTT e.g. time temperature transformation diagram will be provided to the students and explained through graphical repesentation found in literature sources. The topic will then describe the morphology of both types of structures in an explanatory way, the factors that influence their formation such as solution treatment temperature, the alloying content of the steel of alloy, cooling rate during quenching and also quenching medium i.e. indirectly related to the cooling rate, the temperature at which the reaction is first ceased to, how they respond to stress relieving heat treatment and tempering processes and their effect on mechanical properties and other significant properties that are of practical value in industrial applications. This chapter also discusses the basic principles of precipitation reactions and precipitation control mechanisms in phase changing alloys. The precipitation hardening is an important strengthening mechanism in nonferrous alloys as well as stainless steels. The second part this topic begins with a detailed review of the theory of precipitation hardening in many alloy systems, then describes its application to aluminum alloys and nickel-base superalloys. This topic also discusses the role of transformation hysteresis in shape memory alloys. At the end of this topic, students are to be requested to write an essay report on the development of non equilibrium reactions in ferrous and non ferrous alloys and classification methods by which special diagrams e.g. TTT and CCT diagrams are used using academic software databases as given in previous studies. TTT and CCT diagrams will be used in the classroom and many mechanisms will be explained using these diagrams. The students will also have an opportunity to strengthen their knowledge on martensitic and bainitic reactions in alloy apart from steels and precipitation hardening reactions during the course.

3. Learning outcomes

The students can explain and analysis the martensitic and bainitic reactions in ferrous and non ferrous alloys and be content with the understanding of precipitation reactions and resulting hardening mechanisms. The students can also contentedly derive conclusions from the TTT and CCT diagrams presented during the topic and write an essay on how interpretations are made using basic rules of transformations. Students can define the equilibrium and non equilibrium reactions and suggest a mechanism with respect to proposed cooling rate and medium.

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

The course will include a mix of traditional and modern teaching methods using blackboard Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters 15 and 16, F.C. Campbell, editor, Phase Diagrams—Understanding the Basics, ASM International, 2012.

6. Additional notes

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).

MATERIALS SCIENCE MASTERS
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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

Mechanics of Composite Materials

Code: MCM

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO COMPOSITE MATERIALS

2. Thematic scope of the lecture

Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with properties different from those of the individual components. The formation of composites involves the combination of a reinforcing phase, such as fibres or particles, with a matrix phase, typically a polymer, metal or ceramic, to enhance specific properties. The reinforcing material provides strength and stiffness, while the matrix holds the reinforcements together and distributes stresses evenly throughout the composite. This synergy allows composites to achieve high levels of strength, stiffness and other performance metrics, often exceeding those of their constituent materials when used alone. There are several types of composites, categorized according to their matrix components or reinforcement forms. Polymer matrix composites (PMCs) are the most common, using polymers such as epoxy or polyester as the matrix. Metal matrix composites (MMCs) and ceramic matrix composites (CMCs) use metal and ceramic matrices, respectively, to provide improved thermal and wear resistance. Based on the type of reinforcement, composites can be divided into fiber reinforced composites, which include continuous (long) and short fiber composites, and particulate composites, where the reinforcement is in the form of particles. Each type of composite is tailored for specific applications, ranging from aerospace and automotive components to sports equipment and building materials. The benefits of composites are many. They offer superior strength to weight ratios compared to traditional materials, making them ideal for applications where weight savings are critical, such as in the aerospace and automotive industries. Composites also offer excellent corrosion resistance, fatigue resistance and customizable properties; by varying the type, amount and arrangement of reinforcements, manufacturers can tailor the material properties to meet specific application requirements. In addition, composites can be designed to have anisotropic properties, offering the ability to strengthen structures in specific directions. However, there are disadvantages to consider. The cost of composites can be high, both in terms of raw materials and manufacturing processes, which often require specialized equipment and skilled labor. The complexity of design and manufacture can also lead to longer development times. In addition, the recycling and repair of composites pose significant challenges due to their complex structure, potentially leading to higher life cycle costs and environmental impacts. Another consideration is the variability in quality and properties, as the performance of composites can be highly sensitive to manufacturing conditions and material quality. This course will talk about the history of composite materials and how their usage areas have changed over the years. By introducing the structure of composite materials, it will be discussed how this structure affects mechanical properties of a composite

3. Learning outcomes

Students can describe the historical development of composite materials; explain how the use of composite materials has changed over the years; recognize the structures of composites and the difference of this structure from monolithic materials; show how the structures of composite affect the mechanical properties.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://compositesnl.nl/wp-content/uploads/2019/10/Composites-an-introduction-1st-edition-EN.pdf

6. Additional notes

Topics 2

1. The subject of the lecture

FIBER REINFORCED PLASTIC PROCESSING

2. Thematic scope of the lecture

The production of fiber-reinforced polymer composites (FRPCs) involves a complex process that combines fibers and matrices to create materials with improved mechanical and physical properties for specific applications. The fibers play a crucial role as the primary reinforcement, providing the composite with strength and stiffness. Various fiber types are commonly used, including glass, carbon, aramid, and natural fibers, each with their own unique advantages. Glass fibers are a popular choice due to their cost-effectiveness and good tensile strength and electrical insulating properties. Carbon fibers, on the other hand, are a more expensive option but offer superior strength-to-weight ratios and stiffness, making them ideal for aerospace and high-performance applications. Aramid fibers are recognized for their impact resistance and toughness, and are frequently utilized in ballistic and protective applications. Natural fibers such as flax, hemp, and bamboo are increasingly favored for their environmental benefits and robust mechanical properties.

The matrix, which binds the fibers together and transfers stress between them while safeguarding them from environmental and mechanical damage, is a crucial factor in determining the composite's overall properties, including its chemical resistance, temperature performance, and durability. Polymer matrices are typically classified as either thermosets or thermoplastics. Thermoset resins, such as epoxy, polyester, and vinyl ester, are known for their outstanding mechanical properties, chemical resistance, and ability to cure at room temperature, making them suitable for a wide range of applications. Although they are more expensive, epoxy resins in particular offer superior mechanical properties, adhesion, and durability. Thermoplastics, such as polyethylene (PE), polypropylene (PP), and polyamide (nylon), are known for their recyclability and reshaping capabilities. While they may have lower mechanical properties compared to thermosets, they offer unique advantages in certain applications. The production process involves carefully selecting and combining fibers and matrices to achieve the desired properties, which requires expertise and attention to detail. Various techniques are utilized in the creation of fiber-reinforced polymer composites, such as hand lay-up, pultrusion, filament winding, and resin transfer molding. Each method has its own distinct advantages in terms of shape complexity, volume production, and material characteristics. The resulting composites offer a unique combination of strength, stiffness, and lightweight properties, as well as improved durability and design flexibility. FRPCs have been instrumental in revolutionizing industries such as aerospace, automotive, construction, and sports equipment by providing solutions that outperform traditional materials in demanding environments. The continuous innovation in fiber types, matrix formulations, and production technologies further expands the potential of FRPCs, driving advancements in material science and engineering applications. This course covers the classification of composite materials according to their matrices and reinforced materials. Manufacturing, mechanical properties and usage areas of composite materials discuss in detail. In addition, infrastructure is created for future lessons by introducing the terminology used for studying mechanics of composites.

3. Learning outcomes

Students can show the classification of composite materials and describe the ways which fiber reinforced composites are classified; explain manufacturing, mechanical properties and usage fields of composite materials with fiber reinforced additives; explain mechanical properties of composite materials with and without fibers additions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://compositesnl.nl/wp-content/uploads/2019/10/Composites-an-introduction-1st-edition-EN.pdf

6. Additional notes

Topics 3

1. The subject of the lecture

BASIC PRINCIPLES OF MECHANICS OF MATERIALS

2. Thematic scope of the lecture

The stress-strain relationships for various types of materials, including metals, polymers, and composites, explain how materials deform under applied loads and provide critical insight into their mechanical behavior. Stress, defined as the internal force per unit area exerted within a material under load, and strain, the measure of deformation experienced by the material as a result of stress, are fundamental concepts in understanding material response. The slope of the stress-strain curve, known as the modulus of elasticity or Young's modulus, quantifies the stiffness of the material and indicates how much strain a material will undergo for a given stress in the elastic deformation phase, where the material returns to its original shape upon unloading. For metals, the stress-strain curve typically shows a linear elastic region followed by a yield point beyond which plastic deformation occurs, demonstrating ductility. Polymers, on the other hand, may exhibit a more complex behavior with significant nonlinear elasticity or viscoelasticity, indicating a time-dependent strain response. Composite materials that incorporate fibers in a matrix have stress-strain curves that reflect the combined properties of both constituents and the efficiency of stress transfer between them. Focusing on unidirectional and bidirectional composite layers, these materials exhibit anisotropic behavior, meaning that their mechanical properties vary in different directions. In a unidirectional layer, the fibers aligned in a single direction predominantly carry the load, resulting in high stiffness and strength along the fiber direction, which is evident in the stress-strain relationship. Conversely, the material exhibits lower stiffness and strength perpendicular to the fibers. Bidirectional layers, with fibers oriented in two directions, show improved mechanical properties in those two directions, with the stress-strain curves representing a compromise between the properties of the unidirectional constituents. Strain energy, the energy stored in a material due to deformation, is another critical consideration. It is proportional to the area under the stress-strain curve in the region of elastic deformation. Materials with a high modulus of elasticity and the ability to sustain significant strain before failure can store more strain energy, making them desirable for impact resistance and energy absorption applications. Understanding these relationships is critical to material selection and design to ensure that materials perform adequately under expected loading conditions while maximizing efficiency and safety. This course also includes stress, strain, elastic moduli and strain energy concepts; examine stress-strain relationships for different types of materials and stress-strain relationships for a unidirectional / bi-directional lamina structures.

3. Learning outcomes

Students can explain stress, strain elastic moduli and strain energy concepts specific to composite materials; show stress-strain relationships for different types of materials and perform analysis for different conditions of service; explain the stress-strain relationships for a unidirectional / bidirectional lamina.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

Mechanics of Materials; Ferdinand P. Beer, E. Russell Johnston Jr. , John T. DeWolf , David F. Mazurek, Published by McGraw-Hill Education, ISBN 978-0-07-339823-5

6. Additional notes

Topics 4

1. The subject of the lecture

LAMINA STRUCTURES

2. Thematic scope of the lecture

The study of unidirectional and bidirectional laminates in composite materials reveals intricate relationships between their stiffness and compliance parameters, which are critical to understanding their mechanical behavior and performance under various conditions. In unidirectional laminates, where the fibers are aligned in a single direction, the stiffness along the fiber direction is significantly higher than in the perpendicular direction due to the high load carrying capacity of the fibers. This anisotropy is quantified by stiffness matrices [A], which represent the in-plane stiffness of the laminate, and compliance matrices [S], which represent the in-plane compliance of the material, showing its ability to resist deformation and its tendency to deform under stress, respectively. The stress-strain relationships in these laminates are predominantly linear in the elastic region, with the strength along the fibers far exceeding that across the fibers, reflecting the directional dependence of the mechanical properties. Bidirectional laminates, which contain fibers oriented in two different directions, exhibit more complex behavior due to the interaction between the fiber orientations. The stiffness and compliance in these laminates are influenced by the ply angles, with certain orientations providing optimized properties for certain loading conditions. The stress-strain relationships in bidirectional laminates highlight the balance achieved between the stiffness contributions of each fiber direction, allowing tailored mechanical responses by adjusting ply angles and ply sequences. The strengths of uni-/bi-directional laminates are also critically dependent on fiber orientation, with tensile, compressive, and shear strengths varying significantly with the direction of applied loads. Thermal and moisture expansion behavior further complicates the performance of these materials, as different expansion coefficients in the fiber and matrix phases can induce internal stresses that can lead to warping or delamination. The effects of single (duplex) layer configurations and ply angle variations are profound and allow the design of composite structures with desired anisotropic properties, allowing engineers to fine-tune stiffness, strength, and expansion characteristics to meet specific application requirements. Understanding these parameters and their interactions is essential for the effective design and application of composite materials, enabling their superior properties to be exploited in a wide range of engineering and technological applications. The ability to manipulate stiffness, compliance and thermal expansion through strategic layering and orientation provides a powerful tool for creating advanced materials tailored to specific performance criteria, driving innovation in aerospace, automotive and structural engineering. This course aims to tell uni/bi-directional lamina in terms of the stiffness and compliance parameters of the lamina. Stress-strain relationships, strengths, thermal and moisture expansion, and the effects of single/duplex layer and ply angle are also included in this course.

3. Learning outcomes

Students can explain stiffness and compliance parameters of the lamina; explain stress-strain relationships, strengths, thermal and moisture expansion of laminated composites and their effect on their final properties; explain the effects of single/duplex layer and ply angle.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

Mechanics of Materials; Ferdinand P. Beer, E. Russell Johnston Jr. , John T. DeWolf , David F. Mazurek, Published by McGraw-Hill Education, ISBN 978-0-07-339823-5

6. Additional notes

Topics 5

1. The subject of the lecture

TYPES OF COMPOSITES IN DESIGN

2. Thematic scope of the lecture

Fiber composites, characterized by the incorporation of fibers as reinforcement within a matrix material, present a wide variety of structural configurations and mechanical properties tailored for specific applications. These composites can be engineered into a variety of shapes, including sheets and plates, which vary in thickness and structural properties, and sandwich panels, which are known for their lightweight yet high-strength capabilities. Thin sheets, often used in applications requiring precision and flexibility, utilize the high tensile strength of fibers aligned in the plane of the sheet to efficiently resist bending and in-plane loads. The mechanical behavior of thin plates is typically governed by classical plate theory, which assumes small deformations and linear stress-strain relationships, allowing analysis of their stiffness, strength, and vibration characteristics under various loading conditions. Thick plates, on the other hand, have a more complex stress distribution due to their thickness, requiring the use of more sophisticated theories such as three-dimensional elasticity or shear deformation theories to accurately predict their behavior. These panels can better withstand out-of-plane loads and have higher resistance to bending and shear forces, making them suitable for more demanding structural applications. Sandwich panels represent the pinnacle of composite design, consisting of two thin, high-strength skins bonded to a lightweight core. This configuration exploits the high stiffness-to-weight ratio of the skins and the high shear stiffness and low density of the core, resulting in exceptional mechanical efficiency. Sandwich panels exhibit superior mechanical properties, including high flexural stiffness and strength, excellent thermal insulation, and vibration damping. The core material, often a honeycomb or foam, also contributes to the panel's impact resistance and energy absorption capabilities. The mechanical properties and relationships of these fiber composites are inextricably linked to fiber orientation, matrix properties, and fiber-matrix interaction. The orientation of the fibers within planes or sheets can be tailored to optimize the strength and stiffness of the composite in desired directions, while the choice of matrix and core materials can significantly affect the overall performance of the composite, including its resistance to environmental degradation, thermal expansion, and moisture absorption. Understanding these relationships is critical to the design and application of fiber composites in engineering, enabling the development of materials that meet stringent performance and durability requirements across a wide range of industries. This course is about fibrous composites; planes and plates ; thin plates and thick plates; sandwich plates.

3. Learning outcomes

Students can explain fibrous composites and their properties; show how planes and plates affect the properties of fibrous composite materials; explain differences between thin and tick plates and their mechanical properties; explain the properties of sandwich plates under stress conditions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Composite Materials Design And Applications ;Daniel Gay Suong, V. Hoa Stephen, W. Tsai, ISBN 1-58716-084-6

6. Additional notes

Topics 6

1. The subject of the lecture

LAMINATED COMPOSITES

2. Thematic scope of the lecture

Laminated composites, known for their layered construction that combines different materials to achieve superior mechanical and physical properties, have their own terminology and diverse applications in various industries. Fundamental terms in the field of laminated composites include "lamina," which refers to a single layer of composite material, and "laminate," which refers to the stack of these layers bonded together. Each lamina typically consists of fibers embedded in a matrix material, with the fiber orientation within each layer being a critical design parameter. The term "ply" is often used interchangeably with lamina to emphasize the role of each layer in the overall laminate structure. The orientation or "ply angle" of the fibers in each ply, along with the sequence and symmetry of these layers, defines the "lay-up configuration" that is critical to tailoring the properties of the laminate to meet specific application requirements. The interface between the layers, known as the "interlaminar region", is critical to the structural integrity of the laminate and affects its resistance to delamination. Because of their customizable properties and high performance, laminated composites are used in a wide range of applications. In the automotive industry, they are used to produce lightweight, fuel-efficient components with increased strength and reduced emissions. The aerospace industry uses laminated composites for structural parts such as wings, fuselages and tail units, benefiting from their high strength-to-weight ratio and corrosion resistance. Missiles and defense equipment also use these materials for their structural components, valuing the durability and performance of composites under extreme conditions. In the electrical and electronics industries, laminated composites serve as insulators and substrates for printed circuit boards, providing excellent electrical insulation and heat resistance. The marine industry benefits from composites' resistance to water and corrosion, using them in the construction of hulls, decks and masts for boats and ships. Recreational and sports equipment, including bicycles, golf clubs and tennis rackets, take advantage of the materials' light weight and high stiffness to improve performance and ease of use. The future potential of laminated composites lies in their continued development and innovation, with research focused on improving their sustainability, recyclability and manufacturing processes. Advanced manufacturing techniques such as 3D printing and automated lay-up processes promise to further expand the applications of laminated composites, potentially revolutionizing the construction and renewable energy sectors and beyond with materials that offer unprecedented combinations of strength, durability and environmental performance. This broad range of applications and the continued evolution of composite technology underscore the transformative impact of composite materials on modern society. This lecture will focus on general terminology for laminated composites and applications of laminated composites.

3. Learning outcomes

Students can explain general terminologies associated with laminated composites; describe the applications related to laminated structures; describe the production phases of laminated composites with respect to their types.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Composite Materials Design And Applications ;Daniel Gay Suong, V. Hoa Stephen, W. Tsai, ISBN 1-58716-084-6

6. Additional notes

Topics 7

1. The subject of the lecture

METAL MATRIX COMPOSITES FABRICATION PROCESS

2. Thematic scope of the lecture

Metal matrix composite (MMC) manufacturing processes are sophisticated methods for combining metal matrices with reinforcing materials, such as ceramics or fibers, to create composites that take advantage of the best properties of both constituents. MMCs are manufactured using a variety of techniques, each selected based on the desired properties of the final product, the nature of the matrix and reinforcement materials, and the intended application. A common method is powder metallurgy, in which metal powders are mixed with reinforcing particles, then compacted and sintered. This process allows precise control over the distribution of reinforcement within the matrix, resulting in uniform properties and high performance in the final composite. Another method, stir casting, involves melting the matrix metal and then stirring in the reinforcing material, creating a mixture that is then poured into molds. This method is cost-effective and suitable for large-scale production, but it can be challenging to achieve uniform distribution of reinforcement materials. In addition, infiltration techniques, including pressure and vacuum infiltration, allow MMCs to be made by forcing molten metal into a preform of reinforcing material. This method is particularly effective for fabricating composites with high reinforcement content and provides excellent control over the final microstructure. In addition, the squeeze casting process combines the advantages of casting and forging by introducing the reinforcement material into a mold and then infiltrating the molten matrix material under high pressure. This results in composites with reduced porosity and improved mechanical properties. Recently, advanced methods such as in-situ manufacturing processes have gained attention. In these processes, the reinforcement phase is formed directly within the metal matrix by chemical reactions, providing a strong matrix-reinforcement bond and a clean interface, which is critical for the mechanical properties of the composite. Each fabrication technique for MMCs has its own set of advantages and limitations that influence the choice of method based on factors such as the desired mechanical properties, cost considerations, and the specific application of the composite. Ongoing developments in MMC manufacturing technologies are aimed at optimizing the distribution of reinforcing materials, improving the interfacial bond between matrix and reinforcement, and developing composites with tailored properties for applications ranging from aerospace and automotive to sporting goods and infrastructure, demonstrating the versatile potential of MMCs in modern engineering and technology. This lecture will focus on metal matrix composites which includes of reinforcement materials, types, characteristics and selection base metals. First the fabrication of MMC's like Powder metallurgy and liquid metallurgy technique will explain and then the secondary processing, special techniques will describe.

3. Learning outcomes

Students can explain metal matrix composite and their components; explain the fabrication of metal matrix composites and various parameters that control their properties; explain the secondary processing and some special techniques for metal matrix composite.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://www.princeton.edu/~ota/disk2/1988/8801/880107.PDF

6. Additional notes

Topics 8

1. The subject of the lecture

CERAMIC MATRIX COMPOSITES FABRICATION PROCESS

2. Thematic scope of the lecture

The production of ceramic matrix composites (CMCs) involves processes designed to integrate ceramic matrices with reinforcement materials such as fibers or whiskers, resulting in composites with improved toughness, thermal stability, and mechanical strength compared to conventional ceramics. Fabrication techniques are selected based on the desired composite properties, the nature of the ceramic matrix, the type of reinforcement, and the intended application. One of the primary methods for manufacturing CMCs is the powder metallurgy route, which involves mixing ceramic powders with reinforcing materials, followed by compacting and sintering at high temperatures. This method allows precise control of the composite microstructure, resulting in materials with uniform properties and high performance. Another important technique is the infiltration process, which can be divided into two main types: chemical vapor infiltration (CVI) and liquid silicon infiltration (LSI). In CVI, gaseous precursors are introduced into a preform of the reinforcing material; these precursors decompose to form the ceramic matrix within the preform. This method is advantageous for producing CMCs with complex shapes and high purity, but it is relatively time-consuming. LSI, on the other hand, involves the infiltration of molten silicon into a carbon preform containing the reinforcing phase. The silicon reacts with the carbon to form silicon carbide (SiC) in situ, providing excellent control over the density and mechanical properties of the final composite. Pulsed electric current sintering, also known as spark plasma sintering, is a newer technique that uses electrical pulses and pressure to consolidate ceramic and reinforcing powders into a dense composite. This method can significantly reduce sintering times and improve the mechanical properties of the composite by promoting better bonding at the interfaces between the matrix and the reinforcements.

The fabrication of CMCs also involves slurry impregnation followed by hot pressing or tape casting for thin film applications, where layers of slurry containing ceramic and reinforcing materials are poured, layered, and then fused into a unitary structure under heat and pressure. Each of these manufacturing processes aims to optimize the distribution of reinforcement within the ceramic matrix, improve interfacial bonding, and tailor composite properties for specific applications. As a result, CMCs are increasingly being used in demanding environments such as the aerospace, automotive and energy sectors, where materials must withstand high temperatures, corrosive atmospheres and mechanical stresses, demonstrating the critical role of advanced manufacturing techniques in the development of next-generation materials solutions. This lecture will focus on ceramics matrix composites: Reinforcement materials, types, characteristics and selection of matrix, production CMC's and its application. Fabrication Process For MMC's: Powder metallurgy and special fabrication techniques

3. Learning outcomes

Students can explain the concept of ceramic matrix composite and contributions of each component forming ceramic matrix components; explain mechanical and interface characteristics and selection of matrix phase and correlate them with additives; describe production of ceramic matrix composites and their applications.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://www.jmaterenvironsci.com/Document/vol8/vol8_N5/176-JMES-2775-Singh.pdf

6. Additional notes

Topics 9

1. The subject of the lecture

GENERAL PROPERTIES OF MMC'S

2. Thematic scope of the lecture

Metal matrix composites (MMCs) exhibit a unique set of physical, mechanical, wear, and machinability properties that distinguish them from conventional metals and alloys and are largely influenced by the size, shape, and distribution of the particulate reinforcement within the metal matrix. The incorporation of particles such as silicon carbide, alumina, or graphite into a metal matrix such as aluminum, magnesium, or titanium significantly increases the strength, stiffness, and wear resistance of the composite. The effect of particle size on the properties of MMCs is profound; smaller particles can result in a more uniform distribution, which typically improves the mechanical properties of the composite by hindering the movement of dislocations within the matrix. However, an optimal particle size must be maintained to avoid agglomeration, which can create stress concentrations and reduce the overall performance of the composite. The shape of the particles also plays a critical role; for example, spherical particles tend to provide better load transfer and distribution within the matrix, while irregular or angular particles can provide better mechanical interlocking, which improves the strength of the composite but may reduce its ductility. The distribution of particles within the matrix is also critical; a uniform distribution ensures consistent properties throughout the composite, improving its overall performance and reliability under load. These particulate reinforcements significantly improve the wear resistance of MMCs by providing a harder surface that resists abrasion and erosion better than the base metal. This makes MMCs particularly suitable for applications involving sliding or abrasive wear conditions. The improved wear resistance also contributes to the improved machinability of the composites, as tools experience less wear during machining, although the harder particles can present challenges that require more advanced machining techniques and tools. In addition, the thermal conductivity of MMCs can be tailored by selecting the particle type and volume fraction; for example, the addition of graphite particles can increase thermal conductivity, while ceramic particles can decrease it. This ability to engineer the thermal properties of MMCs makes them ideal for heat sink and electronic packaging applications where thermal management is critical. Overall, the size, shape, and distribution of particles within metal matrices profoundly affect the physical, mechanical, wear, and machinability properties of MMCs, enabling the design of materials with targeted properties for specific applications. This versatility underlies the growing interest in MMCs in various industries, including automotive, aerospace, and electronics, where materials that offer a combination of light weight, high strength, and superior wear resistance are increasingly in demand. This lecture will focus on physical mechanical, wear, machinability and other properties of metal matrix composites. Especially, effect of size, shape and distribution of particulate on properties will explain.

3. Learning outcomes

Students can explain properties of metal matrix composites such as physical, mechanical, wear, machinability and other properties of metal matrix composites; describe which parameters affect the features of metal matrix composites and the possible mechanisms based on the literature search.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

Students are expected to read below texts related to the lecture:
https://www.princeton.edu/~ota/disk2/1988/8801/880107.PDF

6. Additional notes

Topics 10

1. The subject of the lecture

GENERAL PROPERTIES OF CMC'S

2. Thematic scope of the lecture

Ceramic matrix composites (CMCs) are known for their exceptional physical, mechanical, wear and machinability properties, which are significantly influenced by the size, shape and distribution of the particulate reinforcements embedded in the ceramic matrix. These composites integrate ceramic matrices with reinforcing particles or fibers, such as silicon carbide (SiC) or alumina (Al2O3), to overcome the inherent brittleness of ceramics while enhancing their toughness, strength, and resistance to wear and thermal shock. The size of the particles plays a critical role in defining the properties of the composite; smaller particles can effectively block the propagation of cracks within the matrix, thereby increasing the toughness and strength of the composite. However, achieving a uniform distribution of these fine particles is critical to prevent the formation of agglomerates that could act as defect sites and compromise the integrity of the material. The shape of the particles also has a profound effect on the properties of CMCs. For example, elongated or fibrous reinforcements can bridge cracks more effectively than spherical ones, further increasing the fracture toughness of the composite. In addition, the interfacial bond strength between the particles and the matrix is critical for load transfer, where a stronger bond can significantly improve the mechanical properties of the composite, but may reduce its resistance to thermal shock. The wear properties of CMCs are significantly improved by the inclusion of hard particles, which provide a protective barrier against surface abrasion, making these composites ideal for applications subject to severe wear conditions. However, the improved wear resistance can pose machinability challenges, requiring specialized tools and techniques for effective machining. The thermal properties of CMCs, including conductivity and expansion, can also be tailored through careful particle selection and distribution, enabling their use in high-temperature applications where thermal stability is paramount. Overall, the interplay between the size, shape and distribution of the particles within the ceramic matrix critically determines the overall performance of CMCs, enabling the development of materials with specific, desirable properties for advanced applications in the aerospace, automotive and energy sectors, where materials must withstand extreme conditions while maintaining high performance. This lecture will focus on physical mechanical, wear, machinability and other properties of ceramic matrix composites. Especially, effect of size, shape and distribution of particulate on properties will explain.

3. Learning outcomes

Students can discover and explain physical, mechanical, wear, machinability and other properties of ceramic matrix composites in detail; give details on which parameters affect the features of ceramic matrix composites and their operational parameters with working mechanisms.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://www.jmaterenvironsci.com/Document/vol8/vol8_N5/176-JMES-2775-Singh.pdf

6. Additional notes

Topics 11

1. The subject of the lecture

RECYCLING OF COMPOSITES AND ITS EFFECT ON PROPERTIES

2. Thematic scope of the lecture

The composites industry, with its expansive growth in the aerospace, automotive, construction and renewable energy sectors, faces significant waste management and recycling challenges. The inherent complexity of composites, especially those with thermoset matrices, complicates their end-of-life disposal and recycling. However, innovative waste management strategies are emerging that focus on converting composite waste into useful products and exploring recycling methods that reduce the environmental impact without significantly compromising the mechanical properties of the recycled composites. Mechanical recycling, thermal pyrolysis, and chemical processing are the main methods being developed to recover fibers and resins from composite waste. Mechanical recycling involves grinding composite waste into fillers or reinforcing fibers for new composites, although this can result in reduced mechanical properties due to fiber shortening and potential damage. However, these recycled fibers can be used in non-structural applications where high performance is not critical, such as automotive interiors or building materials, providing a sustainable alternative to virgin materials. Thermal pyrolysis and chemical processing, on the other hand, aim to recover fibers and resins with minimal damage, potentially preserving the high-strength properties of the original composite. Pyrolysis converts the resin matrix to gases and oil, leaving clean fibers that can be reintegrated into new composites. Chemical recycling dissolves the matrix and separates the fibers, but the challenge is to find environmentally friendly solvents and efficient processes. These recovered materials can be used to make new composites for applications ranging from structural components in vehicles and wind turbine blades to consumer goods, demonstrating the potential for a circular economy within the composites industry. However, recycling composites can affect their mechanical properties. Recycled fibers may have compromised strength due to exposure to high temperatures or chemicals during recycling, affecting the overall strength and stiffness of new composites made with recycled content. However, ongoing research is focused on optimizing recycling processes to minimize these effects, improving the interface between recycled fibers and new matrices, and developing novel composite formulations that are more amenable to recycling. Incorporating recycled composites into new products not only addresses waste management challenges, but also reduces reliance on virgin materials, thereby reducing the environmental footprint of the composites industry. As recycling technologies advance and become more widespread, the industry is moving toward sustainable production and consumption models, highlighting the importance of innovation in achieving environmental and economic goals. This lecture will focus on composite industry and waste management; useful products and applications; how recycling affects the mechanical properties of composites.

3. Learning outcomes

Students can explain the waste management procedures of composite materials and show how to reuse of the waste of composite structures and materials; explain the affects of recycling on the mechanical properties of composites that are produced with recycled composites.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Review Composite Material Recycling Technology—State-of-the-Art and Sustainable Development for the 2020s; Andrey E. Krauklis, Christian W. Karl , Abedin I. Gagani and Jens K. Jørgensen, J. Compos. Sci. 2021, 5(1), 28; https://doi.org/10.3390/jcs5010028.

6. Additional notes

Topics 12

1. The subject of the lecture

FAILURE OF COMPOSITES AND ANALYSIS

2. Thematic scope of the lecture

Destructive testing plays a critical role in evaluating the mechanical properties and structural integrity of composite materials, providing insight into their performance under various load conditions. These tests, guided by rigorous standards and protocols, are designed to push materials to their limits in order to identify their strengths, weaknesses, and failure mechanisms. Standards such as ASTM and ISO provide comprehensive guidelines for conducting destructive tests on composites, ensuring consistency, reliability, and comparability of results across different materials and applications. Among the key destructive tests, impact testing stands out for its ability to simulate real-world impact and shock scenarios that composites may encounter in service. Techniques such as the Charpy and Izod impact tests measure the amount of energy absorbed by a composite specimen during fracture, providing a quantifiable measure of its toughness and resistance to impact loading. In addition, tensile, compression, and flexure tests are fundamental in determining the mechanical properties of composites, such as strength, modulus, and strain to failure. These tests, performed on standardized specimens, provide critical information about the load-bearing capacity of composites and their behavior under different types of loading. Shear and fatigue tests extend this analysis by examining the material's response to shear forces and cyclic loading, respectively, which are critical for dynamic stress applications. By analyzing destructive test data, engineers can refine composite designs, optimize material formulations, and predict the life and performance of composite structures. By understanding the failure modes - whether it is fiber breakage, matrix cracking, or delamination - designers can implement strategies to improve the durability and reliability of composite materials. Adherence to established standards in destructive testing ensures that the properties measured are accurate and that the materials meet the required specifications for their intended use. In summary, destructive testing, supported by rigorous analysis and adherence to global standards, is essential in the development, certification, and application of composite materials. It provides the basis for understanding the mechanical behavior of composites and enables the development of advanced materials that meet the demanding requirements of today's technological and industrial landscapes. This lecture will focus on destructive tests for composites; analysis and standards; impact testing and measurement of mechanical properties of composites.

3. Learning outcomes

Students can perform destructive tests for composites and carry out analysis of the results; interpret and explain applications of impact test and measurement of mechanical properties of composites; explain the formulas and procedures for life prediction and performance of composites in general.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://apps.dtic.mil/sti/tr/pdf/ADA172236.pdf

6. Additional notes

Topics 13

1. The subject of the lecture

EXAMPLES OF INDUSTRIAL APPLICATIONS

2. Thematic scope of the lecture

This lecture aims to show the primary application areas of metal matrix, ceramic matrix and laminated composite structures in general and gives distinctive examples of their usage in industry and in areas special to specific composites. In this lecture, some exemplary studies will be given with respect to applications such as aerospace, machine manufacturing, high temperature applications in radiation facing panels etc... Ceramic Matrix Composites are revolutionizing industries by providing materials capable of withstanding extreme conditions, with applications ranging from aerospace to automotive and energy sectors. As research and development continue, the potential of CMCs is expected to grow, leading to innovative solutions for engineering challenges. CMCs are commonly used in high-temperature applications such as aerospace, energy, and automotive industries. They are particularly useful in situations where high-temperature resistance and corrosion resistance are critical. MMCs are used in a broader range of applications, including aerospace, automotive, and industrial sectors. They are often preferred in situations where high strength, ductility, and impact resistance are important and required. Ceramic matrix Composites are extensively used in the aerospace sector due to their exceptional properties, such as high-temperature resistance, excellent strength-to-weight ratio, and improved fuel efficiency. They are employed in components like turbine blades, combustor liners, nozzle vanes, and thermal protection systems. CMCs are used in the automotive industry for lightweighting purposes, primarily in luxury and sports vehicles. Both metal matrix composites and ceramic matrix composites help reduce the weight of the vehicle by allowing the requirements of strength and other properties hold in one single structure or material, which results in the improved fuel efficiency and the reduced emissions. Applications include brake systems, engine components, and exhaust system. Some of examples will include real specimens used for lathe turning and removal of materials for very hard materials such as highly alloyed steel type M42 or special parts that are used in aviation containing SiC embedded fabric and cured for the highest hardness to withstand both impact and high temperature. Another example that will be mentioned is the ballistic application of body armour using ceramic matrix composites. These armours will be shown to the students and manufacturing procedures and how they stop or divert the bullet at impact will be explained in detail.

3. Learning outcomes

Students can reinforce the subjects with exemplary they have learned theoretically; show how ceramic matrix composites behaves in real conditions of service and conclude to suggest the best use in a particular case; suggest how these CMC and MMC are employed for specific cases and explain the mechanisms of providing high hardness and strength etc...

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

6. Additional notes

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).

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

SOLIDIFICATION AND HEAT TREATMENT PROCESSES

Code: SHTP

Co-funded by the European Union

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO SOLIDIFICATION

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

This topic aims to present a detailed introduction to the basics of solidification process and its development stages in metallic materials with a kinematical approach, starting from the heat transfer from the liquid and its effect on solidification microstructures. The basics of thermodynamics of materials will be detailed, starting from the major concepts of thermodynamics related to the solidification, reactions kinetics and final state equations of the system. The heat of melting and heat of formation of solid will also be elaborated to explain the mechanisms of nucleation and solidification process in pure metals and alloys. It is also important to mention the capillary effect and wetting of a new phase on a neutral substrate during the nucleation and solidification stages in which free energy of mixing of atoms in conventional and non conventional materials are presumed to be rate dependent and path defined processes leading to the equilibrium approaching systems. The topic will continue with explanation of the rate concept due to how fast the heat is extracted from the liquid namely cooling rate, and energy barrier to nucleation and the critical size of nuclei will be dealt with a mathematical expressions and simple calculations using some textbook examples. The students will also expected to be accustomed with diffusion, self diffusion and interdiffusion in the melt and solidifying two phase systems with a special relationship to the interface between the nuclei and phase to phase boundaries. The diffusion in crystalline and non crystalline systems are approached differently where crystalline matter is more regularly bonded and hence the movement of atoms are more restricted whereas non crystalline matters behave more relaxed as the meta stability of the structure allows them experience structural relaxation, phase separation and solidification. In this topic, the driving forces for atomic flux which the behaviour of the concentration around a line source that is diffusing into an infinite isotropic medium will be introduced to the students, as well. The students will be introduced to practical importance of solidification in casting and other manufacturing industry with various examples of solidification. Students will recognise the solidification microstructures from the casting processes and the defects occurring during the casting due to the segregation, incompatibility of type of linings, high casting temperature and improper use of deoxidants for cleaning molten metal, namely cast iron. The topic will be concluded with a discussion on the importance of cooling rate and homogeneous and heterogeneous solidification types in general and in space.

3. Learning outcomes

The students can explain the importance of solidification modes during and after casting or melting process; define the nucleation and growth process and also the effect of cooling rate on the final microstructures of solidified structures; explain solidification parameters for most metallic and alloy systems; recognise the solidified cast structures and defects occurring during and after casting process.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Minkoff, I. (1992). Solidification/Liquid State Processes. In: Materials Processes. Springer, Berlin, Heidelberg.

Kumar Mohanty, U., & Sarangi, H. (2021). Solidification of Metals and Alloys. IntechOpen. doi: 10.5772/intechopen.94393

6. Additional notes

Topics 2

1. The subject of the lecture

Atom transfer and diffusion at liquid solid interface

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

This topic is intended to introduce an atomic transfer and diffusion process at liquid solid interface which is important for the development of solidification of a new phase, which is affected by driving force originating from the chemical and other external sources. The extended treatment of rate equations and related kinetics with the explanation of parameters that include the reference to thermal effect will also be introduced to the students. The solution thermodynamics will be given in brief to describe the atomic interaction in terms of free energy of Gibbs and relate them with solute pile up at the interface due to one of the most important effect e.g. solubility of solutes in the newly forming phase. The topic will continue with the introduction of thermal effect on the pile up behaviour in detail with an exemplary treatment from chemical reactions with mathematical approaches to rate and reaction relationships. One of the most important solute interaction in solidifying state is the Matano interface which defines the solute pile up in a different way other than classical diffusion paths at the interface. Hence, this definition of matano interface will explained to students in detail and some examples will be given from the studies. The second part of this topic will introduce thermal effect during solidification stages such as overheating of liquid and undercooling effect of melt and their effect on the solidification mode and also microstructures and how they affect the interface stability in terms of roughening of the advancing solid front. The lecture topic will also cover the excluded treatment of thermodynamics of solidification with kinetics rate laws. Diffusion, as was mentioned in previous topic, will be revisited to help explain the mechanisms of atomic movement at the interface. Such diffusion mechanisms will involve the vacancy formation and vacancy development during thermally activated reaction in isotropic infinite medium. The vacancy approach will be following the other mechanisms such as interstitial which are more solid state reaction type diffusion mechanism. However, the most important part of this lecture topic will be on the equilibrium in solute distribution in order to establish the new equilibrium concentration. This topic will also cover the effect of heat transfer during solidification with respect to microstructural development of the interface i.e. as the average temperature of the liquid is lower than that of the melting of point of alloy, the interface becomes so undercooled that nucleation begins in the liquid and causes the formation of firstly dendritic structure due to symphatetic or epitaxial nucleation and growth process and as the heat transfer is accelerated from the liquid equiaxed dendritic nucleation and growth takes place. These processes will be given to the students using examples from the studies in casting and welding as well.

3. Learning outcomes

Students can explain solute pile up occurring at the liquid - solid interface and also explain the parameters governing the solid liquid phase line i.e. the interface line roughening due to instabilities driven by chemical and solubility effect of alloying elements present in the alloy; describe the solidification processes in detail by defining the role of diffusion in kinetics of materials; analyse the images of interface between liquid and solid phases at different cooling or heat transfer conditions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Abdallah, Z., & Aldoumani, N. (Eds.). (2021). Casting Processes and Modelling of Metallic Materials. IntechOpen. doi: 10.5772/intechopen.91879

6. Additional notes

Topics 3

1. The subject of the lecture

Solidification microstructures I

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

This topic is aimed to present a detailed overview on the microstructures of solidification in different metallic systems i.e. various alloys and pure metals for comparison. The topic will also be presenting an advanced treatment of equilibrium in liquid and solid and also the solubility related instabilities will be introduced using mathematical expressions related to the equilibrium and non equilibrium states. As given in previous topic, interface stability will be presented from the microstructure point of view using extensive optical and electron microscopy images obtained from different pure metals and alloys, and also high temperature microscopy studies. Similar studies are usually carried out using polymers and other substances that behave similar to crystallisation in metallic materials. Various videos of these incidents will be shown in the classroom and extensive definitions will be also given with each image and videos. Nucleation and growth process will be revisited in this topic in order to remind students how these processes effectively play important role in microstructural development of alloys and pure metals. The microstructural development in solidification stages will also be added to the image and video presentations and students will be accustomed with the every stage in solidification in commercial and non commercial alloys. Cell and dendrite formation at the interface in liquid state will be explained to the students with a special interest to the mechanism by which a fully grown grain is achieved at the end. However, the formation of morphology of intragrain structures will also be shortly introduced to students in order to explain how the number of nuclei affects the orientation of grains and its morphology at the domain level where group of crystalline structures are distributed randomly. These structures will also be subject of the topic with many examples from various metallographic studies. This topic will also cover the kinetic model for the nucleation and growth processes which occur following the liquid to solid transformation. The students will be introduced to the many experimental observations by high temperature microscopy and relevant microscopic analysis collected from the literature studies. The students will also be given a treatment of microstructural development in eutectic and peritectic phase systems with an additional interest to the pearlitic microstructures. Eutectic and peritectic transformations usually end up with interesting microstructures with many industrial or commercial alloys possesses these transformations during their processing routes. Hence it is important to study these microstructures and explain the mechanisms through which mass atomic arrangement is possible. The topic will also cover the diffusion coupled growth in alloy systems and related theories regarding this subject will be given to the students in the classroom. A discussion on the formation of intragrain morphology will take place at the end of the topic in the classroom.

3. Learning outcomes

Students can explain the solidification process and interface formation with parameters governing the stability, leading to the formation of various solidification fronts such as plain, cell and dendritic microstructures; analyse the solidification structures in different pure metals and alloys experiencing the nucleation and growth processes; recognise the microstructures of eutectic and peritectic structures and explain how these microstructures form.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Anna Gowsalya, L., & E. Afshan, M. (2021). Heat Transfer Studies on Solidification of Casting Process. IntechOpen. doi: 10.5772/intechopen.95371

6. Additional notes

Topics 4

1. The subject of the lecture

Solidification microstructures II

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

This topic aims to introduce a more detailed treatment of solidification microstructures with a reference to the dendrite formation and relevant stability issues with dendrite tips which are found in highly cooled metallic alloy systems. An overview on the interface stability in pure metals and alloys will also be revisited to relate the initial microstructures of solidification in different metallic systems i.e. various alloys and pure metals for comparison. In this topic, the interface stability will be enlarged with some mechanistic approach to the shape modifications during the solidification. However, the diffusion process at the tip of the dendrites is more concerned because of its importance in forming chemically driven changes in the vicinity, leading to variations in the liquid compositions. These variations of concentrations in the liquid may lead to the changes of concentration profiles where solidification mode is shifted and segregation reaction is observed. Such concentration changes will also have an effect on the solidification temperature, for example in Fe - C systems it will cause the reduction of liquid to solid transformation temperature e.g. melting temperature and liquid will behave differently. However, a distinction between plain steels and alloyed steels will be made in this topic so that students are accustomed with the different variants of dendrite formation and liquid enrichment. The topic will also present an advanced treatment on dendrite spacing and its formation mechanism with a reference to liquid enrichment and solute distribution. Transient changes in solute diffusion within the liquid will be interwinned with mass balance treatment around the dendrite tips. A classical approach regarding the dendrite shape will be introduced as it is affected by the solubility and diffusion of solutes in the liquid state; the difference in thermal equilibrium in liquid and solid state will be added to the topic in order to explain the dendrite formation and spacing parameters. The topic will continue with the analysis of dendrite morphology in different alloy systems such as low alloyed, high alloyed and alloy rich compositions of steels with or without high amount of carbon. As given in previous topic, interface morphology observed in pure metals and alloys will be revisited and a comparison will be made between the dendritic structures observed in alloyed systems with a reference to chemical instabilities to be presented from the microstructure point of view using extensive optical and electron microscopy images obtained from different pure metals and alloys, and also high temperature microscopy studies. The students will be introduced to the many experimental observations by high temperature microscopy and relevant microscopic analysis collected from the literature studies. There will be a special section called directional growth within this topic and it will be interesting for the students to relate dendrite, cell and other structures with directional growth process that will be introduced briefly to students. A discussion on the formation of directionally grown microstructures and dendritic morphology will take place at the end of the topic in the classroom.

3. Learning outcomes

The students can explain the formation of dendrites from epitaxial source of nucleation and equiaxed nucleation and relate this difference with the alloy composition, cooling rate and substrate chemistry/effect; analyse chemically driven transformation in and around the dendrite tip and consequence of composition change in the liquid; explain the mechanisms by which spacing between the dendrites are formed and explain the role of related diffusive chemically controlled reactions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

J. A. Pero-Sanz Elorz, M. J. Q. Hernández, L. F. V. González,Editor(s): J. A. Pero-Sanz Elorz, M. J. Q. Hernández, L. F. V. González, Solidification and Solid-State Transformations of Metals and Alloys, Elsevier,2017.

6. Additional notes

Topics 5

1. The subject of the lecture

Non equilibrium solidification

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

The topic aims to give an extensive introduction to non equilibrium solidification which does not necessarily end up with crystalline but amorphous and semi crystalline structures. Such transformations are very much intrigued by the engineers and practitioners as to how these outcomes can be materialised in industry with a practical application or commercial application prospect. The main cause of the formation of such microstructures is the sufficient cooling rate of molten or liquid pure metals and alloys, through the mechanism by which perforation of interface and quasi treatment of liquid and solid occur. One of the outcome of this processing is the chemical homogeneity / heterogeneity of the alloying elements in the matrix phase as they are fast cooled the distribution of alloying elements are slow to redistribute in and around the matrix, grain and grain boundaries. Here, the partition coefficient of solutes, as it can be related to non equilibrium distribution of alloying elements, is used as a mathematical tool to analyze chemical heterogeneities, which can also be used to understand solidification of liquid metals. The relationship between undercooling and grain structure is presented with steel ingots and weld microstructures of submerged arc welding which is high heat input weld and laser welds which is low heat inpt and therefore is concluded with high cooling rate. Furthermore, segregations e.g. macro segregation and micro segregation, are described in this topic in order to show the effects of solute redistribution in normal cooling and fast cooling conditions. The effect of nonequilibrium conditions on phase reactions Al-Cu alloy to distinguish zones with considerable chemical segregation during dendrite growth, which can also be observed in Al-Mg or Cu-Sn systems where this type of equilibrium can result in partition coefficient modification. A discussion on the meaning of equilibrium reaching reactions if there is any and how, and the classification of equilibrium reactions will take place and students will be asked to comment on the outcomes of this discussion. Any reaction which tries to reach the equilibrium in any time scale is a non equilibrium reaction. Perfect equilibrium in solidification especially in non equilibrium soldiificaton never occurs in real conditions; among other reasons, because it is practically impossible to achieve total uniformity of the solid at each temperature during cooling. As an introduction to nonequilibrium solidification, two types of solidification will be analyzed: unidirectional and zone melting. In both cases, it can be stated that the homogeneity of the composition of the solid by diffusion of atoms is negligible during the entire process. Industrial freezing conditions of a solid solution are very different from the ones required for equilibrium solidification. With very slow cooling, a perfect homogeneous composition could be reached at all points of the liquid alloy, but uniformity of the solid can never be reached. Consequently, heterogeneities are always present in the chemical composition of a solidified part or ingot. The students will also have an opportunity to refresh their knowledge on amorphisation, solidification and crystallization of metallic systems.

3. Learning outcomes

The students can explain how non equilibrium condition is attained in solutions containing low and high alloying elements; differentiate between amorphous and crystalline microstructures obtained using non equilibrium treatment of metallic materials; recognise the coring and zone melting processes from the images and explain the mechanisms related to these processes; recognise the non equilibrium microstructures of alloys using optical or electron microscopy images.

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

The course will include a mix of traditional and modern teaching methods using blackboard
Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapter 5, J. A. Pero-Sanz Elorz, M. J. Q. Hernández, L. F. V. González,Editor(s): J. A. Pero-Sanz Elorz, M. J. Q. Hernández, L. F. V. González, Solidification and Solid-State Transformations of Metals and Alloys, Elsevier,2017.

Kurz, W. (2001), Solidification Microstructure-Processing Maps: Theory and Application. Adv. Eng. Mater., 3: 443-452.

6. Additional notes

Topics 6

1. The subject of the lecture

Applications utilizing solidification

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

This topic aims to introduce the application that utilises the principles of solidification or near solidification process e.g. partially molten zone, in order to produce a commercially viable part using various alloy systems. Students can be accustomed to the attributes of rapid solidification processes in various systems that have been sufficiently developed for both crystalline and amorphous materials that commercial products are now available in the form of bulk parts, strips and powder. The constitutional and microstructural advantages to be gained using rapid solidification have been used to develop improved structural alloys form crystalline materials with enhanced mechanical, chemical, electrical and magnetic properties as is also in amorphous alloys. Some property predictions of these materials show that rapidly solidified materials will prove to be of significant commercial value in the future for applications ranging from sensors to coatings and structural applications if it is commercially viable to produce. There will be short discussion on the possible uses for these materials and their utilisation in well known current applications in industry and non industrial but critical applications. The topic will go on with the production methods of bulk metallic glasses from the high cooled melts and the basic principles of processing to form similar materials from an alloy melt, and then will continue with the current applications and future prospects at hand. Another application of solidification is the powder production from pure and alloyed melts. Powder production also involves rapid solidification process to control size distribution and prevent sticking of powders or rather sintering following the pulverising. Conventional casting and continuous casting are basically same but practically two different methods as far as the final product is concerned. These differences in production will be visualised and explained in detail to students using many micrographs from optical and electron microscopy. Single crystal manufacturing using zone refining and solidification parameter control of critical parts is important step forward in obtaining the improved materials properties in places where such improvements are appreciated. As a final subject in this topic, processing versus microstructure maps with respect to processing methods such as solidification time versus final microstructures in steels, laser welding speed or laser welding power output versus microstructure, welding heat input versus final microstructures will be introduced to students using resources from literature and some experimental studies. At the end of the lecture topic, there will be a discussion on conventional and new uses of solidification process for the production of materials with different properties.

3. Learning outcomes

The students can explain how classical and non classical solidification routes are employed for the manufacturing of parts with improved mechanical, magnetic and physical properties;

analyse the conventional and non conventional solidification processes; suggest a prospective method for a possible future applications based on the information given in this lecture; critically discuss the use of solidification processes in certain applications and explain the necessity of proposed processing route.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kurz, W. (2001), Solidification Microstructure-Processing Maps: Theory and Application. Adv. Eng. Mater., 3: 443-452. https://doi.org/10.1002/1527-2648(200107)3:7<443::AID-ADEM443>3.0.CO;2-W

Froes, F.H., Carbonara, R. Applications of Rapid Solidification. *JOM* **40**, 20–27 (1988). https://doi.org/10.1007/BF03258827

6. Additional notes

Topics 7

1. The subject of the lecture

Heat treatment and basic principles

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

This lecture aims to introduce the fundamental concepts of heat treatment processing routes for many metallic systems including ferrous and non ferrous alloys with a special attention to the steels and aluminium alloys for different reasons such as precipitation and segregation chemistry. Heat treatment processes will be classified and given in the form of tables based on the targeted final materials properties such as high tensile strength or flow stress, high hardness or softening for the plastic deformation process and turning operation, relieving the stress accumulated during the quenching operation etc… The phase transformations in steels and some non ferrous alloys will be given as an auxiliary material to explain some mechanisms related to the microstructural and physical changes observed after the heat treatment processes. In principle, heat treating already takes place when steel is hot-rolled at a particular temperature and cooled afterward at a certain rate, but there are also many heat-treating process facilities specifically designed to produce particular microstructures and properties with respect to heat treatment purpose such as normalizing which end up with furnace or slow cooling. The allotropic reactions of steels and other alloys will also be explained to reveal the formation and dissolving capacity of second phases and particles. In all heat-treatment operations, the temperatures, holding times, and heating and cooling rates are varied according to the chemical composition, size, and shape of the steel. The presence of grain or preferably phase boundary may be elaborated with a brief introduction of undergraduate knowledge. In this lecture topic, we will also focus on the heat treatment processes carried out with multiple steps and benefits of these extra stages in processing. Students will be introduced to kinetics approach compatible with heat treatment, which is heavily dependent on diffusion process, with respect to heat treatment temperature, specimen holding time in furnace and cooling rate. Each parameter will be explained their possible effect on the final properties will also be elaborated using many resources e.g. images and tables form the literature. Martensitic and bainitic reactions are to be revisited and crystallographic changes will be elaborated using graphical means. Students will be able to analyse how the martensitic reactions or displacive reactions occur in ferrous and some non ferrous alloys and its conclusive evidence on the mechanical and physical changes will be evaluated in the classroom. A discussion on the methods of different heat treatment processing routes producing similar outcomes will be made at the end of the lecture topic. The lecture topic will finally end with extensive exemplary study on the heat treated process of particles and grains and also the progress of with microstructural images obtained from literature.

3. Learning outcomes

Students can elaborate the classification of heat treatment processes and each subclass of heat treatment process; explain the atomistic and bulk diffusion mechanisms by which each heat treatment imposes on the intra-grain microstructure and morphology; explain effects of the heat treatment on different metallic materials and chemical changes that happen during the heat treatment; describe how solute distribution occurs during each heat treatment regime in both ferrous and non ferrous materials.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

V. Singh, Heat treatment of metals, 2017, Standard Publishers Distributors

6. Additional notes

Topics 8

1. The subject of the lecture

Effect of alloying elements on alloy properties of heat treated metals

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

This topic aims to introduce effects of alloying element additions in steels and in various alloys on mechanical and physical properties of target metallic material and the interaction between the atoms of alloying additions and matrix atoms. Alloying element effects in steel properties are well documented and practiced over years by engineers, however, some alloying elements in aluminium alloys and titanium alloys are not well known and widespread for their effect on final properties of target alloys. Hence, this topic will present these effects of alloying elements on the properties of some of the alloys of aluminium and titanium, or it may also cover the superalloys, using literature sources and books and present them to the students. A tabulated table will be presented to the students in a collective manner. Structural alloys can also be included in this tabulated table for their general effect instead of specific result. There will be a section for property diagrams that define the effect of each alloying elements in phase transformation of steels such as carbide, gamma and alpha stabilisers. These diagrams would show the effect of various alloying elements in expanding and closing the gamma loops and also transformation temperatures with respect to increasing alloy content. Students should be given information about the alloying elements that do not affect the transformation points or melting temperatures dramatically, which would help students realise that alloying additions have limits in changing the kinetics of carbide reactions or second phase formations. Alloying elements have considerable influence on the kinetics and mechanism of all three types of transformation of austenite to pearlite, bainite and martensite. In the simplest form this would need analysis of a large number of ternary alloy diagrams over a wide temperature range. However, the characteristics of the transformation in the various iron binary equilibrium systems permit a classification as: open and closed gamma field systems, and expanded and contracted gamma field systems. This approach indicates that alloying elements can influence the equilibrium diagram in two ways: (i) By expanding the gamma field, and encouraging the formation of austenite over wider compositional limits, e.g. gamma stabilizer. (ii) By contracting the gamma field, and encouraging the formation of ferrite over wider compositional limits, alpha stabilizers. Students will also be able to have deeply regulated discussion on how the alloying elements in different concentrations would influence the outcome e.g. microstructure type and carbide type and formation, and also on how the same alloying element behaves differently in low alloy and high alloy steels; students may be asked to write an essay on the outcome of the discussion. In the final part of the lecture, students will be given examples of effect of alloying elements and images from the optical and electron microscopy from different types of steel as a case study in order to reinforce the knowledge learned during the topic. Finally students will be introduced to weld metal compositions and microstructures as to reveal the effect of alloying additions in different processes.

3. Learning outcomes

Students can explain the effect of each alloying element on the phase transformations in different steels; correctly analyse the relationship between the amount and type of alloying addition and the resulting effect on the intragrain morphology e.g. type of microstructure or mechanical properties; define the influence factors of alloying elements in different alloys; explain alloying element interactions between themselves and matrix atoms with a plausible mechanism.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Callegari B, Lima TN, Coelho RS. The Influence of Alloying Elements on the Microstructure and Properties of Al-Si-Based Casting Alloys: A Review. *Metals*. 2023; 13(7):1174

Effects of Alloying Elements on the Heat Treatment of Steel, Ed. George E. Totten, Steel Heat Treatment, 2006, CRC Press

6. Additional notes

Topics 9

1. The subject of the lecture

Property diagrams and their usage in industry

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

This topic aims to present an advanced treatment of Isothermal transformation diagram i.e. Time Temperature and Transformation (TTT), and Continuous Cooling Transformations (CCT), Time-temperature-precipitation (TTP), Isothermal Austenite Transformation Diagrams (ITh – austenite transformation diagram on heating), phase concept and phase transformations in solid in which allotropic transformations take place with respect to three effects from temperature, time and pressure. The kinetic aspects of phase transformations of many structural alloys are as important as the phase equilibrium diagrams for the heat treatment of steels. These kinetic effects can be partially represented in diagrams which are derived from practical applications and be effectively used by engineers; the majority of diagrams are for the most used alloy, that is steel, and few diagrams can also be found for some other alloys, but not as common as steels. The meta-stable phase martensite and the morphologically meta-stable micro constituent bainite, and also retained austenite with or without carbide presence, which are of extreme importance to the properties of steels, can generally form with comparatively rapid cooling to ambient temperature. That is when the diffusion of carbon and alloying elements is suppressed or limited to a very short range. Such practically important transformation products and mechanisms should be explained to students at atomic and macro level in order to strengthen the knowledge. Students may be encouraged for a short discussion on the use of aforementioned diagrams in their experience to date, in either steels or other industrially important alloys. The topic will go on with the explanation of phase transformations in the most common alloys to remind students the important parts of the IT diagrams and also to emphasize the conditions in achieving of equilibrium and non equilibrium microstructures. Students should also be content with the procedures of obtaining these microstructures in these alloy systems, and hence, the metallographic procedures would be intermittently explained if there is any misinformation regarding the obtaining of these microstructures. The instructor should be mostly dwelling on the interpretation of these diagrams in real manufacturing conditions. These conditions such as heat treatment, pre manufacturing or pre heating conditions should be explained as they are the parameters that affect the final properties of target alloy. The history of material prior to final processing is critical in many applications, for example screw manufacturing is one of the sectors. It is also important if the steel has a history of plastic deformation as it may shift TTT diagrams to the left i.e. less time taken to obtain martensite. Failure of large diameter screws which are made of high strength steels would be traced back to heat treatment scheme being wrongly applied without credit of CCT diagrams or TTT diagrams being considered. Finally, this topic will end with exemplary microstructures and their corresponding TTT or CCT curves on which the traces of process are indicated. Students can be asked to join a discussion regarding the formation of bainite or fine and coarse pearlite and may be asked to write an essay on how bainite, martensite and pearlite forms with the help of graphical presentation.

3. Learning outcomes

Students can describe the parameters that lead to formation of equilibrium and non equilibrium phase transformation products and their practical outcome i.e. ferrite, pearlite, bainite, martensite, retained austenite, fine pearlite in steels; define the equilibrium and non equilibrium microstructures in steels and make a connection between the microstructures and IT diagrams, i.e. the practical diagrams obtained through concept in phase formation and transformation processes; also explain the practical route of heat treatment using IT diagrams.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

H.K.D.H: Bhadeshia, Bainite in Steels: transformations, microstructure and properties, IoM publications, 2001 (can be obtained freely on http://www.phase-trans.msm.cam.ac.uk/2004/z/personal.pdf)

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 10

1. The subject of the lecture

Hardenability

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

This lecture aims to provide the deeper understanding of hardenability and its effective mechanisms observed in metallic systems with a special interest to the theories of various mechanisms as defect formation at atomic level e.g. dislocations and irradiation, atomic mismatch and matrix hardening through second phase presence. The topic will also be covering the some mathematical expressions in defining the measurements of hardness and its evaluation with cross reference tables and comparison tables. It may also be informative for students to explain the energetic approach to defect formation e.g. dislocation generation etc… and atomic plane deformation with the effect of external forces that may be related to theoretical calculations and compare them with real measurements. Students should be acquainted with the concept of hardenability in conventional alloys in especially metallic materials with deeper understanding of underlying mechanisms. Students will be aware of the defect generating processes at atomic, micro and macro level and their role in creating a zone with defects that are majorly originating from the dislocation movements of various forms of atomic planes. However, the hardenability also reveals itself with mechanisms that are not related directly to dislocation movements but rather in atomic mismatch mechanism which is sourced from the addition of alloying elements. This effect should be elaborated in the classroom. The addition of alloying elements to steel has a substantial effect on the kinetics of the transformation, and also of the pearlite reaction. As pointed out in previous topic, most common alloying elements such as C, Nb, Mn, Cr… move the time-temperature transformation (TTT) curves to longer times either in austenite region or other formations, with the result that it is much easier to miss the nose of the curve during quenching and get a hardened surface or may pass the nose if less alloying element is present, having the softer microstructure such as ferrite with low amount of pearlite. Higher alloying elements such as Cr, Mo, W, Mo, Ni and C essentially gives higher hardenability, since martensite structures can be achieved at slower cooling rates and, in practical terms, thicker specimens can be made fully martensitic. It is also important if the steel has a history of plastic deformation as it may shift TTT diagrams to the left i.e. less time taken to obtain martensite. The cooling medium effect on the hardenability issue should be given with the hardenability depth profile measurements (Jominy effect) and its parameters in steels. With the cooling medium effect on the hardenability of the matrix, the aftermaths of this process should also be discussed with students and the grain refinement, distortion in matrix and prevention should also be included with advanced level of physical metallurgy. Finally students should be involved in having a discussion regarding the effect of crystal structure in obtaining various hardness levels and correlate them with the alloying element additions. The topic will end with the examples of hardness measurements with different techniques and metallographic images of indent cross sections.

3. Learning outcomes

The students can define hardenability and explain the underlying mechanisms of hardenability in metallic materials through defect generation via dislocations and irradiation, in addition, matrix hardening related to atomic mismatch and distortion; describe the measurements methods of hardness and relate them to hardenability with all relevant mechanisms; describe the effects of alloying elements in commercial steels and make a connection with IT diagrams given in previous topic.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

https://www.doitpoms.ac.uk/tlplib/jominy/hardenability.php

Chapter 3, C. R. Brooks, ASM Technical Books, Principles of the Heat Treatment of Plain Carbon and Low Alloy Steels, 1996

6. Additional notes

Topics 11

1. The subject of the lecture

Case studies and problems in heat treatment

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

The lecture aims to provide extensive and important insights to practical application and understanding of the heat treatment of metallic materials with many exemplary study results and specimens from industry. This topic will also concentrate on the stresses occurring during the heat treatment process, e.g. quenching and following stress relieving, and phase transformations in allotropic metallic materials with different crystal structures. Stresses occurring during phase transformations are generally related to the volumetric changes from a type crystal to b type crystal transformation and in alloy systems experiencing a different size solute atom being enclosed in a matrix/host crystal or unintentional entrapment in a host crystal as a result of limited solubility following the non equilibrium cooling. Residual stresses that appear following the quenching process are often held responsible for the cracking and its propagation within the matrix phase, however, the prevention of crack formation following the high cooling rate and its propagation under residual stress are relatively easy with the right heat treatment. These heat treatments include pre operation and post operation practices which help reduce the cooling rate by limiting heat transfer per surface area e.g. accumulating the heat on base material. A brief introduction to crack propagation and formation may be presented to students prior to prevention of cracking occurring during heat treatment. Residual stresses are usually not harmful to steel with low alloying elements that produce low matrix hardness; however, as the numbers of alloying elements increase the hardenability and eventually cracking may occur, hence, this risk is multiplied in the presence of hydrogen. So, extra precautions should be taken to include external source for the crack formation and propagation to explain the resultant effect of residual stresses. Defects during the heat treatment processes will also be summarised, which include overheating of base material that happens due to very high solution temperature is selected and the cooling down to transformation temperature is prolonged. This changes the segregation and precipitation behaviour of base material and unwanted or undesired results are obtained, a preventive measure should be reheating and faster cooling of base material. Similar preventive measures should be explained to the students with different heat treatment defects. One of the most observed defects is decarburisation of the surface. The burning, which is simply an oxidation reaction, is also highly possible outcome, if the temperature is very high and longer heat treatment duration is selected in some steels and alloys. All preventive measures for these improper applications of heat treatment should be given to students in classroom. A discussion reading the recovering the base material experienced improper heat treatment should be held on different materials in the classroom. Finally, students should be given extensive examples of defects that form during the various heat treatment processes and preventive measurements should also be given in detail.

3. Learning outcomes

Students can explain the necessity of heat treatment in materials that shows allotropic changes; recognise the defects that form during and after the heat treatment process; suggest a recovery procedure for the overheated, decarburised and burnt and decide if it is feasible to do so; define the distortive, transformation stresses and residual stresses occurring due to phase changes after heat treatment especially following quenching and stress relieving heat treatment.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

ASM Technical Books , Ed. By: L.C. F. Canale, R. A. Mesquita and G. Totten, Failure Analysis of Heat Treated Steel Components, ASM international, 2008

Failures Related to Heat Treating Operations, G.E. Totten, M. Narazaki, R.R. Blackwood, L.M. Jarvis, ASM International, Volume 11, 2002

6. Additional notes

Topics 12

1. The subject of the lecture

Heat treatment of welded structures

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

The topic aims to give an introduction to the welding of different base metal types such as light alloys, steels, superalloys etc… and extensive the heat treatment procedures and prevention of defects in these welded structures on which weld thermal cycle and heat input exert undesired effect on the static and dynamic stability. As it is different to classical heat treatment procedures where the whole sample is inserted inside the furnace, weld heat cycle only affects the restricted area of strip on base metal in the immediate vicinity of weld bead. Students should be informed on the effect of this heat cycle or weld heat cycle exercise that inserts residual stresses in about the weld bead due to faster extraction of heat away from the weld pool. As the molten pool is moved along the joint axis, the components are non-uniformly heated and subsequently cooled. During welding process, base metal expand and cools fatser, depending on the thickness, and weld metal contract at the same time in differing amounts with thermal cycle. Student should be accustomed with the effect of thermal cycle on the base metal and should be given sufficient number of examples of weld beads showing distortion, wide and narrow heat affected zones and also multiple layering of welds filled up the V gap with heat affected zones appearing on top of each other. The stresses building up during the welding operation is sometimes preventable prior to or after welding. Here, the introduction of heat treatment procedures that were briefly mentioned in previous topic will be expanded to include detailed procedures for pre heating of base material based on the result of carbon equivalent number according IIW formula; post heating of weld metal is another option for highly alloyed steels or materials in order to prevent cracking in both heat affected zone and especially in weld metal due to segregation effect. However, students should be aware that post heat treating of weld metals may not result in satisfactory result if large precipitation risk or carbide coarsening exists. Hence, students should be advised to look for specifications of steels or the alloy being welded beforehand and apply appropriate precautions prior to welding if exists. In order to assess the stress levels in the base metal and heat affected zone, various stress measurement methods exits such as strain gauges with hole drilling practice and some other definitive measurements X-Ray etc… may be applied. These measurements methods should be given to the students with some details regarding their working mechanisms. Finally, students should be given a complete list of heat treatments that can be applied to the weld metals either for stress relieving or crack prevention purpose. Students should also be discussing the necessity of heat treatment in weld with highly alloyed steel joined to low alloy steels from the metallurgical point of view.

3. Learning outcomes

Students can explain how welded structures are formed and the residual and thermal stresses in the weld zone occur in different metals and alloys; suggest heat treatment procedure for welded structures that are made of different alloys and metals, based on the thickness of the structure; explain the necessity of heat treatment procedures of welding prior and post operation according to IIW carbon equivalent equation and also suggest a stress measuring method in and around the weld bead.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Heat Treatment of Welded Steel Structures, A volume in Woodhead Publishing Series in Welding and Other Joining Technologies, 1996

6. Additional notes

Topics 13

1. The subject of the lecture

Heat treatment with gaseous atmospheres

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

This topic aims to provide a detailed introduction to heat treatment processes carried out to deposit a layer of which its properties are used to protect the surface against wear process. Sometimes the procedure is done to increase the hardness of surface for many reasons apart from wear, such as to prevent the deformation of metallic material when shrapnel hits the surface of a vehicle etc... . Some methods of coating or surface modification are used in industry to improve the surface properties; these methods include carburising, nitriding, and boriding. As the name suggests, carbon, nitrogen and boron atoms are intentionally used to increase the surface hardness by allowing atomic level defect formation using interstitially added atoms e.g. by diffusing the foreign atoms to interstices of a crystal, and hence, to improve the hardness at a depth of microns. The gaseous atmosphere in heat treatment is replaced by compound containing Nitrogen and allowed to diffuse into metal surface to exert an extra strain onto the crystal structure, increasing the resistance to deformation originated from an external effect. Students should be given a brief reminder about the hardness and deformation relations in metallic materials. The formation of gaseous atmosphere should be included into this topic by providing a table of compounds that are used in creating various atmospheres for surface modification purposes. The topic will also include definitions of pack boriding or paste boriding process that are used for the surface modification of metals and alloys in an enclosed containers to prevent the air entering and oxidising the surface of the metal. Pack boriding is also used in the coating of steel surfaces by chromium, nickel and aluminium using pack boriding powder mixtures rich in compounds containing these elements. These procedures are well established and used by many sectors to reduce the wear in machine parts. Students should be given many examples of this procedure and relate these processes the reduced wear and tear in metallic materials. A table of compounds used in pack boriding, chromising or aluminising process should be included in the presentation and lecture notes. Finally ferritic and austenitic nitro- carburising processes, which include both carbon and nitrogen rich compounds in gaseous form, should be explained and examples regarding the procedures and resulting layering must be introduced to the students. At the end of the topic lecture, students would involve a discussion on the necessity of various coating methods if most of the coating methods tend to produce same effect e.g. hardness at the end of the procedure and also a discussion on the difference in diffusion rates in different metallic materials and why coating process is carried out at high temperatures for almost all metals, whether it is allotropic or not.

3. Learning outcomes

Students can explain how viable surface modification processes involving gaseous and solid medium in a heated chamber are carried out on a metallic specimen as oppose to lower temperature surface coating processes; suggest a method of coating methods of those mentioned in this topic with respect to the materials being offered and its final surface requirements; relate the diffusivity of interstitial elements and their hardening effect in host/base metal with a reference to lattice strain effect; explain how pack boriding, pack chromising and pack aluminising can be carried out and also elaborate the mechanism of deposition of these elements on the surface.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

F A P Fernandes, S C Heck, C A Picon, G E Totten & L C Casteletti (2012) Wear and corrosion resistance of pack chromised carbon steel, Surface Engineering, 28:5, 313-317

https://matenggroup.wordpress.com/pack-boriding/

6. Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

NOVEL ALLOYS: HEAS, SUPERALLOYS AND INTERMETALLICS

Code: NAHSI

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO ALLOY THEORY AND HIGH TEMPERATURE ALLOYS

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

This topic aims to give students a detailed introduction to the alloy theory in which the alloying behaviour in conventional and non conventional alloys are presumed from the atomic and properties points of view. The high temperature properties of materials are also included in the topic to indicate that such properties of materials are in great demand due to their application difficulty in practice such as combustion chambers and high performance, high speed statistically durable machines. Alloy theory will be shortly introduced to the students based on the relevance of alloy making and elemental interactions that govern the general properties of the alloy. High temperature properties of materials are considered to be successful with alloying additions such as W, Nb, Mo and Hf, however, recent studies in alloying showed that this may not be strictly valid argument i.e. conventional elements may also contribute to this field of research greatly such as forming highly ordered structures called intermetallic produce-able from comparatively low melting point alloying element such Ni, Cu, Cr, Co and Fe. The physical metallurgy of such alloys will be introduced to the students from the crystalline structure point of view and will be integrated into the present theory of alloys to detail the mechanisms that are giving them such properties and structures. It is also possible that students will be able to comment on the structural differences in different intermetallics and also will be given the main structural difference of superalloys and intermetallics. It is interesting that superalloys are the class of materials that are supposed to be used at high temperature applications such as jet engines, however, these alloys are not free from intermetallic as the core of the superalloys are made of metal - metal compounds e.g. Ni3Al compound that are considered to produce highly stable i.e. dimensionally stable parts to precisely keep its size even at high temperatures. This topic will also introduce the concept of high temperature requirements for certain applications in order to give basic understandings of needs of scientists and practitioners in industry. Such requirements are necessary for the definition of aims and the goals of the research for high temperature alloys. The order disorder reactions are also to be mentioned in explaining the role of property defining compounds and their effect on the general properties of superalloys. This topic will also be contributing to definition of high temperature alloys and their field of use in terms of certain metallurgical processes such as corrosion resistance at high temperatures when exposed to liquid (acid, base or salt) air and pure or gas mixtures that are harmful to conventional alloys in use. The other important part of this topic is to generalise the characteristics of high temperature materials and expand them to how the future needs are to be defined to design new alloy, that is, high entropy and medium entropy alloys, bulk metallic glasses for high temperature applications. The topic will be concluded with a discussion on the future of these alloys and enlargement of field of use in practice.

3. Learning outcomes

Students can explain the concept of high temperature characteristics of materials and propose a generalised solution to certain conditions such as liquids of any sort, gas mixtures that are harmful to conventional alloys; analyse the high temperature alloys that are in use; describe the mechanism involving the production of high temperature alloys specifically intermetallic compounds and specifically formulated bulk metallic and entropic alloys.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. G. Seed, chapter 1, The superalloys: fundamentals and applications, Cambridge University Press, 2009

6. Additional notes

Topics 2

1. The subject of the lecture

ALLOYING PROCESSES FOR SPECIAL ALLOYS

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

This topic is intended to give an extended treat of alloy making procedures for the non conventional alloys which are required to be processed in a way different to conventional melting and re - melting processes. However, this topic will also mention melting and re - melting processes that are used in practice to make bulk alloys that are conventionally produced to use them in buildings, machine parts and various vehicle manufacturing etc.., in order to make the comparison easy for the students to recognize the difference in operation. Melting processes are generally practiced in foundries where the casting process is practiced and starting materials are selected based on the casting type. These remelting is however is also practiced in foundries but in a slightly different way as the scraps are used instead of raw pig irons or similar content. Nevertheless, the remelting for casting conventional materials may not be applied strictly applied to the non conventional alloys that are used at high temperature as they contain high melting point elements that are not easy to melt in bulk as well as in such amounts. One of the restrictions are the melting pot linings that are designed for steels and cast irons are not suitable for remelting of high temperature alloys; they are more acidic linings in nature whereas basic linings are preferred in most alloyed steels and also alloys that contain high melting point elements. In addition to this property, the alloys that are of interest for high temperature applications may not be suitable to casting at all in many ways. The size and dimensions and also their thermal and physical properties are different than conventional alloys for example steels. High casting temperature makes these alloys unsuitable for conventional production but more creative ways in which alloys are made have been invented over the years. Mechanical alloying is one of the methods that are used to produce initial batch of high temperature alloys and also alloys that are difficult to remelt together due to the huge difference in melting points and their general properties such as high affinity to oxidation, nitriding and carbonising. Diffusion based alloying processes are more robust and proven to be successful in many alloys and transient phase melting is also possible. Another method of producing alloy is the high speed high energy processes such as spark and high energy remelting process in which alloying additions are remelted in a bed of powder with a source of high energy e.g. laser or electron beam and also high current pulses are used to produce compacts with desired compositions. This topic will also cover the strengthening processes in short, in order to make students realise how these extra property manipulation or enhancement processes e.g. heat treatment for hardening or softening, are integrated into alloy making to determine its desired property when making the alloy. Students are required to involve in a discussion regarding the effective method of production for selected alloys at t he end of the lecture.

3. Learning outcomes

Students can elaborate on the melting and remelting for the production of alloys that are in interest of high temperature materials; suggest and elaborate on the non conventional alloying theories; analyse the alloys and suggest an alternative method of making the alloy desired when the conventional methods is exhausted; explain the difference in different methods of melting and the elaborate the mechanism between different melting techniques of alloys or raw materials; determine which method is feasible for the property that is desired when making the alloy.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Part Two: Processing, characterization, (solid-state cooling), and testing methods in Structural intermetallics and intermetallic-matrix composites: An introduction, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

Topics 3

1. The subject of the lecture

SELECTION CRITERIA FOR HIGH TEMPERATURE MATERIALS

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

This topic is aimed to give a detailed view into the selection criteria of materials that are intended to be used at high temperatures with regards to their structures, chemical properties, alloy content and thermal properties and most importantly their mechanical properties. For high temperature applications, it is often very difficult to perform a comparison among different materials including ceramics, ceramics metal composites etc.., and alloys and to select the best one for a specific application or use, because the components made for high temperature service are generally subjected to different damage causes (such as fatigue and following cracking and deformation, creep deformation, oxidation damage or surface defects, etc.) and balancing contrasting characteristics of alternative materials is frequently required to make the right choice for the right service conditions. Larson miller criteria for ranking the creep behaviour of high temperature alloys are to be given to the students for listing the materials for the best selection. However, the design values often are not clearly defined in these theoretical works but parameters are, depending on material properties as they are measured in perfect conditions. It is also collective assumption based on the number of available materials suited for the specific application, with new properties such as superalloys, HEAs, intermetallics and BMGs. The new concepts of these alloy groups are needed to be investigated and brifly mentioned in during the lecture. The new alloying techniques brought about a new concept in the evaluation of materials selection as they are investigate more on the practical levels. The properties of superalloys for example are found plenty in numbers however the properties of other alloys are less owing to the less number of researchers. Nevertheless, we have realised that new alloying opportunities with many alloying elements and high cooling rate achieved during the casting give way to many new options for the selection criteria even with the same alloy configurations. Heusler alloys for example are considered to be intermetallics but very suitable for ferromagnetic shape memory properties for example Cu2MnAl, better than Cu2Al and CuAl even though they solidify in the same crystallographic configuration. Selection is therefore required to be completed based on experience as well as measurement made in right temperature and environments. A significant example is the service temperature, which depends on many parameters, such as thermal conductivity, type of cooling, thermal exchange coefficients, etc.; some of these parameters are specific properties of the particular material considered. In order to overcome this problem, a range of design values has been considered in this topic, taking the variations of material properties into account and allowing an objective evaluation for the choice of the best material. A selection procedure has been proposed in this topic in which the variability of the requirements on some parameters (e.g., temperature and service time) is considered. This procedure has been applied to the transition piece of a gas turbine.

Considering the high temperature value on the component, only superalloys and stainless steels have been considered.

3. Learning outcomes

Students can explain the mechanism of feasible selection criteria for high temperature alloys for general and specific applications required in many industrial practices; analyse the need for materials by the aim of the target practice; suggest a good practice routine and finally explain how the selection is made with valid mechanism involving mechanical and other properties.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Chapters: Theoretical and Practical Limits of HT Alloys and The Corrosion Behaviour of Alloys in High Temperature Gaseous Environments in High Temperature Alloys: Their Exploitable Potential, Eds: J. B. Marriott, M. Merz, J. Nihoul, J. Ward,

6. Additional notes

Topics 4

1. The subject of the lecture

PHYSICAL METALLURGY OF SUPERALLOYS

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

This topic aims to provide an advanced treatise in physical metallurgy of superalloys with regards to their composition, thermal, physical and microstructural properties through a discovery of historical development of these alloys as to when it was first discovered and used. It is also the aim of this topic to show the changes in composition of alloys and the challenges that were faced with conventional production processes. The historical development of these alloys will be co joined with the development of production methods by which improved properties were obtained based on the effect on the performance of final products. Physical metallurgy always intends to form a relationship between theoretical background of the subject and final outcome, in this respect, the theoretical treatise of superalloys will be given from the phase formation and also precipitation characteristics of alloys in order to correlate the strength and other properties. However, what is more important is the high temperature properties and how they are tied to the properties obtained from measurements and properties that are tied to practical testing results. For this purpose, there will be an essay preparation study following this topic to lead the way to discussion regarding the sufficiency of superalloys in present applications and practices. The topic will continue with the physical metallurgy e.g. the crystal structures of superalloys especially the formation of gamma phases and gamma double and triple phases within the nickel and other superalloy systems The other phases will also be mentioned for the clarity and briefly mentioned on the pros and fors of the general properties. Strenghtening and corrosion of superalloy parts are prime concern in aviation industry as they define the service life of the parts as they are related to mechanical properties. The types of mechanisms that are found in these superalloys are to be given in detail and classification of all dispersions and matrix hardening agents will be summarised based on literature sources. The topic will continue with the deformation capacity and defect formation in these alloys with the specific focus on the micromolecular to macroatomic approach to understand the mechanisms underlying the crack and crack propagation. The same approach will be employed in order to explain the fatigue and creep failures of such materials as they are considered structurally different to conventional alloys and they are also more resistant to creep and fatigue failures due to their sub microstructural features and their configurational arrangement of precipitates and their size range. This topic will finally end with the generalised summary on the property and composition relationship with respect to types of superalloys and the manufacturing methods.

3. Learning outcomes

Students can differentiate between the compositional variations and resulting property changes in superalloys. Students can explain the atomic and molecular mechanisms by which the improved properties are obtained in these alloy groups. Students can analyse these alloy systems both via metallographically prepared optical and scanning electron microscopy images and various thermal analysis techniques. The student can suggest a solution routine by which the modification of microstructures are possible and the specific needs for industrial use with a specific reference to the atomic mechanisms.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. G. Seed, chapter 2, The superalloys: fundamentals and applications, Cambridge University Press, 2009

6. Additional notes

Topics 5

1. The subject of the lecture

SUPERALLOYS: NICKEL ALLOYS, COBALT ALLOYS AND OTHERS

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

This topic begins with an overview of superalloys with their binary and ternary systems phase diagrams and classification of microstructures that are classified with respect to alloying additions as well cooling medium following the heat treatment process. Microstructural development of superalloys will follow the introduction of phase transformation behaviours of nickel based superalloys, cobalt based superalloys and other type of superalloys that are not very commonly employed using both basic graphical representation obtained from literature sources. Superalloys are utilized at a higher fraction of their actual melting point than any other class of broadly commercial metallurgical materials. Superalloys are the materials which have made much of our very-high-temperature engineering technology possible. They are the materials leading edge of jet engines. Superalloys are heat - treated or more precisely solution treated to produce a desired distribution of precipitates that are producing the strenghening effect during the service performance. The usual heat treatment results in large γ' precipitates (of the order of 0.5 – 1 µm), smaller or so-called strengthening γ' precipitates of the order of 0.1 µm diameter and an extremely fine distribution of cooling γ' which is about 5 nm. Nickel based superalloys are mainly composed of elements such as Nickel, chromium, tungsten, nickel and aluminum. The nickel-based superalloys are often the material of choice for high-temperature structural applications, particularly when resistance to creep and/or fatigue is needed and the risk of degradation due to oxidation and/or corrosion is severe. Their emergence can be traced to the development of the gas turbine engine, particularly those used for jet propulsion. Thus, at the time of writing they are approximately 75 years old; compared to other structural alloys based upon iron, aluminum or even titanium, they are relatively young. But superalloys are now being employed in an increasingly diverse range of applications: e.g. ultra supercritical power plant (both nuclear and fossil fuel-fired), diesel engines and even fuel cells. Their use is particularly pronounced beyond 750 °C, since the properties of ferritic steels degrade markedly beyond this temperature. The urgency to improve the fuel economy—and associated CO_2 emissions—of such energy conversion systems is providing the technological incentive for this, underpinned by significant economic, societal and legislative pressures. Cobalt-based superalloys are widely used in aviation, aerospace, energy, medical and other fields. In aviation and aerospace, cobalt-based superalloys are used in the manufacture of components such as turbine engines and gas turbines. In the energy field, cobalt-based superalloys are used to make turbine blades and other components in thermal and nuclear power plants. In the medical field, cobalt-based superalloys are also used to manufacture medical devices such as artificial bones and artificial joints. Cobalt based superalloys are materials used in high temperature and extreme environments with excellent high temperature strength, corrosion resistance and wear resistance. Cobalt based superalloys are mainly composed of elements such as cobalt, chromium, tungsten, nickel and aluminum. Finally, this topic will end with the overview of nickel and cobalt based superalloys and their prime practical applications in jet engines, high temperature creep resistant furnaces and the result of various solution treatments by heat treatment will be given to students.

3. Learning outcomes

Students can explain the differences in properties of nickel and cobalt based superalloys and their field of use in practical and supposed applications; analyse the microstructural position of both nickel and cobalt based superalloys based on their alloy composition and heat treatment history with specific regards to the precipitation behaviours; suggest some precautions regarding the mechanism of phase separation and second phase redistribution that leads to various microstructural mechanical outcomes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. G. Seed, chapter 2 and chapter 4, The superalloys: fundamentals and applications, Cambridge University Press, 2009

6. Additional notes

Topics 6

1. The subject of the lecture

INTERMETALLICS: INTRODUCTION AND PRINCIPLES

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

This lecture aims to introduce the monotectic and syntactic reaction systems that are also part of binary systems. Intermetallics are solid-state compounds that exhibit metallic bonding, defined stoichiometry, and ordered crystal structure. They are composed of metals and metalloids, and their crystal structure differs from that of the other constituents. Intermetallic compounds have a wide range of crystal and electronic structures, leading to a great variety of properties that justify their application. These compounds offer unique property combinations often superior to those of more conventional solid solution alloys of identical composition. Understanding the bonding in intermetallics is crucial for accelerating the development of intermetallics for advanced and high-performance engineering applications. The study of intermetallics is essential for various fields, including materials science and engineering. They have been investigated systematically using first principles density functional theory to understand their properties and defects. Moreover, the microstructural and compositional evolution of intermetallic compounds in base intermetallics, superalloys and high-entropy alloys have been a subject of interest of research, leading to the introduction of new type of alloys from the aspects of composition design, structure, underlying mechanism, and service performance. Intermetallic alloying principles involve the formation and properties of intermetallics, which are solid-state compounds that exhibit metallic bonding, defined stoichiometry, and ordered crystal structure. The ordering in these alloys are basics of the improved properties and disorder order reactions are believed to be determine the general properties of these alloy group. These alloys have gained attention for their high-temperature properties, such as creep resistance, and their unique combinations of properties often performing better than those of conventional solid solution alloys with identical compositions. Various key aspects of alloying of intermetallics are phase formation, microstructural variations, defect structures. Student will be able to contain following principles of intermetallic compounds. Intermetallics can form through various processes, such as solid-state reactions, mechanical alloying, and high-temperature synthesis. The formation of phases in Al-Si-X alloys, for example, is influenced by primary impurities called intermetallics. Vacancies and antisites are the dominant defects in intermetallics, and their concentrations and formation enthalpies can be computed using first principles density functional theory and thermodynamic formalisms in order to explain underlying mechanisms for order disorder and deformation mechanisms. Deformation in intermetallics is also important part of this study and is essential for tailoring their properties for advanced and high-performance engineering applications. This includes the effects of constitutional and thermal defects on intermetallic properties. In summary, intermetallic alloying principles involve the formation, microstructure, defect properties, bonding, and application of intermetallics in various advanced materials and structures. Understanding these principles can lead to the development of high-performance materials with unique properties and potential applications in diverse industries. Following the introduction of intermetallic systems and their general properties and applications, students will be given essential information regarding alloying principles with the help of phase diagrams. At the end of the lecture, there will be a discussion on the difference of alloying principles in intermetallics and other conventional alloys.

3. Learning outcomes

Students can explain the intermetallics formation rules and their differences in classical alloying principles; explain the differences in order and disorder reactions in intermetallics and their effect on the general properties and defect formation in these alloy systems; analyse the information on the intermetallics and make feasible suggestion on the field of use based on their corrosion properties at high temperatures.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. Mitra, Structural intermetallics and intermetallic-matrix composites: An introduction, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

Topics 7

1. The subject of the lecture

INTERMETALLICS: NICKEL ALUMINIDES

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

This lecture aims to introduce the intermetallics with the brief definition of intermediate phases and categorical classification of intermediate phases in alloy systems. The definition of intermetallic phases and their properties in short will also be explained to the students. It is part of this lecture to explain how these phases are formed and their short mechanisms will be introduced to the students. During the lecture, the phase diagrams will be emphasized from the structural pattern point of view which will give students more understanding of zones of different behaviour, in addition to the topics previously mentioned in other lectures in this topic. Nickel aluminides are intermetallic compounds that are widely used due to their high corrosion resistance, low elemental density, and high temperature strength and are also composed of nickel and aluminum, with properties similar to both ceramics and metals. This is true for all intermetallic alloys. They typically refer to compounds such as Ni3Al or NiAl, which have various applications in industries such as aerospace, automotive, and manufacturing. These alloys are known for their excellent properties, including low density, good thermal conductivity, improved oxidation resistance against air and oxygen containing medium, and high melting temperature. However, they can be brittle at room temperature, which extends to high temperatures for Ni3Al. Nickel aluminides are used in a wide range of applications, from processing glass to making dies for forming beverage containers, as well as in automobile and tool companies for manufacturing rotating parts, dies, high-temperature wear-resistant parts, permanent molds, and turbocharger rotors. The properties and applications of nickel aluminides have been extensively studied, and they have been found to have low density and great resistance to oxidation, while maintaining their strength well at higher temperatures. The synthesis, processing, and applications of nickel aluminides have been the subject of research, with various methods of processing such as melting and casting, powder metallurgy, solid-state sintering, and mechanical alloying being explored. Some features of these alloys are affected by the alloying additions in Ni Al system. Hardness is greatly affected by the addition of alloying elements as well as excessive Ni and Al elements. Nickel aluminides exhibit high level of grain-boundary embrittlement due to their crystal configuration properties, which can be a determining factor in their mechanical properties. The impact of alloying on strength and ductility is a significant factor in the development of nickel aluminides. For example, an alloy of Ni3Al, known as IC-221M, is combined with several other metals including chromium, molybdenum, zirconium, and boron. Adding boron increases the ductility of the alloy by positively altering the grain boundary chemistry and promoting grain refinement. Nickel aluminides are ideal for special high-temperature applications like coatings on blades in gas turbines and jet engines due to their low density, good thermal conductivity, oxidation resistance, and high melting temperature. The lecture

will finally end with how non equilibrium transformations are observed in these alloy system and will also be supported by the microstructural images obtained from literature.

3. Learning outcomes

Students can define the intermetallic phases and classify them with their structural difference by using crystallographic notations; determine the how intermediate phases are defined in phase diagrams and show different variations in phase diagrams based on their knowledge from the previous lectures; differentiate the equilibrium and non equilibrium microstructures using optical electron microscopy images.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Ş. Talaş, Nickel aluminides, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

Topics 8

1. The subject of the lecture

INTERMETALLICS: TITANIUM ALUMINIDES

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

This topic aims to introduce the titanium intermetallic compound system with a reference to their crystal arrangement of atoms and their service properties defined by the phase diagram of binary and ternary form. Titanium aluminium alloy system is significantly important in many non conventional industrial applications such as high temperature applications and construction in general, aviation industry and space vehicle building sectors. Titanium aluminides are a class of intermetallic compounds with promising properties for high-temperature applications in various industries, including aerospace, automotive, and sporting equipment. Some key properties and applications of titanium aluminides are: Titanium aluminides are lightweight and resistant to oxidation and heat, making them ideal for applications such as aircraft, jet engines, sporting equipment, and automobiles. Titanium aluminides have a high strength-to-density ratio, making them strong and durable materials. Titanium aluminides have excellent corrosion resistance, making them suitable for use in moist atmospheres and seawater. Gamma titanium aluminide (γ-TiAl) has excellent mechanical properties and oxidation and corrosion resistance at elevated temperatures (over 600 °C), making it a potential replacement for traditional Ni-based superalloy components in aircraft turbine engines. Titanium intermetallic compounds are a unique group of materials that are classified as intermetallics. Intermetallic compounds based on titanium and aluminum are lightweight and have excellent high-temperature properties, including high strength, oxidation and creep resistance, and low density. Titanium aluminide forming through the alloying of Aluminium has three major intermetallic compounds and TiAl is commonly used intermetallic compound: gamma titanium aluminide (γ - TiAl), alpha 2 - Ti_3Al, and $TiAl_3$. TiAl intermetallic compound has excellent mechanical properties and oxidation and corrosion resistance at elevated temperatures, making it a possible replacement for traditional Ni-based superalloy components in aircraft turbine engines. TiAl - based alloys and compounds have a strong potential to increase the thrust to weight ratio of aeroplane jet engines, which can lead to improved fuel efficiency and reduced exhaust gas emissions in these vehicles. Other intermetallic compounds based on the alloying of titanium and aluminum elements include Ti_3Al, Al_3Ti, and Ti_2AlNb_8. Ti_2AlNb shows excellent properties like very high strength, high oxidation and creep resistance, ductility, and low density compared to superalloys. Titanium aluminides can maintain their mechanical properties at low and ultra-low temperatures, making them suitable for various applications. However, there are some challenges associated with the use of titanium aluminides, such as their high cost, difficulty in casting, and poor weldability. Despite these challenges, titanium aluminides are expected to play a significant role in the future of high-performance materials due to their unique properties and potential applications in various industries. In this topic, the effect of alloying addition on the properties of titanium intermetallic compounds will also be given in the form of table template and categorical development over the years. The effect of each element on the specific properties will also be explained based on literature sources.

3. Learning outcomes

Students can classify titanium aluminides according to their phase diagram information and explain their crystal structure and differences in them with respect to the amount of Aluminium content; analyse the compounds based on their intended use of service application based on their mostly corrosion behaviour and also their mechanical properties that are relevant to alloying additions; determine the microstructures that form in equilibrium and non equilibrium cooling paths and classify them according to their appearance and explain how they form in detail in these intermetallic alloys.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. K. Gupta, B. Pant, U. Prakash, Titanium aluminides, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

Topics 9

1. The subject of the lecture

INTERMETALLICS: IRON ALUMINIDES

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

This topic is aimed to present an advanced treatment of iron aluminides which are one of the first intermetallic alloys produced in bulk by the researchers to test them in practice. Iron intermetallic compounds are widely investigated because of their potential in applications where stainless steels are insufficient such as seawater applications but later found that iron aluminides are better suited for high temperatures applications where sulphide compounds are hazardous to many metals and alloys such as hot gas chimney outlets or furnace grids. Iron aluminides are intermetallic compounds made of iron and aluminum, typically containing around 18 at. % aluminium for the minimum amount of ordered intermetallic phase of Fe_3Al. Further addition of aluminium, i.e. up to 48 at % of aluminium, produces the maximum ordered phase of intermetallic structure with FeAl type compound. Iron aluminides possess several notable properties such as high corrosion resistance against several gases, highly suitable against sulphides but low to medium level protection in oxidising medium, making them promising materials for structural applications. Iron aluminide intermetallic compounds with several alloying additions have strength comparable to steel alloys, but low ductility at room temperature, and their strength drops substantially over 600 °C. Due to their high amount of aluminium content, lower density is appreciated compared to steels; the cost of iron aluminides are far lower than those of titanium alloys since they are made from common elements, contributing to their low cost. The main problem with intermetallics are their intrinsic brittleness to which hydrogen contributes drastically, hence, issues with hydrogen embrittlement are barriers to their processing and use in structural applications. Reaction with water can lead to embrittlement via hydrogen produced in the reaction between aluminium in the alloy and water or water vapour present in the air. However, the alloying with elements such as carbon, chromium and small additions of boron into iron aluminides can improve the ductility of iron aluminides. Research on iron aluminides has focused on their mechanical properties, corrosion resistance, processing, and physical properties, with recent studies demonstrating improved engineering ductility in some compositions. The Fe_3Al intermetallic compound is the most studied alloy, other intermetallic compounds based on the alloying of iron and aluminum elements include FeAl, Al_3Fe. In summary, iron aluminides offer a good combination of mechanical chemical and physical properties, but their low ductility at room temperature and issues with hydrogen embrittlement present challenges for their wider use in structural applications. Ongoing research on iron aluminide compounds focus to address these limitations and further develop the potential of iron aluminides for specific applications. Finally this topic will end with microstructures of the binary iron aluminide and ternary and multinary iron aluminide systems and their analysis of phases present in the to be defined by the students.

3. Learning outcomes

Students can classify iron aluminides according to their phase diagram and explain their crystal structure ad differences in them with respect to the amount of Aluminium content; analyse the iron aluminide compounds based on their intended use of service application ; classify them based on their mostly corrosion behaviour and also their mechanical properties that are relevant to alloying additions; determine the microstructures that form in equilibrium and non equilibrium cooling paths and classify them according to their appearance and explain how they form in detail in iron aluminide intermetallic alloys.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

U. Prakash, Intermetallic matrix composites based on iron aluminides, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 10

1. The subject of the lecture

OTHER TYPES OF INTERMETALLICS

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

This lecture aims to introduce the intermetallics that are less known by the researchers and practitioners, making them special for certain applications such as high temperature heating elements, electronic resistors and well known compounds for electronic industry such as transistors, processors and diodes. Typical examples for such intermetallics are well known molybdenum and tungsten di silicides that are employed in both electronics and heating industries. Hence, this topic will start with the silicide intermetallic compounds. Silicides are chemical compounds that combine silicon with a usually more electropositive element. They are structurally closer to borides than to carbides, but not isostructural with them due to size differences. Silicides have a wide range of structures, from conductive metal-like to covalent or ionic bonds. They are used in interconnects in microelectronics due to their low resistance and good process compatibility with silicon, as they can withstand high temperatures and various chemical cleans used during processing. Silicides are also used in forming metal silicide thin films to make resistors and diffusion junctions for MOS and mosfets such as NiSi, CoSi2, TiSi2, WSi2 and Ni(Co,Ti)Si2, which have applications in microelectronics due to their adjustable and low contact resistance. Additionally, silicides are used in the self-aligned silicide (salicide) process, which is commonly implemented in MOS / CMOS processes for ohmic contacts of the source, drain, and poly-Si gate, producing very low background noise when operating such as hearing aids and low noise high definition image processors. Silicides are non-stoichiometric compounds with large free carrier concentrations. Metal silicides are compound phases between metals and silicon, and metal layers deposited on silicon are unstable against silicide formation in the presence of heat. This topic will continue with the introduction of other types of important intermetallic, such as gold based intermetallics which are mainly used in microelectronics and also tin based intermetallics which are formed when soldering in electronics industry. Tin intermetallic compounds are one of the intermetallics that are importance to industry, as it forms at the interface of tin and the base metal in tin-plated copper alloys. The main compounds formed are Cu6Sn5 and Cu3Sn, which are hard and brittle and can adversely affect contact resistance and solderability. These intermetallic compounds are important in solder joints, and their formation rate is highly dependent on soldering temperature and time, with higher processing times and temperatures thicker intermetallics layer is resulted with many side effects. The intermetallic Cu6Sn5 is particularly important due to the large number of tin-lead and lead-free solder joints formed directly to copper, and it can be found in the bulk microstructure of solder joints where excessive time and temperature are involved during the soldering process. The topic will end with the examples of Si, tin, gold and copper based intermetallics and their phase types and compound variations will be explained using their phase diagrams obtained through experiments or their

calculated diagrams obtained from various literature sources, softwares etc… will be presented in the classroom.

3. Learning outcomes

Students can explain how the intermetallic compounds of silicon, gold, tin and copper are formed and which phases are present with respect to composition and temperature based on their phase diagrams; recognise the type of intermetallic compound and suggest an application for that intermetallic compound based on industrial applications; explain soldering with Pb and Pb free solders and their defects emanating from the formation of tin based intermetallics which reduces the performance of electronics soldered joints.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. S. Kumar, Intermetallics: Silicides, Encyclopedia of Materials: Science and Technology (Second Edition), 2001

R. Mitra, Molybdenum silicide-based composites, Intermetallic matrix composites: properties and applications, Ed. By: Rahul Mitra, 2018, Elsevier Ltd.

6. Additional notes

Topics 11

1. The subject of the lecture

HIGH ENTROPY ALLOYS: BASICS, PRINCIPLES AND SYNTHESIS

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

The lecture aims to provide an extensive introduction to high entropy alloys e.g. HEAs, which are newly developed alloy systems based on the highly complex mixing effect of elements in a solid solution with at least one dissolving phase and may be more than one phase appearing following the melting and solidification processes. This topic will involve brief physical chemistry of high entropy alloys from the atomic construction and entropic energy point of view and later physical metallurgy will proceed with the general properties of proposed alloys. The topic will include the problems and advantages of these new alloy systems with respect to their applications and limitations in general. It will also be contributing factor for the topic to include the fabrication routines that these alloys are produced including many methods of production such as vacuum melting, mechanical alloying, laser remelting etc… The phase diagrams for these systems are relatively new and modern techniques have to be used in order to generate data that show melting temperature, number of phases etc… Designing high-entropy alloys (HEAs) presents several challenges due to the large number of elements involved and the complexity of their interactions. The study of high-entropy (HE) alloys has seen significant growth in recent years due to their exceptional properties, including enhanced oxidation resistance, superior mechanical properties, and desirable magnetic properties. However, the identification of promising HE alloys is challenging due to the large number of distinct systems that may be fabricated from the available palette of elements. To address this challenge, machine learning strategies have been employed to reduce the size of the associated chemistry/composition space. These strategies have led to the identification of useful alloys, a better understanding of the thermodynamics and kinetics of these systems, and guided high-throughput experimental design. High entropy alloys are designed using many methodologies such as machine learning, computational techniques, deep learning and experimental validations techniques. Machine learning techniques have been employed to reduce the size of the chemical properties / composition range associated with high-entropy alloys, causing the identification of useful alloys and a better understanding of the thermodynamics and kinetics of these systems. Various computational techniques such as Calphad etc… have been useful in the characterization and design of high-entropy alloys based on some thermodynamical constants of elements and pre experimented alloy systems. These techniques have permitted the identification of useful high entropy alloys and guided high-throughput experimental design. Deep learning methods have been used for phase formation prediction and composition design of high-entropy alloys. These studies have demonstrated the potential for data - driven alloy design and have provided insights into the compositional dependence of high entropy alloy properties. The proposed calculation or prediction methodologies and models for high-entropy alloys have been validated through experimental studies, demonstrating the potential for practical application and further development. This topic will also be introducing many examples regarding the different types of high entropy and their ability to be joined using conventional and non conventional techniques.

3. Learning outcomes

Students can explain the rules that are important to calculate the phase composition and their formation in ternary systems; derive conclusions how ternary phase systems are constructed and calculations are made in complex systems in addition to the general rule of application of ternary systems in industrial alloys; analyze and explain the parts of zones in ternary systems.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

George, E.P., Raabe, D. & Ritchie, R.O. High-entropy alloys. *Nat Rev Mater* **4**, 515–534 (2019). https://doi.org/10.1038/s41578-019-0121-4

Lilensten, L. et al. New structure in refractory high-entropy alloys. *Mater. Lett.* **132**, 123–125 (2014).

Zhou, J. et al. High-entropy carbide: a novel class of multicomponent ceramics. *Ceram. Int.* **44**, 22014–22018 (2018).

6. Additional notes

Topics 12

1. The subject of the lecture

METALLIC GLASSES: PRINCIPLES AND REQUIREMENTS

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

The topic aims to give extensive introduction to bulk metallic glasses based on the studies on fully soluble and complex structures in mostly metallic systems. The main idea behind the bulk metallic glasses is the cocktail effect of alloying elements, as the number of alloying elements increase the better the results are for the amorphous structure. The topic will later continue with explaining the glass forming ability that affects the formation of amorphous structure along with fabrication routes by which synthesis is carried out. The phase formation rules will be added to the topic with s special visit to the solidification and crystallization subjects. Bulk Metallic Glasses (BMGs) are a new class of materials with many desirable and unique properties, such as high strength, good hardness, good wear resistance, and high corrosion resistance that can be produced in near net shape components. These amorphous materials have many diverse applications, from structural applications to biomedical implants. Some key aspects of BMGs are amorphous Structure, Glass Transition Temperature (Tg), supercooled liquid region and the critical rate of cooling of bulk. Bulk Metallic Glasses have a non-crystalline, amorphous structure that lacks grain defects, giving them their unique properties. Bulk Metallic Glasses exhibit a glass transition, which is the temperature at which a material transitions from a crystalline to a glass like structure, exhibiting unique properties. Bulk Metallic Glasses show viscous flow in a certain temperature range called the super-cooled liquid region. The formation of BMGs requires rapid cooling rates to avoid crystallization. Techniques such as 3D printing have been used to manufacture bulk metallic glasses. Bulk Metallic Glasses hold great promise for structural and functional applications and are viewed as one of the most important materials due to their unique properties of extreme strength at room temperature and high flexibility at high temperature. However, many fundamental questions remain, and our understanding of the properties and structures of BMGs is far from comprehensive. BMGs can have tensile strength up to 3000 MPa with good corrosion resistance, reasonable toughness, low internal friction, and good elasticity. BMGs are twice as strong as titanium, tougher and more elastic than ceramics, and have excellent wear and corrosion resistance, making them attractive for a variety of application. The amorphous structure of BMGs, lacking in grain defects, gives them their strength, toughness, hardness, elasticity, and corrosion and wear resistance. The mechanical properties of BMGs are closely related to the chemical and physical properties of their component elements, and changes in chemical composition can result in significant differences in mechanical performance, such as strength and ductility. BMGs exhibit superior mechanical properties compared to conventional materials, making them more attractive for various critical industrial applications. The students will also have an opportunity to refresh their knowledge on amorphisation, solidification and crystallization of metallic systems, and attend the discussion regarding the future alloy systems and the benefits of bulk metallic glasses.

3. Learning outcomes

Students can explain how bulk metallic glasses are formed and the rules that are important to obtain bulk metallic glasses from a cocktail of alloying elements; analyse the parameters of obtaining bulk metallic glasses and related definitions that are unique to this sort of materials and alloys; suggest the application areas of these kinds of alloys based on the composition of bulk metallic glasses; analyze and explain the parts of zones in bulk metallic glass microstructures and suggest mechanisms by which these microstructures are formed.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

A. Inoue, A. Takeuchi, Bulk Metallic Glasses: Formation and Applications, Encyclopedia of Materials: Science and Technology (Second Edition), 2001

A. Inoue, Materials Science and Engineering: A, Volumes 304–306, 31 May 2001, Pages 1-10

6. Additional notes

Topics 13

1. The subject of the lecture

HIGH ENTROPY ALLOYS AND METALLIC GLASSES: APPLICATIONS AND PROSPECTS

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

This topic aims to provide a detailed summary of the generalised phase transformations and second phase and intermetallic phase subgroups and many physical properties of newly developed high entropy alloys and bulk metallic glasses and more precisely their practical, industrial and future applications on the basis of information given in the literature and various sources. The topic will also include high temperature superalloys designed as high entropy alloys and high entropy metallic glasses designed using high entropy cocktail concept; some research on these alloy groups will be exercised within the classroom. The magnetic and corrosion behaviour of these alloys are of interest to the researchers as a soft magnetic material should have good mechanical property, structural stability at high temperature and low coercivity with high magnetization. Recently, reported FeCoNiMn0.25Al0.25 and CoCrFeNiM (M = Cu, Mn) HEAs got attention as a better soft magnetic material because these HEAs having good soft magnetic characteristics along with good mechanical and excellent structural stability at high-temperature. The potential applications and prospects of high entropy alloys and bulk metallic glasses will be discussed based on the information given in the classroom and students will be asked to propose a potential applications based on their experience in industry and studies. As is given in previous topics, Bulk metallic glasses (BMGs) and high entropy alloys offer superior mechanical and physical properties compared to conventional materials such as disordered crystalline metals and alloys. These alloys surely differ in the behaviour of phase transformations from the kinetics point of view. Some examples of conventional materials that BMGs and high entropy alloys compare to in terms of strength and durability are, for example, steels, titanium alloys, crystalline metals and alloys but it would be insufficient to compare to superalloys as they do not seem to have any alternative at this stage of technology. BMGs have superior strength and high elasticity compared to steel. They also have excellent wear and corrosion resistance, making them attractive for various applications. BMGs are twice as strong as titanium and tougher and more elastic than ceramics. BMGs and high entropy alloys have been shown to have superior strength, high elasticity, and excellent wear resistance compared with conventional crystalline metals and alloys due to their nature of high dislocation energy required during the deformation process. In summary, BMGs exhibit exceptional mechanical properties, including superior strength and durability, when compared to traditional materials such as steel, titanium, and conventional crystalline metals and alloys. Some examples of metallic glasses include: Pd77Cu6Si17, Fe40Ni40B20, Ni49Fe29B6P14Si2, Ni–Nb, Mg–Zn, Hf–V and Cu–Zr systems. These examples represent metal–metalloid and metal–metal type metallic glasses, showcasing the diverse compositions and combinations that can form metallic glasses with unique properties. At the end of this topic, students are requested to write a an essay on the development of bulk metallic glasses and high entropy alloys in order to strengthen the knowledge attained in the classroom activities.

3. Learning outcomes

Students can recognize the importance of bulk metallic glasses and high entropy alloys as new types of alloy; explain the prospective capacity of metallic glasses and high entropy alloys through their phase transformations, physical properties, and practical applications; discuss and elaborate on the magnetic and corrosion behavior of these alloys, their potential applications, and prospects.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

George, E.P., Raabe, D. & Ritchie, R.O. High-entropy alloys. *Nat Rev Mater* **4**, 515–534 (2019). https://doi.org/10.1038/s41578-019-0121-4

Lilensten, L. et al. New structure in refractory high-entropy alloys. *Mater. Lett.* **132**, 123–125 (2014).

6. Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

KINETICS OF METALLURGICAL PROCESSES

Code: KMP

Co-funded by the European Union

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Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO THERMODYNAMICS AND KINETICS

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

This topic aims to present a detailed introduction to the basics of thermodynamics and kinematical relationships related to processing of materials. The basics of thermodynamics of materials will be detailed, starting from the reversible and irreversible reactions kinetics and their effect on the thermodynamics of final state equations of the system. It is also important to mention the variations in free energy in which the mixing behaviour of atoms in conventional and non conventional materials are presumed to be rate dependent and path defined processes leading to the equilibrium approaching systems. The rate dependence of the system will be emphasized as they are the main driving force for the kinetics The equilibrium of systems are moderately expressed differently if the scale of the system is large or small such that large scale systems are rapidly occurring in short scale distances inside the system, hence the local equilibrium is nearly satisfied in regions of the whole system. The diffusion driven reactions in metals and gas reactions are also included in the topic to indicate that such properties of materials have different reaction rates due to their bonding capacity per unit length and per unit area. The topic will continue with explanation of the rate reactions in general and energy barrier to any reactions will be indulged in a mathematical expressions and simple calculations using some textbook examples. The students are expected to define diffusion, self diffusion and interdiffusion and its equations in 2 dimensional and three dimensional infinite isotropic matter and apply this knowledge in examples to be given during the lecture. The diffusion in crystalline and non crystalline systems are approached differently where crystalline matter is more regularly bonded and hence the movement of atoms are more restricted whereas non crystalline matters behave more relaxed as the metastability of the structure allows them experience structural relaxation, phase separation and solidification. In this topic, the driving forces for atomic flux which the behaviour of the concentration around a line source that is diffusing into an infinite isotropic medium will be introduced to the students, as well. Another state of non crystalline matter is liquid where the diffusion is rapid compared to solid and also crystalline state. The students will be introduced to various examples of thermodynamical approach to the kinetics of materials especially based on the reaction rate kinetics of any mixture that is loosely and tightly connected and also mixtures of highly entropic atoms e.g. different atomic variants within the system. Students will be introduced of the fact that thermodynamics is the starting point of kinetics and any treatment without thermodynamic lacks in the definition of rate. The topic will be concluded with a discussion on the driving forces in alloy systems and equilibrium state.

3. Learning outcomes

Students can explain the role of thermodynamics in kinetics of materials and with a special interest to reversible and irreversible reactions; define the equilibrium state and its effect on the rate of reactions in binary and multinary systems with a touch of mathematical expressions; analyse and explain the need for equilibrium state in diffusion driven systems; be content with the fact that thermodynamics is the starting point of kinetics and any treatment without thermodynamic lacks in the definition of reaction rates.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 2

1. The subject of the lecture

KINETICS IN MATERIALS AND DIFFUSION PATHS

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

This topic is intended to introduce an extended treatment of rate equations and related kinetics with the explanation of parameters that include the activation energy of a reaction with a reference to thermal effect, activity of solution of reacting species and free energy in gaseous and solid systems. The topic will continue with the introduction of thermal effect on the rate laws in detail with an exemplary treatment from chemical reactions with mathematical approaches to rate and reaction relationships. The field of kinetics in materials science involves the study of the rates of chemical reactions and the factors that affect them, particularly in the context of materials and their processing. This field encompasses various topics such as diffusion, phase transformations, and the development of microstructure. Kinetics in materials science is crucial for understanding the behavior and properties of materials, as well as for the design and optimization of material processing techniques. The second part of this topic will introduce thermally activated reactions in various mediums and empirical and semi empirical approaches to the rate laws in order to relate the effect of rate laws to metallurgical systems of which various examples to be given during the course, and the kinetical approach to the problems presented. The lecture topic will also cover the excluded treatment of diffusion in crystalline systems as it more relates kinetics to the rate laws. Diffusion, as was mentioned in previous topic, will be revisited from the mechanisms point of view and various types of mechanisms will be elaborated. Such diffusion mechanisms will involve the vacancy formation and vacancy development during thermally activated reaction in isotropic infinite medium. The vacancy approach will be following the other mechanisms such as interstitial which are more solid state reaction type diffusion mechanism. However, the most important part of this lecture topic will be on the equilibrium in kinetic analysis which has not been given in previous lecture topic. When the temperature of the crystal changes, vacancies must leave or enter the source / sinks, and then diffuse through the crystal in order to establish the new equilibrium concentration. How rapidly this happens will depend on the density of source/sinks, on how rapidly the vacancies join and leave them, and how rapidly they diffuse through the crystal. In a typical metal, there are many dislocations that can act as sources and sinks for vacancies. And so the vacancy concentration in a metal is usually close to the equilibrium value. This topic will also cover mechanistic approach in kinetic analysis which involves the use of Reaction Progress Kinetic Analysis (RPKA), which combines in situ measurements and graphical rate equations to analyze the reaction and distinguish between different proposed mechanistic models. It allows for the rapid determination of concentration dependences of reactants and aids in the design of further supporting experiments.

3. Learning outcomes

Students can elaborate on the diffusion processes in detail by defining the role of diffusion in kinetics of materials along with the effective diffusion paths in crystalline materials; analyse the diffusion paths that were created by the thermal and mechanical effects and its role on the rate defining processes especially dislocations and vacancy like defects; explain how mechanistic approach will be implemented in kinetics of materials.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 3

1. The subject of the lecture

TIME DEPENDENCY AND KINETICS

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

This topic is aimed to give a detailed view into the time dependency of a reaction intertwined with kinetics using some mathematical expressions. The time dependence of a chemical reaction is described by a rate law, which defines the rate of a chemical reaction as the time needed for a change in concentration to occur. The rate law can be defined by the change in concentration of the reactants or products over time, and it is governed by the stoichiometry of the reaction. This topic will also cover the kinetic model for the nucleation and growth processes which occur following the phase transformation from example liquid transforming from liquid to solid. These kind of transformations are generally termed as thermally activated transformation and are characterized by interface migration (e.g. recrystallisation and grain growth) or by long range "diffusive" transport (e.g. precipitation and dissolution). Kinetical model will involve the early stages of nucleation in liquid state with an extensive mathematical expression defining the volumetric and surface are changes taking place. The students will be introduced to the many experimental observations by high temperature microscopy and relevant microscopic analysis collected from the literature studies. Early microstructural observations showed that progress or evolution of such transformations i.e. the formation of nuclei can well be described by the frequency of the nucleation of the new phase and its subsequent growth at the expense of the disappearing matrix. This idea was first put forward by Johnson and Mehl but later on modified by Kolmogorov and also Avrami's equation was inserted to relate the time of nucleation taken and percentage of phase transformed. Hence it became Kolmogorov Johson Mehl Avrami equation, which is KJMA, the KJMA rate equation is valid for non-isothermal transformations only when very particular conditions are met. Despite these severe limitations, non-isothermal experiments are commonly interpreted within the KJMA rate equation. This variation or percentage of second phase transformed act like sigmoid like functions as it relates the percentage transformed is initially very slow but later paces up at very high volumetric increase and hence very sharp increase is observed. The number of nuclei increases rapidly but towards the end of the transformation growth is the dominant factor and hence the increase in percentage completion is greatly reduced as the equilibrium is slowly attained to make full grain consuming initial phase. The students will also be given a treatment of mathematical development of KJMA equation and its applications in allotropic metals and alloys. Some researchers claim that KJMA equation requires further treatment in order to correct the sigmoid behaviour; the fact is that good agreement with other exact methods is often obtained. This is a strong indication that many properties of the exact solution are shared by the KJMA rate equation. The topic will also contain a discussion on the efficiency of KJMA equation based on an experiment from literature.

3. Learning outcomes

Students can explain time dependency of a reaction intertwined with kinetics using some mathematical expressions; analyse the need kinetic model for the nucleation and growth processes which occur following the phase transformation from example liquid transforming from liquid to solid; characterize the nucleation stages of liquid to solid transformation with a special treatment of KJMA; explain how the rate of transformation is controlled.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 4

1. The subject of the lecture

CHEMICALLY CONTROLLED REACTIONS AND DIFFUSION

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

This topic aims to provide an advanced treatment in chemically controlled diffusive dominated reactions in solid and liquid state of mostly metallic materials. The topic will continue with the introduction of chemically controlled reactions in general terms and later explain the rate controlling expressions in early stages of diffusion reactions. Diffusion is the basic step n these transformations and hence requires a driving force to complete the transformation. It is also the aim of this topic to show the changes in composition of alloys and the challenges that were faced with conventional production processes. Diffusion controlled (or diffusion-limited) reactions are reactions in which the reaction rate is equal to the rate of transport of the reactants through the reaction medium, usually a solution. In these reactions, the observed rate of chemical reactions is generally the rate of the slowest or "rate-determining" step. Diffusion control is more likely in solution where diffusion of reactants is slower due to the greater number of collisions with solvent molecules. Students will be familiarised with the concept of interface mobility as the reaction takes place and the interface reaction control will have an impact on the rate reactions such as Arrhenius which gives the dependence of the rate constant of a chemical reaction on the absolute temperature with respect to activation energy and modified Avrami equations. This interference with rate equations and will be shortly introduced to the students. Reactions where the activated complex forms easily and the products form rapidly are most likely to be limited by diffusion control. Examples are those involving catalysis and enzymatic reactions. Heterogeneous reactions where reactants are in different phases are also candidates for diffusion control. Diffusion controlled (or diffusion limited) reactions are reactions in which the reaction rate is equal to the rate of transport of the reactants through the reaction medium, usually a solution. The process of chemical reaction can be considered as involving the diffusion of reactants until they encounter each other in the right stoichiometry and form an activated complex which can form the product species. The observed rate of chemical reactions is, generally speaking, the rate of the slowest or "rate determining" step. Diffusion control in reactions especially interface controlled reactions is more likely in solution where diffusion of reactants is slower due to the greater number of collisions with solvent molecules. Reactions where the activated complex forms easily and the products form rapidly are most likely to be limited by diffusion control. Examples are those involving catalysis and enzymatic reactions. Heterogeneous reactions where reactants are in different phases are also candidates for diffusion control. This topic will finally end with the generalised summary on the diffusion controlled transformations and order of reactions in defining chemical kinetics of reactions with a special interest on the interface controlling processes.

3. Learning outcomes

Students can differentiate between the chemically driven transformation and thermally driven transformations in metallic systems; analyse chemically controlled diffusive dominated reactions in solid and liquid state of mostly metallic materials and also explain chemically controlled reactions in detail; explain the rate controlling expressions in early stages of diffusion reactions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 5

1. The subject of the lecture

DIFFUSION THROUGH REACTION LAYER

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

This topic begins with an overview of diffusive reactions in metal and alloys, which transformation into a new phase occurs at a distance, in addition, a brief explanation of the reaction layer that compromises short range and long range reactions, requiring a thermally induced or athermally occurring changes upfront will also be included in the lecture topic. A solid state reaction is more likely to occur at lower rate controlling diffusion controlled interface however the solid liquid reactions are faster as they have high mobility at atomic level, increasing the reaction constant. This process will not be limited to liquid solid interface in fact it will also cover the solid - solid reaction fronts and kinetics governing the thickening or segregation will also be indulged during the source of topic. If a solid reaction product is formed on the reacting solid, the kinetics of reaction may be governed by the character of the coating and the diffusion process. If the coating is very porous, then there will be no resistance to reagents reaching the reaction interface and the coating will have no effect. In case the porosity is low or non-existent, then the reagent has to diffuse through the protective film (by pore diffusion and lattice diffusion, respectively) before it reaches the interface. In this case, the reaction rate is likely to decrease progressively because of the gradual thickening of the product layer. There will be a special interest to segregation process in diffusion controlled systems, starting from the basic, the segregation will be explained to the students and relevant mathematical expressions are to be given in detail. As it is a pure thermodynamic event, how the segregation occurs and how to prevent the segregation in metals and alloys will be given a special treatment and solution this problem will be discussed in the classroom with students. Hence, there will be a discussion period to relate the segregation and rate theories with a touch of thermodynamics treatment in order to properly address the problem. The nucleation and growth theory and growth of second phase in a matrix govern the fact that the second phase is assumed to be in the form of disc, or spherical form to ease the mathematical expressions. This will be also a subject in this topic to explain the growth of reaction layer in case diffusion exists. Finally, this topic will end with the overview of metallic segregation examples in various metallic binary or ternary systems and alloys that are prone to produce segregates such as aluminium silicon lithium alloys and superalloys where diffusion is responsible for the generation of secondary intermetallic segregates. Optical and electron microscopy images will be used to strengthen the topic outcomes.

3. Learning outcomes

Students can explain how interfaces between the phases are formed and how they can be defined by the atomic arrangement; explain why the diffusion rates are different in different interface systems; describe the effect of chemical control at the interface and its stability with time; explain the growth of reaction layer that leads to segregation or other structures such as intermetallics.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 6

1. The subject of the lecture

MOTION OF DISLOCATIONS AND INTERFACES

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

This lecture aims to introduce the motion of dislocations in pure and alloy systems to infer that such movements play important role in kinetics of materials as they ease the movements of atoms along the diffusion paths. There is special section of dislocation generation in order to remind the students the key points of how dislocations move and generate defects within the crystal. The motion of dislocations by glide and climb is fundamental to many important kinetic processes in materials. Gliding dislocations are responsible for plastic deformation of crystalline materials at relatively low temperatures, where any dislocation climb is negligible. Students will also be informed on the importance of dislocations on the role in the motion of glissile interfaces during twinning and diffusionless martensitic phase transformations. In general, these interfaces move in coordinated fashion with a content of dislocations. Glissile interfaces are both gliding and climbing, dislocations cause much of the deformation that occurs at higher temperatures where self-diffusion rates become significant, and significant climb is then possible. Climbing dislocations act as sources and sinks for point defects. This topic establishes some of the basic kinetic features of both dislocations glide and climb processes with relation to the kinetics of materials. The topic will also cover the effect of curvature of the interface and how it modifies the energy of interface surface to control the rate of growth of related grain or new phase. In materials, crystal/crystal interfaces possess more degrees of freedom than vapour/crystal or liquid/crystal interfaces. They may also contain line defects in the form of interfacial dislocations, dislocation-ledges, and pure ledges. Therefore, the structures and motions of crystal/crystal interfaces are potentially more complex than those of vapour/crystal and liquid/crystal interfaces. Student will be introduced to the interface structures such as epitaxial interfaces which does not move but act as passive nucleation site for nuclei where glissile interfaces are mobile towards either a phase or b phase whichever is energetically favourable. An extensive graphical representation of interfaces with many examples from literature will be introduced to the students in the classroom. Crystal/crystal interfaces experience many different types of pressures and move by a wide variety of atomic mechanisms, ranging from a rapid glissile motion to slower thermally activated motion. Common sources of driving pressures for the motion of vapour/crystal and liquid/crystal interfaces are to be described. These and additional sources of pressure exist for crystal/crystal interfaces. For example, during recrystallisation stage, interfaces between the growing recrystallised grains and the deformed matrix are subjected to a pressure that is due to the bulk free-energy difference (per atom) ΔG between the free energy of the deformed matrix and that of the recrystallised grains. At the end of the lecture topic, there will be a discussion on the effects of several defects available in the matrix on the generation of new diffusion paths.

3. Learning outcomes

Students can explain how the motion of dislocations in pure and alloy systems occur and why such movements play important role in kinetics of materials as they ease the movements of atoms along the diffusion paths; elaborate on glissile and crystal to crystal interfaces in case of dislocation and thermal loads; explain the role of dislocations at interface formation and driving forces leading to glissile dislocation generation and also thermally induced interface movement.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 7

1. The subject of the lecture

MORPHOLOGICAL EVOLUTION DUE TO CAPILLARY AND APPLIED FORCES: COARSENING AND SINTERING

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

This lecture aims to introduce the capillary forces in liquid and solid states under certain forces such as chemical and mechanical driving forces with atomic mobility affecting the shape of the boundaries namely grain boundary and phase boundaries. The presence of grain or preferably phase boundary may be elaborated with a brief introduction of undergraduate knowledge. In this lecture topic, we will focus on capillarity driven processes that primarily alter the shape of a second phase particles or grains which exist in either thermally induced atomic flux or static addition of atoms in a field other than thermal influence. One can observe two types of changes which are those driven by reduction of surface area, and those driven by altering the inclination of grain boundary surfaces. Students will also be accustomed to grain and particle coarsening process with a extensive mathematical expression defining the free energy requirement for the processes to occur. Coarsening is an increase in characteristic length scale during microstructural evolution. Total interfacial energy reduction provides the driving force for coarsening of a particle distribution. When a particulate phase is embedded in a matrix of a second phase, flux from smaller to larger particles causes the average particle size to increase as the total heterophase interfacial energy decreases. The particles compete for solute and the larger particles have the advantage of reducing their free energy of by increasing volume and reducing surface area. This process degrades many material properties, depending on the presence of fine precipitates. In single-phase polycrystalline materials, larger grains tend to grow at the expense of the smaller grains as the total grain-boundary free energy decreases. In the second part of the lecture topic, students will be introduced to the combined effects of capillary and applied mechanical forces on mass redistribution between surfaces and internal interfaces which include diffusional creep in dense polycrystals and sintering of porous polycrystals under the influence of temperature and holding time. Diffusional creep and sintering derive from similar kinetic driving forces effective. Diffusional creep is associated with macroscopic shape change when mass is transported between interfaces due to capillary and mechanical driving forces. Sintering occurs in response to the same driving forces, but is identified with porous bodies such as in powder metallurgy processes in which powder of metals are compacted and later heated to allow the sintering between the powders. Sintering changes the shape and size of pores; if pores shrink, sintering also produces macroscopic shrinkage (densification). The lecture will finally end with extensive exemplary study on the growth process of particles and grains and also the progress of sintering in porous materials with microstructural images obtained from literature.

3. Learning outcomes

Students can define the capillary effect in liquid and solid state and its result on the development of shape of grain and phase boundary; describe how coarsening occurs in metallic systems and the driving forces that are actively controlling the growth of a phase of grain; define the stages of mechanism by which sintering proceeds and advances to the completion e.g. high densification.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 8

1. The subject of the lecture

SEGREGATION

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

This topic aims to introduce the segregation process in an alloy in which a solid solution forms two components with a thermodynamically favourable A to A bonding in matrix of B + B atoms, usually appear in grain or phase boundaries. These segregations are for example elemental segregation between the dendrites, sulphur or oxide segregation in castings. The topic will continue with the introduction of solidification modes of alloying element rich liquid and definition of Scheil principles in segregation process during the solidification stage. In this topic, the segregation during a phase change will be discussed. We will focus on these effects for the solidification process, which is the most common and most widely used phase transformation in materials processing. Segregation processes are similar for any phase transformation, but the details may differ due to differences in transformation rates, in mobilities, diffusion rates, etc., of the species involved. Students will be made aware of equilibrium concepts during segregation and alloying concentrations in liquid state and solid phase. At equilibrium, the composition of one phase is, in general, different from that of the others. This difference in equilibrium concentrations is described by the phase diagram. At true equilibrium there are no composition gradients in any phase, and so the composition of each phase is uniform, at the equilibrium concentration for the appropriate temperature. In practice, a solid of varying composition can form as the growth conditions change during a phase transformation. Once such a solid has formed, it can take a very long time for the composition to become uniform, and so true equilibrium is seldom achieved. Students will also have a period of discussion on how the growth conditions can change the composition distribution in a solid while it is forming with the help of lever rule. The lever rule is often used as an approximation for analysing fluid flow and segregation during dendritic growth of alloys where the dendrites are thin and the liquid channels between them are narrow, where scheil equation finds its use. The Scheil equation is also called the normal freezing equation. It is based on the assumption that the local composition of the solid does not change after it has formed. It also assumes that the concentration of the liquid is uniform during the solidification process. The second component that is rejected by the solid stays in the liquid, and so the composition of the liquid increases as solidification proceeds. The composition of the liquid is uniform throughout, but increases with time. So the composition of the solid that forms, given by $C_S = kC_L$, also increases with time. The average composition of the final solid must be the same as the average composition of the starting liquid. Finally, the effect of alloying concentration on the Scheil distribution will be explained and diffusion at moving interface will be realized in 3 dimensional space.

3. Learning outcomes

Students can explain the segregation processes in two phase binary alloy systems; define the segregation in solute rich systems and how they develop from the supersaturated solutions; describe the zone refining process and the role of moving interface at high temperatures to brush off the unwanted solute by using segregation effect.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

Topics 9

1. The subject of the lecture

PHASE TRANSFORMATIONS KINETICS

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

This topic is aimed to present an advanced treatment of phase concept and phase transformations in solid in which allotropic transformations take place with respect to three effects from temperature, time and pressure. The pressure effect is omitted in metallurgical processes as the processing pressure is the atmospheric condition. Students will also be introduced to phase transformations in many metallic and non metallic systems in brief and will be asked to make a statement how these groups of materials would change in case of phase transformations conditions are met. Phase transformations are of central importance in materials science and engineering. An understanding of the thermodynamics of phase equilibria is the foundation for understanding their kinetics. Necessary conditions for equilibrium include: uniformity and equality of the diffusion potential for each chemical species that can be exchanged between the phases; equality of temperature; and equality of pressure if the two phases can freely exchange volume of atoms. Deviations from these equilibrium conditions set the stage for kinetic processes. Students will be required to attend the discussion on the kinetic processes in phase transformations with the help of previously acquired knowledge from previous weeks. A separate section will be devoted to kinetics that derived from non uniformity of a potential, such as chemical potential or temperature, within a single phase as a stepping bases to phase transformation in multi phase systems. Phase transformations occur when a region of the material can reduce the total free energy by changing its symmetry, equilibrium composition, equilibrium density, or any other quantity that defines a phase. Order and disorder phase changes may be introduced to the students at this stage with a special interest to intermetallics with brief introduction. A mechanistic approach to the phase to phase interactions will be introduced to the students. In this approach, the transforming material portion may be adjacent to its prospective phase, which is the case for growth of a new phase; or the portion may be isolated, which is the case for nucleation of a new phase. Contiguous phases such as austenite and second phase particles of cementite must be separated by an interface, and therefore considerations of interface and morphological evolution play a role in phase transformation kinetics. However, every interface need not separate two phases-grain and antiphase boundaries defined by the separate atomic mobility, crystallographic or symmetric variants of a single phase. Nevertheless, it is instructive to treat such interface motion where a single phase alters its orientation analogously with phase transformations. Such a treatment naturally introduces two different kinds of order parameters. Regions of material defined by one kind of order parameter such as spin density, symmetry, and orientation may alter without a corresponding atomic flux. Finally this topic will end with microstructures of the summary of phase transformation with a kinetic approach apparent in binary, ternary and multinary systems and their analysis of phases to be presented to the students.

3. Learning outcomes

Students can describe the parameters that lead to phase changes in metals and alloy systems; define the equilibrium concept in phase formation and transformation processes; explain the symmetrical and crystallographical changes; elaborate on mechanistic approach to the phase to phase interactions with a perspective on nucleation and atomic mobility near and about the new phase nuclei; elaborate on the antiphase boundaries.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 10

1. The subject of the lecture

NUCLEATION AND GROWTH

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

This lecture aims to introduce the basics of nucleation and growth processes in metallic systems with a special interest to the classical theory of nucleation and various rate controlling approaches to the nucleation process. The topic will also be covering the Gibbs free energy treatment for nucleation and mathematical expressions defining the initial stage where metastable matrix phase is formed and no stable second phase is introduced. The formation of a new phase by a discontinuous phase transformation (such as the formation of a solid from a liquid or the precipitation of a solute-rich solid phase from a supersaturated solid solution) requires the nucleation of the new phase in highly localized regions of the system. In this chapter we present the general theory of this nucleation, including classical and non classical models. Rates of nucleation are analyzed under quasi steady state and non-steady-state conditions. The influence of the nature of the nucleus / matrix interface, as well as effects due to the nucleus shape and presence of elastic strain energy, are included. Both homogeneous and heterogeneous nucleations are treated. Homogeneous and heterogeneous modes of nucleation generally compete with one another, and the predominant mode is the one that proceeds more rapidly. Nucleation theory deals for the most part with Stages I and II. The treatment which follows starts with the relatively simple classical theory of the homogeneous nucleation of a new phase in a one-component condensed system without strain energy. This sets the stage for a description of the complications that occur when two components are present and for cases in which significant elastic strain energy is associated with the formation of a nucleus. Students will be introduced to the heterogeneous nucleation and its parameters to form in an alloying element rich matrix. Heterogeneous nucleation in crystalline systems is taken up with emphasis on grain boundaries and dislocations as heterogeneous nucleation sites. The classical nucleation model will be dealt with mathematical expressions using both thermodynamic and chemical reaction approach. According to the classical model, in order to nucleate the p phase, it is necessary for some of the a phase to be converted into small clusters of the B phase and, in turn, for at least some of these clusters to survive possible conversion back to the a phase and grow into much larger stable clusters corresponding to the bulk alpha phase. The small alpha clusters will have a large surface to volume ratio, and their interfacial energies will therefore be relatively large. This relatively large interfacial energy will make the formation of small clusters difficult and act as a barrier to the nucleation. When clusters form in solids, elastic misfit strain energy is generally present because of volume and / or shape incompatibilities between the cluster and the matrix. This energy must be added to the bulk chemical free energy. The topic will end with the examples of optical and electron microscopy images of the stages of nucleation and the growth of nuclei in a meta-stable matrix.

3. Learning outcomes

Students can explain basics of nucleation and growth processes in metallic systems with a special interest to the classical theory of nucleation and various rate controlling approaches to the nucleation and growth process; elaborate the Gibbs free energy treatment for nucleation and basic mathematical expressions defining the various stages of nucleation and growth; recognize and analyse the nucleation stages from the optical and electron microscopes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

R. W. Balluffi, S. M. Allen, W. C. Carter, Kinetics of Materials, Wiley-VCH Verlag GmbH & Co, 2005

6. Additional notes

Co-funded by the European Union

Topics 11

1. The subject of the lecture

CRYSTAL GROWTH METHODS

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

The lecture aims to provide an extensive introduction to necessity of crystal growth and crystal growth processes in order to employ such materials in specific applications such as single crystal jet combustion chamber blades or creep resistance applications taking place at high temperatures. Students will be aware of the parameters of the crystal growth and chemistry of growth from either pure or multinary solutions. This topic will involve brief physical chemistry of high floating zone and melt growth processes and some mathematical expressions will be involved based on these two processes as they are the most used main methods of crystal growth. Growth of crystal ranges from a small inexpensive technique to a complex sophisticated expensive process and crystallization time ranges from minutes, hours, days and to months. The starting points are the historical works of the inventors of several important crystal growth techniques and their original aim. The methods of growing crystals are very wide and mainly dictated by the characteristics of the material and its size.

The basic common principle in all these methods is that a nucleus is first formed, and it grows into a single crystal by organizing and assembling ions or molecules with specific interactions and bonding, so that the process is slow and multiple nucleation sites are minimized. Crystal growth process and size of the grown crystal differ widely and are determined by the characteristics of the material. A plausible growth method is essential because the possible impurity and other unwanted concentrations within the melt have to be eliminated. These methods will be discussed in detail. The different techniques are vapour growth, melt growth, gel growth, solution growth and high temperature solution growth. Melt Growth is the process of crystallization by fusion and resolidification of the pure material. In this technique apart from possible contamination from crucible materials and surrounding atmosphere, no impurities are introduced in the growth process and the rate of growth is normally much higher than that possible by other methods. Mainly for the latter reason, melt growth is commercially the most important method of crystal growth. The growth from melt can further be sub-grouped into various techniques: Bridgman, Czochralski, Chalmers, Zone melting, Verneuil Techniques, Heat exchanger Method, Skull melting and Shaped crystal growth. The major practical factors to be considered during growth of crystals from melt are, volatility, chemical reactivity and melting point. Flux and hydrothermal growths form the category of high temperature solution growth. In the growth of crystals from high-temperature solutions, the constituents of the material to be crystallized are dissolved in a suitable solvent and crystallization occurs as the solution becomes critically supersaturated. The supersaturation may be promoted by evaporation of the solvent, by cooling the solution or by a transport process in which the solute is made to flow from a hotter to a cooler region. The topic will also include the problems and advantages of these methods of crystal growth with respect to their applications and limitations in general.

3. Learning outcomes

Students can explain the necessity of crystal growth for some applications, especially need for the single crystal materials specific applications; explain how and why parameters of crystal growth can be controlled in order for the best performance from these materials and analyse the methods for a suitable applications; describe the methods of crystal growth and classify them according to the starting materials and solutions.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

K. A Jackson, Kinetic processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004

R. W. Balluffi, S. M. Allen, W. C. Carter, Kinetics of Materials, Wiley-VCH Verlag GmbH & Co, 2005

6. Additional notes

Topics 12

1. The subject of the lecture

NON EQUILIBRIUM CRYSTALLIZATION OF ALLOYS

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

The topic aims to give an extensive introduction to non equilibrium crystallization of alloys and the mechanism by which perforation of interface and quasi treatment of crystallization occurs. In addition, the resulting microstructures of some non equilibrium alloys will also be introduced to students with detailed explanations of the mechanisms of formation of such morphologies. The important outcome of non equilibrium processing is highly disordered structures and in some cases, when the alloying additions are not sufficient, the structure becomes mechanically disordered, that is, crystallographically displacive or non diffusively transformed structures, as the number of alloying elements increase in the solution the better the results are for the amorphous structure as the cocktail effect kicks in. The topic will later continue with explaining the ability that affects the formation of amorphous structure e.g. glassy structure formation. The phase formation rules will be added to the topic with special visit to the solidification and crystallization subjects. The compositions, structure and properties of multi-component materials produced by phase transformations that occur under conditions that are far from equilibrium are often quite different from those predicted by equilibrium thermodynamics. Students will be accustomed with the concept of metallic glasses and normal glasses to compare with. The alloys that form metallic glasses are usually a mixture of metallic elements and semi-metals or semiconductor elements, which crystallize into a complicated crystal structure usually with short range order of crystals with multi directional orientation. Due to this arrangement and also the number of alloying elements, these materials have large entropies of fusion which is difficult to extract during the speedy solidification route. Since these alloys crystallize slowly, they can be quenched into a glassy state where the atom mobility is very small. For pure metals, the crystallization rate is so fast that this cannot happen. In this topic, we will consider what happens when the rate of advance of the interface becomes comparable to the rate at which atoms can move by diffusion. In this regime, the quasi equilibrium treatment based on thermodynamics will be modified by kinetic effects. Glasses usually crystallize at reasonable rates only far below their equilibrium melting points. However, in glasses, unlike in liquids, the diffusion rate of dopants or second components is often much faster than diffusion rate of the components of the glass matrix. The crystallization rate depends on the mobility of the major components of the glass matrix. Dopants that can move by diffusion much faster than the growth front moves will not be trapped into the crystal. The students will also have an opportunity to refresh their knowledge on amorphisation, solidification and crystallization of metallic systems, and attend the discussion regarding the future alloy systems and the benefits of non equilibrium microstructures.

3. Learning outcomes

Students can explain how non equilibrium is attained in solutions with low and high alloys and can differentiate between amorphous and crystalline structures obtained using non equilibrium heat treatment of metallic materials; recognise the need for the non equilibrium structures and suggests an application where these non equilibrium processed alloys can be employed; recognise the non equilibrium microstructures of alloys using optical or electron microscopy images.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. W. Balluffi, S. M. Allen, W. C. Carter, Kinetics of Materials, Wiley-VCH Verlag GmbH & Co, 2005

6. Additional notes

Topics 13

1. The subject of the lecture

MARTENSITIC REACTIONS

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

This topic aims to provide a detailed summary of the phase transformations in general happening in metallic materials as a reminder to the students and then students will be given a broad definition of martensitic reactions or transformations apparent for their mechanical inducement similar to twinning due to thermal shock assisted with atomic plane deformation as a follow up topic from non equilibrium processing. The topic will also include definitions of displacive and non displacive phase transformations as will be given in the first part of the lecture in summary, elaborating their role in the explaining the mechanical element in such transformations i.e. it is also called the invariant plane strain element of transformation; some research on these transformations will be exercised within the classroom and a discussion will be ignited on the practical use of martensitic transformations, too. Following the introduction of martensitic transformation in carbon containing iron alloys e.g. steels and iron alloys without carbon e.g. FeNi alloy, students will be given examples of martensite morphology in these alloys. Students will also be able to recognise martensitic microstructure in both alloys using optical microscope images. It is important transformation product for a metallurgist or materials engineer to obtain a hard layer which is useful against the wear occurring in machine parts etc… Martensitic transformations are discontinuous transformations that are diffusionless and displacive and occur by the forward glissile motion of the interface between the growing martensite and its parent phase. The theory of the crystallography of these transformations is to be presented by employing either a pole figure description or a deformation-tensor formulation. Topics will include the prediction of the crystal orientation relationship between the martensite and parent phase, the habit plane of the martensite in the parent phase, and the macroscopic specimen shape change due to the transformation. The nucleation of martensite prior to the introduction of habit plane and glissile interface will help to understand the interface behaviour. The glissile nature of the martensite / parent phase interface is explained in terms of a coherency anticoherency dislocation model. The nucleation of martensite is also considered and found to be heterogeneous in nature. Finally, martensitic transformations in three widely contrasting systems are described to illustrate the wide range of phenomena that can occur. Martensitic phase transformation is similar in a number of respects to mechanical twinning. Both processes are displacive because they occur by the local transfer of atoms across an advancing interface by a highly organized "military" shuffling of atoms across the interface at conservatively moving dislocations. In both cases, this induces a macroscopic shape change of the specimen. Both processes are conservative; no long range diffusion is involved, and the martensite and its parent phase must therefore be of the same chemical composition. At the end of this topic, students are to be requested to write an essay on the development of martensitic reactions in steels such as high alloy and low alloy steels as well as other alloys that do not contain carbon.

3.	**Learning outcomes**

Students can explain how phase transformations happen in a metallic material in a slow cooling medium as oppose to the fast cooling medium where displacive transformations occur; explain definitions of displacive, non displacive transformations and also realize the necessity of martensitic transformations in commercial applications; explain on how martensitic reaction can be induced and progress in steels and make a connection with the formation of similar transformations in other materials, too.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

R. W. Balluffi, S. M. Allen, W. C. Carter, Kinetics of Materials, Wiley-VCH Verlag GmbH & Co, 2005

6.	**Additional notes**

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

THEORY OF WELDING AND JOINING TECHNIQUES FOR INDUSTRIAL MATERIALS

Code: TWJTIM

UNIVERSITY OF SILESIA IN KATOWICE
UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

WELDING, JOINING, WELDABILITY OF MATERIALS.

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

This topic aims to give students the subject overview of welding, joining and weldability concepts of materials that are used in industry, in addition, it also presents basic definitions and terms, and an overview of the importance of welding process related to conventional and non conventional joining of materials. The need for joining in industry is acute for many types of materials, e.g. plastic or superalloy or even ceramic matrix composites, due to the difficulty of producing of parts in bulk which comes with a reliability issue in joining and welding processes. The weldability of materials are affected by many factors such as joint design, the alloying element content of the materials being welded, the heat and cool cycle of the weld and base metal before and after the welding process and finally the type of electrode coating. Although, the weldability concept can be generalised for all techniques of welding, the every welding technique has its own weldability to do list, for example, arc welding is affected by the coating or the amount of alloying element in the weld metal whereas the resistance spot welding is more affected by the electrical resistance of materials being welded. The classification of welding and joining processes are also to be provided to students to memorize the fact that joining is an important tool in a metal processing and plastic industries for many types of materials and alloys with a specific use of applications. It is also important for students to recognise the types of joining with respect to materials type. The welding and joining processes should be well understood from the basics and its concepts in order to propose a correct welding procedures and joining processes with regards to conditions for which materials and alloys are changing in fast fashion. Therefore an atomistic approach to joining and welding processes would make students understand key points in joining and welding of engineering materials. With many materials and alloys being joined, there is difficulty in understanding what is joining and what is welding and hence we give the definition of weldability and joinability of materials which also classifies the official terms that are being uttered in literature and give a clear understanding of whole processes used in industries which are regulation driven due to the safety and health risks. The last part of the topic will involve a discussion regarding the variety of weld techniques and their applications as to how these techniques can be simplified in order to use them in joining of advanced alloys and materials.

3. Learning outcomes

The students can differentiate the welding processes with respect to materials; distinguish the welding and joining processes with their advantages and disadvantages; define a strategy on the weldability and joinability of materials and alloys that are frequently used in industry.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 2

1. The subject of the lecture

ARC, PLASMA AND REACTIONS WITH GASES

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

This topic introduced the basic concepts and overview for the least understood part of the arc welds e.g. the electrical discharge and plasma formation during high voltage and high current electron transfer including the effect of type of medium i.e. gases. The electric discharge occurs when the electron transfer barrier to corresponding pole or terminal is broken due to excessive accumulation of electrons on the side where electrons are received at a lightning speed, generating a heat by which the discharging electrode and receiving electrode is affected tremendously. The melting or remelting of electrodes is of practical concern to welders and designer to either prevent them from melting of to ease their melting when needed such as it is in the interest of welder to melt the electrode whereas resistance welder would require more tough metal or alloy to prevent the electrode melting. This topic also introduces the use of arc and therefore plasma formation in welding and heat dominated joining processes which are also explained through the Electric current and voltage drop across the plasma. The arc plasma formation is to be given in a slightly visual means and be explained how the heat formation changes with respect to arc voltage and arc current. As the formation of heat is produced in the plasma and heat flow is observed in the region where electrode and base metal then the heat transfer efficiency from the arc plasma to the weld zone becomes more complicated and methods in which the concentration of heat per area is increased is studied in short. The heat transfer over the weld zone will be detailed by giving examples of heat transfer within the arc plasma and base metal. One of the important processes in arc based joining processes and the most studied subject is the gas – metal reactions in the plasma and their effect on the weld metal composition. This is the utmost importance to weld metal composition design and has many factors regarding the prediction of weld metal, generally in most ferrous welds as they have the highest number of literature sources, both theoretically and experimentally. It is such that overall properties of weld metal such as mechanical properties, the percentage of weld metal microstructural composition and the hardness by which failure of weld metal is measured, is also affected by the composition of weld metal. In general, the arc, heat generation and plasma properties have a common effect on the outcome of the weld metal, that is, the melting of both electrode and just base metal form a weld pool and alloying.

3. Learning outcomes

Students can describe the difference in arc formation, plasma formation and heat distribution in plasma zone; understand the effect of heat formation on the base metal and electrode and the formation of weld pool due to this heat formation; correlate the arc plasma, heat input and composition changes of weld metal and also how weld pool is formed and sustained afterwards.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987.

6. Additional notes

Topics 3

1. The subject of the lecture

ARC WELDING OF METALLIC MATERIALS

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

This topic aims to give an advanced understanding of fusion weld metal formation with the effect of heat generated by the effect of arc plasma. The arc plasma will be defined by the elements of electrical discharge and the properties of arc plasma will be detailed using graphical presentation. The role of arc plasma in welding process will be elaborated on droplet transfer characteristics of the molten electrode with respect to the variations in parameters such as weld current and weld voltage. This metal transfer characteristic affects the deposition rate and weld pool shape, giving either convex or concave appearance based on the junction type or heat generated by the effect of current. This topic will also elaborate the principles of the solidification of weld pool with respect to well known principles in place with theoretical and practical background information. The students will be provided with information about the sympathetic solidification in weld metals that differs compared to the castings as the heat and cool cycle is affected more drastically due to the size of the weld pool. It is imperative to assume the fact that heat distribution in and around the weld pool strongly affects the formation distinctive subzones around a fusion weld zone varying with respect to type of metals and alloys. That is, the arc generation and its effect on the base metal is also the most important part of the weld region as it determines how the base metal is affected. The students are to be requested to write an essay on the heat affected zones in different metals and steels with different alloying content such as varying carbon content and alloying content etc… The physical i.e. shape and other intrinsic properties of metals and alloys i.e. heat conductivity are prime factors in zone formation behaviour such that heat transfer efficiency under predetermined conditions establishes the fact that how wide the subzones will be formed or if any are to be formed as a result of heat flow from the weld pool towards the base metal. The fusion zone is formed due to the effect of heat but the alloying in weld pool is an inevitable process as the mixing of electrode material and base metal are observed; even though the base metal is the only metal melting i.e. adiabatic process, the composition of weld pool differs from the prior to welding which also eventually make difference in solidification of a weld metal and more effectively solid phase separation process is affected by different diffusion and solubility of components, that is, macroscopic aspects of weld metal solidification is also affected. The process parameters of arc welding such as the effect of travel speed and temperature gradient i.e. heat input concepts are also given to students to make that correlate between microscopic aspects of weld metal solidification, HAZs and, the recystallization and grain growth in heat affected zone.

3. Learning outcomes

Students can explain how the subzones in heat affected zone are formed the heat transfer mechanism in weld zone through arc plasma and weld pool; explain weld pool solidification and analyse via well known solidification principles; evaluate the differences in microstructural changes in all heat affected subzones in the light of well known weld parameters such as heat input (travel speed, weld current and weld voltage) and physical parameters of base metal.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987.

6. Additional notes

Topics 4

1. The subject of the lecture

ARC WELDING: ELECTRODE, CARBON ARC & SUBMERGED ARC WELDING

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

This topic will initially introduce the basics of arc welding processes in graphical presentation and their known classification, specifically, stick electrode welding, carbon arc welding and submerged arc welding processes. Carbon arc and stick electrode arc welding or otherwise known as shielded metal arc welding methods are considered to be the basic methods and the submerged arc welding is known as slightly advanced form of these welding methods, respectively. The first arc welding is unintentionally employed first by Volta and then he applied this remelting to other metals and alloys, for example, to melt the copper wires with and without remelting filling materials to form a proper weld pool. Students are expected to learn how these welding methods including carbon arc and shielded metal arc welding are developed over the years with a reference to the years, persons and companies along with historical timetable. Similarly, the historical development of submerged arc welding is also to be given to students in a similar way and they are expected to learn their disadvantages and advantages and field of use. The submerged arc welding is still in use as is shielded metal arc welding however the limitations such as its inability to be used with robots or lack of automation are the main limitations. It is also important to present to students what the main parameters of carbon arc welding and submerged arc welding methods are and also why these methods of joining, especially, submerged arc welding process are considered for heavy industrial applications such as welding of thick sectioned steel parts and petrol pipe welding. The theoretical background of three welding operations in addition to operational principles are to be given to the students in a simplified way and their types for general and specific applications are to be given in less detail as they are not as common as some inert gas welding methods. Consumables for submerged arc welding is rather straight forward but carbon arc welding is used primarily for steel welds, as it is less common may be absolute for many applications of industry. A comparative cross table for the three methods of welding and their consumables with respect to each method welding is intended to be given prior to lecture to the students. The most important aspects of these weld methods are their mechanical and physical properties; although there is plenty of resources and study on submerged arc welding method but the literature study on carbon arc welding is both limited in terms of material to which the method is applied and also results are rather old and unrepeated. Within the context of lecture, defect formation in these weld methods and suggestions for the repair or prevention are to be provided to the students, too.

3. Learning outcomes

Students can distinguish between the carbon arc welding and submerged arc welding with respect to their operating principles and the field of use in industry; differentiate between the arc formations in carbon arc welding which resembles to TIG welding, and submerged arc welding, which is the most efficient welding method available in terms of energy efficiency; explain formations and their properties will be also be analyzed by the students with respect to common weld metals such as metal inert gas welding etc..

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley Interscience publications, John Wiley and Sons, Newyork, 1987.

6. Additional notes

Topics 5

1. The subject of the lecture

ARC WELDING: GMAW, TIG AND PLASMA ARC WELDING

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

This lecture begins with the brief definition of Gas Metal Arc Welding, Tungsten Inert Gas welding and plasma arc welding methods. Students are expected to learn how these welding methods of Gas Metal Arc Welding, TIG and plasma arc welding are developed over the years with a reference to the years, persons and companies along with historical timetable. The difference between these three welding methods is in general lies in the melting of filler metal i.e. GMAW which is gas metal arc welding is also known as inert gas welding. Tungsten inert gas welding and plasma welding methods are used without filler metal feeding to the weld zone and but the heat is generated at the tip of the tungsten rod, therefore, the weld pool formation and resulting solidification and heat flow efficacy in and around the arc plasma and on the base metal are different to those having the filler wire melting into arc zone on the base metal to form a weld pool. This issue will be elaborated in the classroom with the students. The lecture also provides a detailed historical development on all methods starting from the need of industry and defence industries. The theoretical background and parametric principles of three methods are to be given to students by referring to their operational principles, which are in general dissimilar in terms of power source and accessories but being the most efficient and common welding methods in industry of any size. This lecture will also provide an insight on the consumables that all three methods of joining use for effective joining process. The similarity between TIG and plasma welding is relatively striking as both uses a heat generating tungsten electrode but differs in the gas medium of which plasma also uses argon for welding and a special gas to generate higher arc temperature whereas the gas in TIG is more to protect the weld pool from oxidation and harmful effect of air. A comparative cross table will be given to the students to revive the three welding methods in terms of their most effective properties and general use principles. Students are expected to learn and analyse the difference between the mechanical and physical properties of welded joints produced from these three welding methods, which present a great deal of variations in term of solidification and microstructural development due to the difference in filler metal inclusion, heat input and heat generation. The students will also be able to learn how defects form in the weld pools of these three welding methods and possible suggestions for the remedy of such defects along the welding and after welding operations.

3. Learning outcomes

Students can analyse the important operating parameters of GMAW, TIG and plasma arc welding methods with a possible physical and mechanical property outcome of each weld metals; select methods of welding with regard to their general specifications and as opposed to the welding conditions; differentiate between the microstructures of weld metals and HAZs and explain the properties of each zone in a standard weld metal.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 6

1. The subject of the lecture

NON ARC JOINING TECHNIQUES AND PRINCIPLES: HIGH ENERGY BEAM WELDING

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

This topic aims to introduce the principles of non arc welding techniques that use high energy beam welding and welding methods that are emanating from introduction of high energy waves produced using non conventional techniques apart from resistance heating, arc heating and ultrasonic heating etc... A short introduction on the heating principle of high energy beams will also be explained to the students. A brief definition of high energy beam joining methods are to be given to the students with an additional improvisation on how these welding methods have emerged rather recently from the invention to application i.e. development background of how high energy welding methods are developed over the years with a reference to the years, persons and companies along with historical timetable. The theoretical background of joining by these methods are to be explained in detail by using both verbal and visual aids and parametric principles that controls the weld metal formation and practical applications are also to be introduced to the students. The operational principles of high energy beam welding methods are particularly different than those of arc heated or resistance heated methods, in which no contact or contactless heating introduces new challenges and advantages, which will be introduced to the students during the course of the lecture. The heating without the help of arc source may be less efficient in terms of heat loss, but, the focused heat source requires the heat beam to be accurately right on the joint to melt both sides of the base metals and hence an adequate alignment should be maintained with specimens in order to produce a sufficient amount of weld pool. This topic will also introduce the main types and classifications of these welding methods, consumables and comparative cross table information will be given as usual and as much as the literature allows. The important aspect of these welding methods are that they are deemed to be a perfect solution for many problems that arc heated and resistance heated welding methods present and hence better performance of mechanical and physical properties of joints are expected, however, this will be dependent on many parameters such as weld advancement rate, the powder density per area, focused beam size and also the type of base metal being welded. The mechanical and microstructural properties of high energy beam welds, namely laser and electron beam welds, will be compared to the the ones obtained from conventional welding methods of shielded metal arc welding, gas metal arc welding, submerged arc welding and also tungsten inert gas welding. Students will be able to analyse the outcomes in this topic with extensive examples from the industry. This topic will also be introducing defect formations in these high energy welds and suggestions for solution during and after the welding operation will be given in detail with industrial examples.

3. Learning outcomes

Students can select methods as to which high energy method is suitable for the type of material or alloy being welded; can predict expected results and determine pre-weld preparations and operation parameters selections and make a comparative analysis by critically commenting on mechanical, physical and other properties of high energy beam welds.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 7

1. The subject of the lecture

SOLID STATE WELDING: DIFFUSION BONDING

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

This topic is aimed to give detailed information about a joining process called diffusion welding or bonding. Diffusion bonding or diffusion welding is named after a process that requires the movements of atoms in materials where at least one of the parts has fully or partially metallic bonding character as it requires the free movement of atoms from opposing ends. Diffusion bonding is the only method of joining of vast majority of metallic and non metallic material range, which are presumed to be non joinable by classical, conventional or even non conventional methods of joining. As given in the previous lecture topic, high energy beam weld types, relatively new joining techniques are also reliable in joining some of the dissimilar metallic materials but this method of joining is only one that is considered to be conventional and yet capable of joining dissimilar materials without many drawbacks. The lecture topic will proceed with the basics of non arc welding solid state welding i.e. diffusion processes within the metallic systems and definition of weldability concept in diffusion bonding as oppose to conventional welding processes. This lecture will also continue with the theoretical background in addition to parametric and operational principles which are defined as temperature, holding time and holding pressure as well as material properties such as diffusion coefficients, solubility and also physical properties such as surface roughness of opposing faces of the parts being welded. The students will be introduced to the concept of diffusion bonding processes which have advanced through the years with special applications, that is, transient liquid phase bonding of metals and alloys in which a eutectic making phase is intentionally formed between the opposing faces or an interlayer placed between two opposing faces of the parts being joined. A comparative cross table showing possible matches of materials that can be joined using diffusion bonding will be given separately following the concept of diffusion bonding and its parameters. Students will be indulged into discussion how this type of joining technique is different to the ones that have been mentioned in previous lecture topics. There will be a section where generalised mechanical properties will be compared to other types of arc and non arc welding weld metals in terms of mechanical and microstructural properties. A discussion will also be induced to propose a solution to how one can fast cool and harden the parts being welded just after the diffusion bonding. Diffusion bonded joints have relatively unique mechanical and physical properties compared to other welding techniques or methods, which is due to the fact that atomic diffusion make them stronger with minimal defect formation which is a topic which will also be elaborated at the end of the course using experimental studies.

3. Learning outcomes

Students can differentiate the different types of diffusion bonding processes i.e. transient liquid phase and classical diffusional exchange driven process; analyse weld properties and their physical outcomes with respect to conventional joining methods; analyse the materials pairs and also suggest a possible matching material to join without fail and minimum defect formation; if exist; propose a proper solutions to correct the process.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 8

1. The subject of the lecture

SOLID STATE WELDING: ULTRASONIC, FRICTION AND COLD WELDING

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

This lecture aims to introduce three important solid state welding methods that are used for joining dissimilar and similar materials used in industry which spans from the plastics to metals and gold wires to the integrated circuit connections. Initially, students are to be given brief introduction to the definitions of joining methods and their general working principles and later on, with information regarding how these methods of joining affect the mainstream industry. Mainstream industrial joining applications and these types of solid state joining techniques will be a subject to discuss with students to relate them the size of the parts, thickness and also ease of joining when compared to other joining methods so far has been mentioned to date. A historical development is to be mentioned as background of how ultrasonic, friction and cold welding methods are developed over the years with a reference to the years, persons and companies along with historical timetable. in addition to theoretical background of the processes as to make them clear about their working principles. Ultrasonic, friction and cold welding processes are primarily different in the working principles, however, parametric and operational principles such as frequency, horn shape and mass and welding pressure for ultrasonic welding and rotation speed and weld pressure for friction welding and also pressure for cold welding. In ultrasonic welding, high-frequency mechanical vibrations are transferred to the parts to be joined, which cause sliding one part over another, producing heat to join the thin sections on which the pressure is applied. Friction welding uses the heat that is generated during the action of friction between the opposing faces and this heat is used to soften and compression force is applied to finish off the joining. As per cold welding, the heat is produced in a fraction of the time and then the deformation helps form the minimum atomic spacing between opposing atomic planes. As can be gathered, the atomic distance in all joining methods is adjusted by auxiliary force being active during the process. The comparative cross table for joining different materials and alloys etc.. will be provided in detail along with materials property e.g. thickness etc.. as they are important to the selecting the process for various applications. Ultrasonic welding is more common compared to other welding or joining methods however require an extensive equipment and electronic power whereas friction and cold welding are less complex and easier to control the parameters which would have a significant effect on mechanical and physical properties of joints. A comparison will also be made to analyse the related weld zone and hence microstructural outcome. Various suggestions are to be provided for the successful weld formation and reduce the defect formation in all weld types and weld zones.

3. Learning outcomes

Students can differentiate between operating principles of ultrasonic, friction and cold welding processes and also the materials that can be welded using these methods of joining; analyze the weld metal properties and compare them with conventional welds and non conventional methods of joining; propose proper solutions to correct the defects problems appearing during these welding processes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 9

1. The subject of the lecture

RESISTANCE WELDING: SPOT, PROJECTION AND FLASH WELDING

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

The lecture aims to give extensive information on the resistance spot welding process and its variations, which are one of the most employed welding methods of joining sheet metals in automotive industry. Resistance spot welding is relatively common compared to other types of resistance welding methods, however, projection and flash welding are more specialised and they will need different configuration of machines. A brief definition of spot welding is to be given at the beginning of the lecture and proceed with its types and uses in industry by giving real life examples from an industrial site producing automotive parts. The historical background for the resistance welding in general and spot, projection and flash welding in detail will be given to students in a chronological order and theoretical background on all three welding processes is to be thought with respect to the formation of welds and joints in general. The formation of weld pool and its solidification behaviour in these weld zones will also be introduced to students along with the heat affected zone occurring during the welding process, being different from spot welding, projection welding and flash welding require less time in forming, and therefore, should be considered differently as to what parameters are effective. Parameters of resistance welds are rather complicated as they are mostly reliant on the type of equipment and over the years many research has gone into the control of weld sequence and efficiency, therefore, a great deal of parameters such as ramping current and ramping time, holding time, pressure for welding and cooling stages, current and voltage variables with respect to the thickness of sheet metals and their contact resistances are the main parameters for achieving successful joints. On the other hand, both flash and projection welding processes have less number of parameters i.e. the compaction pressure during the heating and cooling period, ramping current and operation voltage. As it is different to spot welding, projection and flash welding machines usually have in built capacitors whose capacity and discharge current as well as discharge frequencies control the operational capacities of these methods and controlled by the Farad unit of the capacitor. Operational principles of all weld processes are to be given in a simplistic way in order to reinforce the basics of the processes. Consumables and comparative cross tables are necessary for students to understand the limits of the processes, hence to be provided to the students in addition to the mechanical and physical properties of welds and common defects and possible suggestions for remedy of such defects during the joining process and after the process is completed.

3. Learning outcomes

Students can differentiate between the different welding processes falling into the category of resistance welding; determine and comment on the type of materials to be welded and the type of joining process with respect to application will be analysed; analyze the weld joint properties and defects and propose proper solutions for the process parameters.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 10

1. The subject of the lecture

OTHER WELDING METHODS: GAS-FUEL AND THERMITE WELDING

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

The lecture aims to introduce a detailed overview of the gas fuel and thermite (exothermic) welding processes that are used for repair works and *in situ* rail joining and repair work, respectively. The gas fuel constitutes for many flammable substances such as propane, acetylene and vaporized gasoline fuel including hydrogen which has lower heat of formation / dissociation but very efficient under water applications. The most effective fuel is acetylene which produces sufficiently high heat at the tip of burner to melt big chunk of steel. A brief definition of gas fuel and exothermic thermite welding methods will proceed with historical background of the processes and variations of applications up to date. The gas constitutes oxidising gas e.g. oxygen, is the only option, however, the burning of fuel needs more oxygen than supplied and hence the oxygen in air is used during flame burning. The fuel efficiency matters when high melting point metallic materials such as steel are being welded. The fuel to oxidiser ratio is maximised to generate enough heat when welding high strength or alloyed steels, called rich mixture, whereas the fuel to oxidiser ratio is maximised when cutting steels, which is called poor mixture. The theoretical background is slightly different in both gas fuel and thermite welding in which a pyretic effect of aluminium is used to generate heat for joining the rails as opposed to fuel burning reactions and hence the generated heat is used for joining many metals and alloys. Parametric studies are as a matter of fact not well studied as the resources for the processes especially for the gas welding are not updated or old; however, the grain size of aluminium and the content of iron oxides and other compounds are effective in burning speed and alloying of cast region, whereas, gas fuel welding is solely dependent on the fuel to oxygen ratio which determines the amount of heat generation and combustion products of the flame. The weld metal and heat affected zone formations and microstructures in both methods are different due the effect of oxygen in combustion gas or in the reaction chamber during pyretic process, making mechanical properties of these welds poorer than other type of welds such as shielded metal arc welding. Heat affected zones are generally larger than those of shielded metal arc welding etc… The operational principles for both processes are to be given with use of practical applications; types of processes are also aimed to be given to the students in addition to consumables that are used for the joining of materials with comparative cross table. The mechanical and physical properties of joints are to be given comparatively with conventional mainstream welding processes with a view of defect formations and suggestions for the remedy of the each problem.

3. Learning outcomes

Students can differentiate the process in terms of their operating principles and the applications fields; analyze the weld properties with respect to the type of process and weld defects; propose proper solutions to correct the defect formation process in aforementioned weld methods.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 11

1. The subject of the lecture

ADHESIVES AND ADHESIVE BONDING

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

This lecture topic aims to introduce a general view of adhesives and adhesive bonding processes in the initial stage and proceeds with the operational principles and controlling properties of joints such as the mechanical properties e.g. tensile strength, shear strength, detaching capacity, cleavage deformation and peeling properties. A brief definition of adhesives and their comparative table for types and adhesive bonding applications are to be given at the beginning of the lecture. The adhesive types are plenty in number and there are thousands of adhesives that are being used in industry and household appliances with different purposes. The adhesives employed in industry are generally required to perform at high tensile forces and solidify or crystallise in a relatively short time in order to reduce the cost of labour during the montage stage of cars of machine parts. The adhesives used in industry should be stronger than common ones and also more resistant to heat, water, water vapour, acids and bases and well known solvent liquids that are harmful to glued joints during service. Some joints require single component glues whereas the industrial types of adhesives are usually two part adhesives and require a curing period of minutes before it is fixed. The historical background of adhesives is an important subject as it helps to understand the field applications, as it is a very old process, used for buildings and fine works for jewellery etc… The theoretical background of adhesives and adhesive bonding of materials is to be given with a perspective from the application point of view, beginning from the historical examples such as the use of early adhesives in buildings, historical artefacts and planes used in WWI. Parametric principles of adhesives are rather complicated as there is vast amount of information due their extensive use in industry spanning from the automotive industry to high temperature sealing and adhesive and surface protection applications etc… Operational principles of adhesives are strictly determined by the manufacturers due their chemical nature and surface properties of substrate materials affecting their proposed strength, sealing and absorption on the surface. Surface roughness, preparation technique of surfaces prior to application of adhesives, environmental effects such as rain, moisture, exposure to high temperature gas or liquid etc.., application temperature and pressure in addition to holding time are the main parameters for a good and successful joint formation. The types and forms of adhesive bonding are also to be introduced to the students. Consumables along with adhesives and comparative cross table for the variety of application with regards to the type of adhesives are to be given in detail with mechanical and physical properties of joints. There will be a section regarding the formation of defects and suggestions for the remedy of the problem.

3. Learning outcomes

Students can differentiate the different types of adhesives and their prime field of application, in addition their individual uses with respect to the environmental service conditions; analyze the adhesive joints from the perspective of types and outcomes with the help of mechanical and physical properties of the joints in question; explain the criteria of successful adhesive joints and also formation of defects in order to propose proper solutions to correct the adhesive joining process.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

Topics 12

1. The subject of the lecture

SOLDERING AND BRAZING

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

This lecture topic aims to introduce the basics of soldering and brazing processes by initially introducing the surface to solder interactions and also aims to present advanced properties of soldered joints by referring to mechanisms of soldering on a viable substrate. Soldering and brazing processes are commonly used for the joining of thin metallic parts and electronic components which are part of electronic circuitry, but brazing has wider applications such as the joining of carbide tips to the cutting disks and strips, coolant pipes to itself and to the body of chassis and also inserts to the cutting tool base etc… The lecture also aims to give a historical background with a theoretical background on both soldering and brazing processes, which will also make the students comprehend both processes in a broader view especially in industrial perspective. The parametric principles of the processes are to be given in detail and are few in number and mostly dependent on the solder and substrate matching in general, however, other parameters include substrate type, solder type, soldering temperature, surface contaminants as well as reactivity of substrate and solder to form intermetallics. The use of solders in particular received a special interest in last decade because of their lead content which will be mentioned during the course of lecture regarding the historical development and solutions to this issue and their replacement solders and their classifications will also be given in the lecture based on the literature and practical examples. The quality of solder or braze joints are greatly controlled by the formation of certain compounds on the surface during the soldering processes whereas brazing requires a formation of high temperature resistant compounds and diffusion of some alloying elements to the opposing surface. Intermetallics play a great role in controlling the strength of solder or braze joints; as the solder layer on the surface or between the opposing faces thickens the joint becomes more brittle and various defects such as voids, are formed easily during the soldering operation. The soldering temperature will also cause similar problems. Operational principles are to be given on the basis of soldering and brazing preparations and related content The types of solders and brazes and their consumables that are used for surface cleaning or surface energy modification of solders and brazes such as fluxes and pastes are to be given together with comparative cross table arranged according to solder types. Mechanical and physical properties of solders, brazes and their joints will be specifically dealt with respect to their alloy content, microstructure and substrate type. Various defects formations will be discussed and viable suggestions will also be provided.

3. Learning outcomes

The students can differentiate the soldering and brazing processes with respect to their operating and joining temperatures and additionally offer the right process by taking type of substrate and temperatures of operations such as cutting or slicing etc...; analyze the joint properties in terms of substrate – solder/braze interactions based on previous research; explain the mechanisms of substrate-solder/braze wetting which are main outcomes of this lecture in addition to possible defects; propose proper solutions to correct the soldering / brazing defects.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

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6. Additional notes

- The topics will be covered in next week's lecture.

Topics 13

1. The subject of the lecture

JOINING METHODS FOR EXEMPLARY STRUCTURAL APPLICATIONS AND MATERIAL PROPERTIES

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

This lecture aims to provide a general perspective for joining of structural materials and alloys, lightweight alloys and materials, hybrid structures; reactive materials and alloys that are available for industrial applications. The first part of the lecture will deal with the introduction of potential industrial materials which are grouped into categories such as plastics, metals and alloys, composites and also structural materials. In this part, hybrid structures, lightweight materials or systems and reactive materials will be introduced in general. Following the introduction of materials, a brief description of joining methods will follow with a reference to their capacity to join number of materials and material systems. A potential joining method for any material in any shape would be suggested using a comparative table chart which will be provided to the students. In addition, a small reminder of methods and their limitations are also to be given with respect to their applications within the industry and specific field of use in order to strengthen the knowledge on the wider use and correlate the joining methods and their success and failures with respect to their operational and parametric principles in place. In order to correlate the defects and their mechanism in relation to successful joints and also their effect on the physical and mechanical properties with a special relation to the type of materials will also be provided with up to date literature information. In last part of the lecture, examples of uses of joining methods will be given from the practical and general application in industry point of view.

3. Learning outcomes

The students can differentiate between the different joining methods and their possible use in joining of materials with respect to the type of materials; analyze the successful and failed joining processes by using the comparative table; propose proper solutions to correct the defects with reference to mechanisms given thereof.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

Kou, Sindo, Welding metallurgy, Wiley interscience publications, John Wiley and Sons, Newyork, 1987

6. Additional notes

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Content Preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

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

NUMERICAL SIMULATIONS FOR METAL PROCESSING

Code: NSMP

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO FORMING AND PROCESSING OF METALS

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

Forming and processing metals are fundamental aspects of manufacturing, involving various techniques to convert raw metal into usable forms. Metal forming involves shaping materials into desired geometries while maintaining their integrity, strength, and other essential properties. This process encompasses a wide range of activities, from the initial production of metal in foundries to its final shaping in manufacturing industries. Metal production typically involves extracting raw material from ores, refining it, and casting it into basic shapes like ingots, billets, or slabs. These primary forms are then processed further to produce industrially feasible shapes like sheets, rods, tubes, and profiles, which form the basis for further manufacturing. Numerous forming and shaping processes for metals are broadly categorized into bulk forming and sheet forming. Bulk-forming includes processes like forging, extrusion, and rolling, where large volumes of metal are deformed to create shapes like beams, rails, and other structural components. On the other hand, sheet forming involves operations like bending, deep drawing, and stamping, primarily used for making thinner, flat products such as automotive panels, appliance housings, and aircraft skins. Each process can be performed at various temperatures – cold, warm, or hot – depending on the metal's properties and the desired outcome. Understanding the mechanical properties of metals is crucial in forming processes. Properties such as ductility, malleability, strength, and hardness dictate how a metal can be formed. Ductile materials, like aluminum and copper, can withstand extensive deformation without fracturing, making them suitable for processes like deep drawing and extrusion. Harder materials, like steel, require more force to shape but result in stronger end-products. The relationship between mechanical properties and forming methods is a key consideration in manufacturing, as it influences the selection of suitable materials and processes for specific applications. Modeling and simulation play significant roles in metal forming and processing. Computational methods, such as finite element analysis (FEA), predict how metals behave under various forming conditions. These models help optimize process parameters, reduce trial and error, and minimize waste. Simulations can forecast issues like stress concentrations, the potential for cracking, and final part geometry, aiding in designing tools and dies for efficient and effective manufacturing.

The modern metal forming industry has evolved to include advanced technologies such as additive manufacturing (3D printing) and laser forming. These technologies allow for the creation of complex shapes and structures that were previously impossible or too costly to produce using traditional methods. They offer greater design flexibility, reduced material waste, and the ability to produce customized parts rapidly. In summary, the forming and processing of metals encompass a broad range of techniques and principles, each contributing to transforming raw metal into functional parts and products for various industrial applications.

3. Learning outcomes

Students can explain the basic steps in metal forming, from raw material extraction and refining to casting into primary shapes like ingots and billets; identify various forming techniques such as bulk forming (forging, extrusion, rolling) and sheet forming (bending, deep drawing, stamping) and their applications in producing different industrial shapes; acquire knowledge about how the mechanical properties of metals influence their suitability for different forming processes; explain the importance of computational methods, such as finite element analysis, in predicting metal behavior during forming and optimizing manufacturing processes; recognize the evolution of metal forming and additive manufacturing and laser forming, offering increased design flexibility and efficiency.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 2

1. The subject of the lecture

MECHANICAL PRINCIPLES OF FORMING AND SHAPING

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

Forming and shaping metallic materials are key production processes that involve the deformation of metals into desired forms and sizes while maintaining material qualities. These operations are governed by several mechanical laws, determining the effectiveness and efficiency of the shaping methods employed.

Plastic deformation is the primary mechanical principle in metal forming. Metals exhibit plasticity under certain conditions, allowing them to be permanently deformed without breaking. This property is used in forging, rolling, extrusion, and drawing. Forging is the process of shaping metal by hammering or pressing it into shape, using its ability to flow plastically under compressive stresses. Another important approach is rolling, which includes passing the metal through rollers to reduce its thickness or change its cross-sectional area. The metal's ability to undergo plastic deformation without fracture is critical in these processes. The amount of deformation a metal can withstand is determined by its ductility, which is governed by elements such as temperature, strain rate, and the original microstructure of the metal.

The second principle involves metal work hardening (or strain hardening). Dislocations within the crystalline structure of metals increase and intersect when plastically bent, making further deformation more difficult. This phenomenon increases the metal's strength and hardness at the expense of its ductility. Work hardening is essential in operations such as cold rolling, in which metal is formed at or near room temperature. Although the increased strength and hardness can be advantageous in some applications, the lower ductility may demand intermediary annealing operations to restore some of the material's elasticity. A fundamental challenge in designing metal forming procedures is the balance between hardening and preserving enough ductility for future processing. The third concept is the use of heat, sometimes known as hot working. Hot working is the process of shaping metals at temperatures higher than their recrystallization point. Metals become more ductile and require less force to deform at these high temperatures. This idea is used in hot rolling, hot forging, and hot extrusion. The advantage of hot working is that the metal's strength and hardness are lowered, allowing for more extensive deformations and intricate shapes. Hot working can also help to improve the grain structure of the metal, improving its mechanical qualities. However, careful temperature control is required to minimize problems such as oxidation or grain formation, which can have a negative impact on the final material qualities. To summarize, the mechanical principles of forming and shaping metallic materials are centered on the concepts of plastic deformation, work hardening, and hot working. Each of these concepts is important in establishing the manner and efficacy of the metal-forming process. Understanding and controlling these principles enables manufacturers to create metal products with desired shapes, sizes, and mechanical properties that may be used in various industrial applications.

3. Learning outcomes

Students can show how metals can be permanently deformed under specific conditions is vital for procedures like forging and rolling; explain how plastic deformation leads to increased strength and hardness as a result of work hardening and its impact on metal ductility; describe advantages of shaping metals at high temperatures, where reduced hardness facilitates deformation and can enhance grain structure; explain the capacity to balance strength, hardness, and ductility in metal forming, which is required for making products with appropriate mechanical qualities.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 3

1. The subject of the lecture

NUMERICAL ANALYSIS PRINCIPLES AND ANSYS

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

Numerical analysis is a branch of mathematics that deals with algorithms and methods for obtaining numerical solutions to mathematical problems. This field is particularly relevant in engineering and physical sciences, where precise models of real-world phenomena are required. The advent of computerized analysis has significantly enhanced the scope and accuracy of numerical analysis, enabling complex computations and simulations that were previously impractical or impossible. One of the most common techniques in numerical analysis is the Finite Element Method (FEM). FEM is a computational technique used to obtain approximate solutions to boundary value problems in engineering and physics. It subdivides a large problem into smaller, simpler parts called finite elements. The solutions to these simpler parts are then assembled to give a solution to the original problem. This method benefits structural analysis, heat transfer, fluid dynamics, and electromagnetic potential. Boundary element methods (BEM) are another crucial numerical technique. Unlike FEM, which subdivides the entire problem domain, BEM only requires discretization of the problem's boundary, making it more efficient in specific scenarios. BEM is particularly effective for problems involving unbounded domains, such as those encountered in acoustics and fluid flow around objects. ANSYS, a powerful and widely used engineering simulation software, integrates these numerical analysis principles. It provides tools for FEM and BEM, among others, making it a versatile choice for various engineering applications. ANSYS is used for simulating interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer, and electromagnetic for engineers. LISA is another software often recommended for beginners in numerical analysis and simulation. It is a lighter and more user-friendly option than ANSYS, but it has enough capabilities to perform serious engineering simulations. It also uses FEM and offers tools for structural, thermal, and fluid dynamics analysis. In ANSYS and LISA, simulations involve creating a model, defining material properties, applying loads and constraints, and then running the analysis. The software processes the input data using numerical methods and generates results that can be visualized and interpreted. Reporting in these software packages often includes graphical displays of stress, displacement, temperature fields, fluid flow patterns, and numerical data outputs. This comprehensive approach to simulation and analysis helps engineers and scientists predict real-world systems and components' real-world behaviors with high accuracy.

3. Learning outcomes

Students can explain the principles of numerical analysis, including its significance in solving complex mathematical problems in engineering and physical sciences and how computerized analysis enhances these capabilities; comment about the Finite Element Method (FEM) and Boundary Element Method (BEM), their methodologies, and applications; show how to perform simulations using ANSYS or LISA, interpret the results, and generate comprehensive report; present methods for visualizing and understanding outputs like stress distributions, displacement, temperature fields, and fluid flow patterns.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 4

1. The subject of the lecture

SHEET METAL FORMING AND SPRINGBACK PROBLEM

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

Sheet metal forming is a fundamental process in the manufacturing industry, used to create parts of various shapes and sizes from sheet metal. This process involves bending, stretching, and compressing the metal to achieve the desired shape. The formability of a metal sheet is determined by its ability to undergo plastic deformation without damage. Formability diagrams, which are graphical representations of the forming limits of metals, play a crucial role in this process. These diagrams help us understand how much a metal can be formed before it fractures or develops defects. They are essential in planning the forming process to ensure the integrity and quality of the final product. The forming principles involve techniques like deep drawing, bending, and stretching. Each of these methods has specific applications and is selected based on the desired shape and characteristics of the final product. For example, deep drawing is used for making cups or boxes, while bending is ideal for angles and channels. The choice of method also depends on the type of metal being used, its thickness, and its mechanical properties. The technology used in sheet metal forming has evolved significantly, with advanced machinery and tools enabling more precise and efficient operations. The use of numerical expressions in the form of mathematical models and simulations has enhanced the predictability and control of the forming processes. One of the significant challenges in sheet metal forming is the springback problem. Springback occurs when a metal tries to return to its original shape after being formed, leading to inaccuracies in the final product. This phenomenon is caused by the material's elastic recovery after forming forces are removed. The extent of springback varies depending on factors like material properties, sheet thickness, and the type of forming process used. Engineers often use over-bending techniques to address this issue and adjust tooling to compensate for the expected springback. Numerical methods and finite element analysis (FEA) software like DEFORM are crucial in predicting and analyzing springback. DEFORM, a powerful simulation tool, allows engineers to model the forming process and assess the likelihood of springback. This analysis enables the optimization of tool design and process parameters to minimize springback, ensuring the accuracy and quality of the final product. The application of such advanced software reduces trial and error in the manufacturing process and contributes to cost efficiency and improved product performance.

3. Learning outcomes

Students can describe various techniques like deep drawing, bending, and stretching, and how these methods are chosen based on metal properties, desired shapes, and product characteristics; interpret formability diagrams, which are critical in assessing the limits to which a metal can be formed and understanding the influence of material properties on the forming process; explain the springback phenomenon, its causes, and the strategies used to mitigate it, such as over-bending and tooling adjustments; explain the use of numerical expressions, mathematical models, and simulation tools like DEFORM for predicting and analyzing springback, thereby enhancing process planning and product quality.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 5

1. The subject of the lecture

ROLLING, FORGING AND EXTRUSION PROCESSES

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

Rolling, forging, and extrusion are fundamental metal-forming processes in manufacturing, each distinguished by its methodology, applications, and the type of products it produces. Rolling is a metalworking process in which metal stock is passed through one or more pairs of rolls to reduce thickness, make the thickness uniform, and/or impart a desired mechanical property. It is one of the most widely used forming processes and provides high production and close control of the final product. Forging, on the other hand, involves shaping metal using localized compressive forces. The blows are delivered with a hammer (often a power hammer) or a die. Forging is usually classified according to the temperature at which it is performed: cold forging, warm forging, or hot forging. Finally, extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or drawn through a die of the desired cross-section. The two main advantages of this process over other manufacturing processes are its ability to create complex cross-sections and work with brittle materials because the material only encounters compressive and shear stresses.

The mechanical expressions for these processes are derived from fundamental principles of material science and mechanical engineering. In rolling, the primary variables are the roll force and torque, which are influenced by factors such as the geometry of the rolls, the friction condition at the roll-material interface, and the material's properties. The deformation of the material can be modeled using the laws of plasticity and elasticity. Forging, meanwhile, relies on understanding the flow stress of a material, which is the stress required to deform it plastically. This stress varies with temperature, strain rate, and the extent of deformation. In extrusion, the critical mechanical expression involves calculating the extrusion force, which depends on the material's flow stress, the geometry of the die, the extrusion speed, and the lubrication conditions. In both rolling and extrusion, the process can be modeled using finite element analysis (FEA), which allows the prediction of the flow of material and the final geometry of the product.

Modeling these processes, mainly rolling and extrusion, is crucial for optimizing production, ensuring quality, and reducing costs. In rolling, models are used to predict roll forces and torques, temperature distribution throughout the rolling process, microstructural evolution, and final mechanical properties of the rolled product. In extrusion, modeling helps in designing die profiles, predicting the flow of material through the die, and assessing the quality of the extruded product, such as its surface finish and dimensional accuracy. Modern modeling techniques often use advanced simulation software that incorporates thermomechanical considerations, material behavior models, and the dynamics of the machinery involved. These simulations allow manufacturers to experiment virtually with different process parameters and conditions before implementing them in actual production, thus saving time and resources in developing efficient and effective manufacturing processes.

3. Learning outcomes

Students can elaborate on rolling, forging, and extrusion definitions and methodologies. Understand how rolling reduces metal thickness, forging shapes metal using compressive forces, and extrusion creates objects with fixed cross-sectional profiles; explain the mechanical principles underlying these processes, including calculating roll force and torque in rolling, flow stress in forging, and extrusion force in extrusion and comprehend how material properties, geometrical factors, and process conditions influence these factors; describe how rolling and extrusion processes can be modeled using finite element analysis.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 6

1. The subject of the lecture

CUTTING PROCESS

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

The cutting process of metals is a fundamental aspect of manufacturing and engineering, involving various techniques and principles to achieve desired shapes and finishes. The concept of shear force and stress is at the core of metal cutting. The shear force causes layers or parts of a material to slide past each other in opposite directions, while shear stress is the internal resistance to this sliding. Tools with a hard, sharp cutting edge remove material from the workpiece through shear deformation in mechanical cutting, such as milling or turning. The magnitude of shear force and stress involved in the process depends on the material properties of both the tool and the workpiece, as well as the cutting speed, feed rate, and depth of cut. These parameters need to be precisely controlled to optimize the cutting process, minimize tool wear, and ensure the quality of the finished product. Besides traditional mechanical cutting, advanced methods like laser and water jet cutting are also widely used in the industry. Laser cutting employs a high-powered laser beam focused onto the metal surface to melt, burn, vaporize, or blow away the material with a jet of gas, leaving an edge with a high-quality surface finish. This process is highly precise and can make intricate cuts and fine details. On the other hand, water jet cutting uses a high-pressure jet of water, sometimes mixed with an abrasive material, to cut through metal. This method is renowned for its ability to cut without influencing the material's inherent structure, as it does not generate heat. Both laser and water jet cutting are versatile, can handle various materials and thicknesses, and are used in applications where precision and material integrity are paramount. Blade cutting is another significant aspect of the metal cutting process, involving principles such as the hardness of the blade material, edge geometry, and the mechanics of the cutting action. The effectiveness of a cutting blade depends on its hardness, which is typically achieved through processes like tempering and material selection, such as high-carbon steels or carbides. The blade's geometry, angle, and sharpness are crucial for efficient cutting. Mathematical blade-cutting expressions often relate to calculating the required force and stress for a given material thickness and angle. Modeling of blade cutting is an advanced field that uses computational methods to predict and optimize the cutting process. This involves simulating the interaction between the blade and the metal, understanding the stress distributions and deformation patterns, and assessing wear and tear on the blade. Such models are invaluable for designing blades for specific applications, improving cutting efficiency, and extending the life of cutting tools. In essence, the cutting process of metals is a complex interplay of material science, mechanical principles, and technological advancements, each contributing to the precision and efficiency of modern manufacturing.

3. Learning outcomes

Students can explain the fundamental concepts of shear force and stress and their significance in mechanical cutting processes such as milling or turning. Learn how these forces interact during cutting and influence the material removal from the workpiece; describe advanced metal cutting methods like laser and water jet; show how these techniques differ from traditional mechanical cutting, focusing on their precision, ability to maintain material integrity, and suitability for intricate cuts and complex designs; acquire knowledge about the principles of blade cutting, including the importance of blade hardness, achieved through material selection and tempering, and the role of blade geometry in effective cutting; elaborate how computational methods are used to model blade-cutting processes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 7

1. The subject of the lecture

SEMI SOLID METAL PROCESSING

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

Semi-solid metal processing (SSMP) represents a significant advancement in metalworking technology, offering a unique approach to shaping metals. Unlike conventional methods that work with metals in solid or liquid states, SSMP involves processing metals in a semi-solid state, where the metal exhibits both solid and fluid characteristics. This dual-phase nature is typically achieved by bringing the metal to a temperature where it partially melts. The metal forms a slurry-like mixture with solid particles and a liquid matrix at this point. The primary advantage of SSMP is the reduction in energy required for processing, as metals in a semi-solid state require less force for shaping. SSMP also allows for more precise control over the alloy's microstructure, improving mechanical properties such as strength and ductility. The process is especially beneficial for complex geometries and thin-walled parts, where traditional casting or forging methods may struggle. The range of alloys suitable for semi-solid processing is diverse, though certain properties make some alloys more amenable to this technique. Alloys used in SSMP generally need to have a wide range between solidus and liquidus temperatures, allowing a significant proportion of the metal to be in the semi-solid state at a given temperature. Aluminum alloys are particularly well-suited for SSMP due to their thermophysical properties, including a relatively low melting point and good fluidity in the semi-solid state. Magnesium and copper alloys are also commonly used, offering benefits like high strength-to-weight ratios and excellent electrical conductivity. The choice of alloy depends on the desired properties of the final product, such as weight, strength, corrosion resistance, and thermal conductivity. It's crucial for the alloy to maintain cohesiveness and flowability in the semi-solid state, as this ensures the material can be effectively shaped and solidified into the final product. In terms of properties, semi-solid processed metals generally exhibit superior qualities compared to those processed by conventional methods. The unique microstructure achieved through SSMP — characterized by globular, rather than dendritic, solid particles within the liquid matrix — results in better mechanical properties. These include increased ductility, improved resistance to fatigue and cracking, and enhanced overall strength. Additionally, the semi-solid state allows for a more uniform distribution of alloying elements, leading to more consistent material properties throughout the part. This uniformity also contributes to better surface finish and dimensional accuracy. The reduced porosity and fewer internal defects typical of SSMP products make them ideal for applications where structural integrity and reliability are paramount, such as in the aerospace, automotive, and electronics industries. In summary, semi-solid metal processing provides a more energy-efficient and versatile approach to metal forming and enhances the final product's quality and performance. Modeling of semi-solid metal processing involves simulating the behavior of metal alloys in their semi-solid state to predict flow characteristics and final microstructure. This typically uses computational methods like finite element analysis (FEA) to understand the

material's thermophysical properties, ensuring optimal process parameters for improved quality and efficiency in manufacturing.

3. Learning outcomes

Students can explain the unique characteristics of SSMP, where metals are processed in a semi-solid state, offering advantages in energy efficiency and precision in shaping complex geometries and thin-walled parts; describe the range of alloys ideal for SSMP, particularly those with a wide temperature range between solidus and liquidus, such as aluminum, magnesium, and copper alloys, and their respective advantages like strength-to-weight ratio and electrical conductivity; acquire an understanding of how SSMP leads to superior mechanical properties in metals, including increased ductility, improved fatigue resistance, uniform alloy distribution, and reduced porosity, making them suitable for critical applications in various industries; show how computational modeling, particularly finite element analysis, is crucial in optimizing semi-solid metal processing by predicting flow characteristics and microstructure, thereby enhancing the efficiency and quality of manufacturing processes.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 8

1. The subject of the lecture

WELDING AND MOLTEN METAL OPERATIONS

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

At its core, welding is a process of joining two or more materials, typically metals or thermoplastics, by causing coalescence. This is commonly achieved by melting the workpieces and adding a filler material to form a strong joint upon cooling. Among the array of welding methods, some of the most common include Gas Metal Arc Welding (GMAW or MIG), Gas Tungsten Arc Welding (GTAW or TIG), Shielded Metal Arc Welding (SMAW), and Flux-Cored Arc Welding (FCAW). Each method serves specific needs: MIG welding is known for its speed and adaptability, TIG for its precision, SMAW for its simplicity and portability, and FCAW for its effectiveness in outdoor applications. The choice of process depends on factors like the type of material, thickness, and the desired strength of the joint. Considering specialized welding techniques, spot and laser welding stand out for their unique applications. Spot welding, a type of resistance welding, is highly efficient in joining metal sheets, notably in the automotive industry for assembling vehicle bodies. This process involves applying pressure and heat generated from an electrical current to the area around the spot to be welded. Laser welding, on the other hand, uses a concentrated laser beam as a heat source. It's renowned for its high precision and control, making it ideal for delicate and intricate work, such as in the electronics and medical device industries. Laser welding's ability to focus energy on a small area results in minimal distortion and high-quality joints.

The evolution of welding has been significantly impacted by technological advancements, particularly in software and simulation. Software like SmartWeld plays a crucial role in modeling and simulating common welding operations. It allows engineers to visualize the welding process, assess the effects of various parameters, and make data-driven decisions to optimize the quality and efficiency of the welds. This reduces the need for trial-and-error in physical prototypes, saving time and resources. In metal casting, software tools such as Sucast and eFoundry are instrumental. They enable precise casting process modeling, helping predict how molten metal will behave when poured into molds. These tools can simulate the casting process, including mold filling, solidification, and cooling, and are invaluable in identifying potential issues like air entrapment or shrinkage. This level of simulation is crucial for ensuring the quality of cast components, which are integral in industries ranging from automotive to aerospace. Through these advanced software tools, welding and casting operations' precision, reliability, and efficiency have seen remarkable improvements, paving the way for more innovative and complex metalworking projects.

3. Learning outcomes

Students can describe various welding methods like MIG, TIG, SMAW, and FCAW, each tailored for specific materials and applications, highlighting their distinct advantages and suitability for different tasks; elaborate on the unique applications of spot welding in assembling vehicle bodies and laser welding's precision in intricate tasks, such as electronics and medical device manufacturing; recognize the role of software like SmartWeld in simulating and optimizing welding operations, enhancing the quality and efficiency of welds through data-driven analysis and reduced physical prototyping; show the application of software tools like Sucast and eFoundry in metal casting, enabling the precise simulation of mold filling, solidification, and identifying potential issues in the casting process.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

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

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 9

1. The subject of the lecture

ELECTROMAGNETIC AND EXPLOSIVE METAL FORMING

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

Electromagnetic and explosive metal forming are advanced manufacturing techniques that have significantly impacted industrial processes, particularly in sectors requiring precise and intricate shaping of metals. These methods are known for their efficiency and the ability to form complex shapes, which are often challenging to achieve through conventional mechanical forming methods.

Electromagnetic metal forming utilizes magnetic fields to shape metal workpieces. This process involves passing a high-voltage electric current through a coil to generate a rapidly changing magnetic field. The metal piece to be formed, usually an excellent electrical conductor like aluminum or copper, is placed within this magnetic field. The interaction between the magnetic field and the induced currents in the metal (known as eddy currents) creates powerful repulsive forces, which cause the metal to deform. One of the key advantages of this method is its ability to form metals without direct contact, reducing tool wear and the risk of contamination. The behavior of metals under magnetic force fields is complex. It depends on various factors like the metal's electrical conductivity, magnetic permeability, and the intensity and frequency of the magnetic field. In electromagnetic forming, metals exhibit different behaviors based on their properties. For instance, ferromagnetic materials like iron are strongly attracted to magnetic fields, while induced eddy currents influence non-magnetic materials like aluminum. Understanding these behaviors is crucial in designing effective electromagnetic forming processes, as they directly affect the efficiency and precision of the shaping process. Shaping metals under a magnetic field can be done with or without molding aids. When molding aids are used, they often take the form of dies or mandrels that help guide and constrain the deformation of the metal workpiece. This is particularly useful for achieving specific shapes or dimensions. The magnetic field interacts with the metal, pressing it against the molding aid, resulting in the desired form. Conversely, when no molding aids are used, the process relies solely on the magnetic field to shape the metal. This method, often called freeform electromagnetic forming, is highly versatile and can create complex, three-dimensional shapes. However, it requires precise magnetic field control and usually involves sophisticated computational models to predict and control the outcome. Explosive forming is another advanced technique where the force required to shape the metal is generated by a controlled explosion. This process is beneficial for forming large or thick metal plates and is widely used in the aerospace industry for manufacturing components like fuselage panels, wing skins, and engine components. An explosive charge is detonated in a fluid medium (like water) above the metal workpiece in explosive forming. The shockwave from the explosion travels through the medium and imparts a high velocity to the metal, causing it to deform and conform to the shape of the die underneath. One of the critical advantages of explosive forming is its ability to form large, complex shapes in a single operation, which is often not feasible with traditional mechanical forming methods. Moreover, the shock waves generated during the explosion can result in the work-hardening of the metal, potentially enhancing its mechanical properties. In aerospace applications, this technique is particularly valued for its ability to produce strong, lightweight components that can withstand extreme flight conditions.

3. Learning outcomes

Students can elaborate on electromagnetic metal forming, including how magnetic fields interact with different metals to shape them without direct contact, reduces tool wear and contamination risks; explain how metals behave under magnetic force fields, influenced by properties like electrical conductivity and magnetic permeability, is crucial for designing effective forming processes; explain shaping metals with and without molding aids in electromagnetic forming, highlighting the versatility and precision achievable in freeform and mold-assisted methods; elaborate on explosive forming principles, particularly its application in aerospace for forming large, complex metal parts, and its ability to enhance mechanical properties through shockwave-induced work-hardening.

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

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

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

Students are expected to read below texts related to the lecture:

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 10

1. The subject of the lecture

PARTICULATE MATERIAL FORMING

2. Thematic scope of the lecture (abstract, maximum 500 words)

Particulate material forming, encompassing a wide range of techniques, is a critical aspect of modern manufacturing, particularly in powder metallurgy. This process begins with manufacturing powders, which can be metals, ceramics, or composites. The properties of these powders, such as size, shape, and distribution, play a pivotal role in determining the characteristics of the final product. Smaller-sized powders generally provide a larger surface area, leading to better sinterability and denser products, while larger particles are often used for coarser structures. The powder production methods, like atomization, milling, and chemical reduction, significantly influence these properties. Powder metallurgy principles involve the compaction of these powdered materials into a desired shape, followed by heating (sintering) to bond the particles together. This process allows for the creating of complex shapes and unique material properties unattainable by traditional forging or casting methods. The compaction is often done under high pressure, sometimes in a high hydrostatic pressure environment, to achieve uniform density and minimize porosity. This pressure-based method is crucial for achieving high-strength and high-precision components, commonly used in aerospace, automotive, and medical industries. Sintering, an essential process in powder metallurgy, involves heating the compacted powder below its melting point to facilitate particle bonding. This process can be enhanced by various methods like laser and electron beam (EB) remelting. Laser remelting involves using a high-energy laser beam to selectively melt and fuse powder particles, allowing for controlled microstructure and enhanced mechanical properties. EB remelting utilizes a focused electron beam as the heat source, providing high precision and purity in the sintering process. Both methods offer improved control over the material's final properties, including its mechanical strength and wear resistance. High current passage sintering is another innovative method involving the passage of electric current through the compacted powder. This technique enables rapid sintering, often in seconds, and is particularly effective for materials with high electrical conductivity. The high current induces localized heating at the particle contacts, resulting in faster bonding and densification. This method is advantageous for producing materials with unique microstructures and properties, catering to specialized applications. The advent of 3D printing has revolutionized the formation of particulate material. Also known as additive manufacturing, it involves layer-by-layer construction of a product from powdered materials guided by digital models. 3D printing with powders encompasses techniques like selective laser sintering (SLS) and electron beam melting (EBM), providing unparalleled design flexibility and material efficiency. This technology has extensive applications in customizing medical implants, aerospace components, and intricate tooling. In essence, particulate material

forming, through its diverse processes and advancements like 3D printing, is crucial in modern manufacturing, offering tailored solutions with enhanced material properties.

3. Learning outcomes

Students can elaborate on the manufacturing of powders for particulate material forming, and how the size, shape, and distribution of these powders influence the characteristics and quality of the final product; describe the principles of powder metallurgy, including compaction and sintering processes, and the role of high hydrostatic pressure in achieving uniform density and high-strength components; acquire knowledge about enhanced sintering methods such as laser and EB remelting and high current passage sintering and their advantages in controlling microstructure and improving material properties; explain the application of 3D printing in particulate material forming, particularly its flexibility in creating complex shapes and efficiency in material usage, expanding the possibilities in various industrial applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 11

1. The subject of the lecture

FUNDAMENTALS OF METAL MACHINING AND TOOLS

2. Thematic scope of the lecture (abstract, maximum 500 words)

Metal machining is a critical process in the manufacturing industry, essential for shaping and finishing metal parts with high precision and accuracy. It encompasses various operations tailored to achieve specific shapes and surface finishes. Turning, one of the most common machining operations, involves a rotating workpiece cut by a stationary tool. This process produces cylindrical parts and can be performed on lathes. Parameters like cutting speed, feed rate, and depth of cut are crucial in turning, significantly affecting the part's surface finish and dimensional accuracy. Boring, closely related to turning, involves enlarging a hole or cavity made previously by another process. It's often done after drilling to achieve greater diameter and surface finish accuracy. Milling, another versatile machining operation, involves a rotating cutting tool moving against a stationary workpiece. This process produces various shapes and features on parts, such as slots, threads, and complex contours. Less common but still significant planning involves a straight or linear cutting motion with a single-point cutting tool. It's mainly used for producing flat surfaces and grooves on larger workpieces. The parameters of these operations are fundamental to their success. In turning, for example, the cutting speed must be carefully selected based on the material and desired outcome. A higher speed can lead to a better surface finish but might increase tool wear. Similarly, the feed rate must be balanced to achieve the required surface quality without inducing excessive tool wear or part deflection. Depth of cut also plays a critical role, as a deeper cut can remove material faster but requires more power and can cause more tool wear and vibration. The shape of the tool's tip is another critical factor in machining. Different tip shapes are used depending on the operation and the desired outcome. For example, sharp tips are used for fine, precision work, while rounded tips are better for roughing operations where more material needs to be removed quickly. The tool's material is equally important, with choices ranging from high-speed steel (HSS) for general-purpose machining to tungsten carbide, ceramics, and polycrystalline diamond (PCD) for high-speed or high-precision machining. These materials offer various trade-offs between hardness, toughness, and wear resistance. Modeling chip removal in metal machining is a complex aspect that involves understanding the mechanics of how the material is sheared and displaced by the cutting tool. It's critical for predicting tool wear, machine power requirements, and the final surface finish of the part. Advanced computational models and simulations are increasingly used to predict these factors accurately. This modeling aids in optimizing machining parameters, selecting appropriate tool materials and geometries, and improving the overall efficiency and quality of the machining process. In summary, metal machining is a multifaceted process requiring a deep understanding of operation parameters, tool design, and material behavior to achieve the desired outcomes in manufacturing.

3. Learning outcomes

Students can explain different metal machining operations such as turning, boring, milling, and planning, and how each is uniquely suited to specific manufacturing tasks; explain the importance of machining parameters like cutting speed, feed rate, and depth of cut in turning, and how they impact the efficiency, surface finish, and dimensional accuracy of the final product; acquire knowledge about the effects of tool tip shapes and the selection of tool materials, ranging from high-speed steel to tungsten carbide, on the machining process; explain the significance of modeling chip removal in machining, which is crucial for predicting tool wear, power requirements, and achieving optimal surface finish and efficiency in the machining process.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 12

1. The subject of the lecture

PRODUCTION AND FORMING OF LIGHTWEIGHT ALLOYS

2. Thematic scope of the lecture (abstract, maximum 500 words)

Lightweight alloys play an essential role in modern engineering and production, especially in fields where weight reduction is critical, such as aerospace, automotive, and defense. These alloys typically include materials like aluminum, magnesium, titanium, and their composites. Aluminum alloys are renowned for their excellent strength-to-weight ratio, corrosion resistance, and formability. Even lighter than aluminum, magnesium alloys offer significant weight savings and are known for their high specific strength and stiffness. Titanium alloys stand out for their exceptional strength, resistance to corrosion and fatigue, and high-temperature performance. These materials can be classified based on their primary metal and alloying elements, which determine their mechanical and physical properties.

The importance of lightweight alloys cannot be overstated. They are instrumental in enhancing fuel efficiency, reducing emissions, and increasing payload capacity in transportation systems. In aerospace, for instance, using lightweight alloys significantly improves aircraft performance and efficiency. In the automotive industry, these materials contribute to lighter, more fuel-efficient vehicles without compromising safety or performance. Their reduced weight also allows for innovative designs and applications in various fields, including electronics and construction. Manufacturing methods for lightweight alloys need to address their reactivity and melting behavior. These materials, particularly magnesium and titanium, are highly reactive, which poses challenges in melting and casting. Exceptional handling and protective atmospheres are often required to prevent oxidation and contamination. For instance, magnesium alloys are usually melted under a protective gas cover, like SF_6 or CO_2, to prevent oxidation. Due to its reactivity with oxygen and nitrogen at high temperatures, titanium is often melted in vacuum or inert atmospheres. Advanced techniques like vacuum arc remelting and electron beam melting produce high-purity titanium alloys. Melting and casting of lightweight alloys also present specific challenges. Their high reactivity and affinity for oxygen necessitate controlled environments to prevent the formation of oxides and other defects. In addition, their thermal properties, such as high thermal expansion coefficients and low thermal conductivities, require careful control of temperature gradients during casting to avoid internal stresses and distortions. Precision casting methods, like investment casting for titanium alloys, are often employed to produce complex shapes with high dimensional accuracy. Lightweight alloys are shaped and formed using various processes tailored to their properties. Aluminum alloys are easily formable by rolling, extrusion, and forging. Magnesium alloys, though less ductile than aluminum, can be formed using die casting, which is widely used for intricate parts. Due to their strength and high-temperature resistance, titanium alloys are often processed through forging and machining, though they pose challenges due to their work-hardening characteristics and abrasive nature. Recent advancements include additive manufacturing techniques, allowing for the creation of complex, lightweight structures with minimal material waste. Overall, the production and forming of lightweight alloys are vital to advancing technologies in sectors where reducing weight while maintaining strength and performance is crucial.

3. Learning outcomes

Students can explain different types of lightweight alloys, such as aluminum, magnesium, and titanium, and their classifications based on alloying elements and properties; comment on the critical role of lightweight alloys in enhancing fuel efficiency, reducing emissions, and enabling innovative designs in industries like aerospace, automotive, and electronics; acquire an understanding of the unique manufacturing challenges posed by the reactivity of lightweight alloys, necessitating special handling and protective atmospheres during melting and casting processes; explain about the various processes for shaping and forming lightweight alloys, including rolling, extrusion, die casting, and advanced methods like additive manufacturing, tailored to each alloy's specific properties.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

Topics 13

1. The subject of the lecture

INJECTION AND PRESSURE ASSISTED FORMING

2. Thematic scope of the lecture (abstract, maximum 500 words)

Injection and pressure-assisted forming of metals are advanced manufacturing processes that involve shaping materials under high-pressure conditions. These techniques have revolutionized the production of complex metal parts, offering improved material properties and design flexibility. Pressure-assisted forming processes include hydroforming, injection molding, Hot Isostatic Pressing (HIP), and Cold Isostatic Pressing (CIP). In these processes, metal or metal powders are shaped or densified using fluid or gas pressure at room or elevated temperatures. Hydroforming is a widespread technique where high-pressure hydraulic fluid presses a metal blank into a die. This process allows for the creating of complex shapes with smooth surfaces, often unachievable through traditional stamping methods. Hydroforming is especially beneficial for producing lightweight, structurally strong components in the automotive and aerospace industries. Injection molding, on the other hand, involves injecting molten metal into a mold under high pressure. This technique is typically used for mass-producing small to medium-sized parts with intricate shapes and fine details, commonly in the electronics and medical device industries. Hot Isostatic Pressing (HIP) and Cold Isostatic Pressing (CIP) are processes used to consolidate powders or improve the properties of castings. HIP involves simultaneously applying high temperature and pressure to a component, typically in a gas medium like argon, to remove porosities and improve mechanical properties. CIP, however, compresses powders at room temperature in a fluid medium, creating a uniform, high-density green part that can be sintered later. These processes are crucial in industries where material density and strength are critical, such as aerospace and biomedical implants. Modeling studies play a vital role in these pressure-assisted forming processes. Numerical simulations using finite element analysis (FEA) and computational fluid dynamics (CFD) are used to predict the behavior of materials under pressure, optimize process parameters, and design molds or dies. These models help understand the stress distribution, deformation patterns, and potential defects, enabling manufacturers to refine the process for better quality and efficiency. Case studies in industries like automotive and aerospace showcase the effectiveness of these forming processes. For example, hydroformed components are widely used in automotive chassis and structural parts for their strength and lightweight. In aerospace, HIP is used for manufacturing critical turbine components with enhanced mechanical properties. The success of these case studies highlights the advantages of pressure-assisted forming methods in producing high-quality, complex parts with reduced material waste and improved performance. In summary, injection and pressure-assisted forming of metals are essential in modern manufacturing, offering innovative solutions for complex part production across various industries.

3. Learning outcomes

Studens can elaborate about various pressure-assisted metal forming techniques, including hydroforming, injection molding, HIP, and CIP, and their applications in shaping and densifying metals; suggest a method with the advantages of these processes, such as producing complex shapes and improved material properties, and their use in industries like automotive, aerospace, electronics, and medical devices; describe the importance of numerical simulations, like finite element analysis and computational fluid dynamics, in optimizing these forming processes, predicting material behavior, and designing molds or dies; acquire knowledge of practical applications through case studies, demonstrating the effectiveness of these methods in producing high-quality, complex components with enhanced mechanical properties and efficiency.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-Sinan Müftü, Finite Element Method: Physics and Solution Methods (2022 Edition) Academic Press.

6. Additional notes

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).

Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS‘ GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

WEAR PREVENTION AND IMPROVEMENT OF SURFACE PROPERTIES

Code: WPISP

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO SURFACE CHARACTERIZATION AND TRIBOLOGY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present a detailed introduction to the surface characterisation and science of tribology, which involves the general properties of surfaces and techniques of surface modification to obtain desired result such as highly resistance to wear and tear. Students should be given an introduction to the concept of surface energy with a perspective on the application of Young's principles and its atomic representation to cover the effect of surface reactants and surface wetting together. Students should be given brief information regarding the difference in surface modification and tribology. Surface modification should enclose the external effects that give rise to improved local properties, whereas, tribology is on the other hand, the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. Students should be given brief information on the concepts of lubrication, friction and wear to refresh their knowledge and in addition to the concepts of surface improvement by hardening due to the effect from the alloying elements in the base metal, external mechanical effect from balling, chemical effect of Boron and coating with hard phases such as ceramic and metal based layering processes. The topic should continue with the roughness of the surfaces by mentioning the fact that surface asperity is responsible for the contact points and typical morphological properties such as wave form. The level of surface roughness after grounding and polishing or some common processes are important for surface properties and should be explained to the students. Surface of metals, ceramics and plastics should be given to the students in detail to make sure that students can easily recognise the surface appearance to reach a conclusion on how the surface looks before use. The effect of hardness can be given with a graph showing the hardness vs wear rate. There should be a brief introduction to the effect of microstructure on the friction process and a graph should be introduced from literature, depicting how different microstructural components and crystal structures are effective in reducing the friction. The surface roughness should continue with the wetting effect and its variation with surface roughness and surface active elements with respect to the type of melt. The topic should continue with the brief introduction of lubricants such as mineral and organic based lubricants and how they behave differently under the opposite facing loads. The topic will be concluded with a discussion on the importance of surface properties and the aim of surface modification and various effects of typical surface modification techniques such as coating, quench hardening and mechanical hardening and prevention measures.

3. Learning outcomes

Student can explain the importance of tribology and surface modification processes and their impact on industry in terms of cost and indirect or incidental losses; define the effect of alloying element in improving the surface properties such as surface hardness; describe the contribution of surface coating processes and differentiate between different coating processes available in industry; explain surface properties at atomic level and possible changes after surface modification processes.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

S. Ebnesajjad, Chapter 4: Surface and Material Characterization Techniques, Editor(s): Sina Ebnesajjad, Surface Treatment of Materials for Adhesive Bonding (Second Edition), William Andrew Publishing, 2014,39-75,

6. Additional notes

Topics 2

1. The subject of the lecture

FRICTION ON SURFACES

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic is intended to introduce an advanced approach to friction phenomenon on surfaces and their explanation at atomic level. The interactions that occur between moving and stationary surfaces would require an external loading which imposes a strain on the both surfaces. Students at this stage should be given a treatment of mathematical expression of how the level of friction force plays an important role in the calculation of friction coefficient on a planar surface with or without lubricant. Friction coefficient calculation using few equations should be described to students and explained how the parameters are modified when lubricant is used and the role of lubricant as a medium to carry the load afflicted on the load carrying surface. The strain effect should be emphasized in two ways; the first one is that the load pre-strains the surface below the limit of failure of yield stress criteria as Von Misses suggests, the second one is the overstrained surface which exceeds the limit of yield stress and failure occurs by which various wear mechanisms begin to act and accelerated with the heat evolving during the action of friction. The atomistic approach to normal and failing surfaces using graphical media should help students understand the basics of atomic movements with respect to binding energies and atomic movement during each pass e.g. the formation of hardening layer by lattice and plane distortion in addition to dislocation generation and movement. Surface degeneration is therefore be visualised and friction coefficient proliferation can be justified by developing surface roughness. Students should be introduced to the effect of surface roughness and its effect on the friction process and wear development. Wear process should be given lightly with basic level of mechanisms such as adhesive wear, contact fatigue, abrasive, fretting wear, rolling or sliding wear and also erosion wear. Dry sliding should be introduced to students with the effect of heat generation and its accumulation on the substrate. Heat generation can be graphically introduced using literature studies and also the effect of excessive heat on the surface atoms at atomic level can be explained and shown to students with many examples. In the final stage of the lecture, a discussion on the effect of heat generation during surface- surface interactions and how it is overcome by engineers should be initiated and it should be followed by the prevention of dry sliding wear process and the role of lubricants.

3. Learning outcomes

Students can explain the different wear mechanisms occurring during the surface to surface interactions and third body abrasion wear; analyse different wear mechanisms on the optical and electron microscopy images based on wear traces and depth profile; elaborate how heat is generated during the friction process between opposing surfaces and its effect on the surface characteristics of load bearing surface; suggest a mechanism involving the heat generation and how it causes degeneration of surfaces.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. https://phys.org/news/2019-08-chemical-physical-friction-surfaces-atomic.html
2. Liang, X.M., Xing, Y.Z., Li, L.T. *et al.* An experimental study on the relation between friction force and real contact area. *Sci Rep* **11**, 20366 (2021).
3. Friction and adhesion: fundamentals. In: Attachment Devices of Insect Cuticle. Springer, Dordrecht. (2002), https://doi.org/10.1007/0-306-47515-4_1

6. Additional notes

Topics 3

1. The subject of the lecture

LUBRICATION OF SURFACES AND LUBRICANTS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present a detailed overview on the lubrication process and its necessity from the perspective of materials scientists and mechanical engineer. The topic also covers an introduction to the greater variety of lubricants in the form of solid, liquid and gas and summary table should be given for further reference with a comparison to unlubricated surfaces. The effect of surface roughness in the use of lubricant and their effectiveness should be debated based on their knowledge from previous lectures. This topic should also present an advanced treatment on the hydrodynamic lubrication film formation on the opposing surfaces and the parameters that affect the motion of lubricant film formed by liquid lubricant as oppose to solid lubrication. The presence of asperities and their interactions with lubrication films are also subject of this topic. Lubrication films can be introduced with fluid dynamic principles, including shear force and load relations, and also molecular behaviour of lubricants under the load from the mechanistic point of view. Boundary, full fluid film and mixed lubrication concepts should be explained and elaborated to students with theoretical background and the important phenomenon of scuffing on the surface should also be described with some examples from literature studies. In addition to reducing friction, lubricant may have other functions. It may remove heat from the tribological system or protect the surfaces against environmental aggression (preventing, for example, oxygen and moisture from reaching the metal surfaces thus causing corrosion phenomena). In this topic, the main features of solid lubricants and solid lubrication will be initially introduced. Then, the salient features of the main liquid lubricants and of the fluid film lubrication theory will be described. Since gas lubricants (air, N_2, H_2, He) are used in some special cases only, the gas lubrication will be treated very shortly and examples will be given from industry of special applications. The topic should end with an introduction to lubrication when large plastic deformations are involved. The topic will also cover the tribo-corrosion effect occurring during the friction process in the presence of any type of lubricant. Wear is also influenced by chemical reactions of the sliding materials with the environment or with each other. Such reactions are often accelerated by friction, in which case they are called tribochemical. Tribochemical reactions can increase wear, when they increase fracture rates; they can decrease wear when they produce a smooth surface or a soft reaction product and reduce contact stresses; or they can produce a lubricating layer that decreases friction and wear. Related theories regarding this subject will be given to the students in the classroom. A discussion on the tribology of formation of passive surface layers in some alloys for example Co-Cr alloys and their mechanical removal should be initiated at the end of the topic in the classroom.

3.	Learning outcomes

Students can explain the difference between un-lubricated and lubricated surfaces by examining the surface traces of worn region; describe the modes of lubrication and their effect on the surface protection and against the wear process; elaborate on the result of the tribocorrosion process on the surface and formation of passive layers on some alloys; explain the hydrodynamics of lubrication films forming on the opposing surfaces and parameters that have effect on the surface integrity.

4.	Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. S. N and M. A (2013) Lubrication and Lubricants. Tribology - Fundamentals and Advancements. InTech.

2. S. McGrory, Lubrication, Plant Engineer's Handbook, 2001, Pages 915-960

6.	Additional notes

Topics 4

1. The subject of the lecture

WEAR PROCESSES

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present a detailed treatment of majority of wear processes that are observed in surface to surface and third body surface interactions, including the mechanisms of surface degeneration with respect to duration and load variations with dynamic and hydrodynamic effect. Wear is a material's response to the stresses occurring in a moving mechanical contact. The local contact stresses depend on the surface topography, which is usually modified by the wear processes, and by plastic or elastic deformation of contacting asperities. In metals, the contact stresses are roughly equal to the hardness of the softer material, wear occurs by plastic deformation and fatigue. The amount of material removed is roughly proportional to the contact load, sliding distance and inversely proportional to the hardness. Wear processes or mechanisms are of great importance to machine producers and technicians as to improve the effective use of the machine or mechanical system built with moving parts. Students should be aware of the fact that wear processes can be related to increased cost of operation and maintenance. The topic should include a generalised wear processes definitions and then elaborate them with many surface images depicting each wear mechanism in different materials. Common alloys such as steels, brass, aluminium alloys and titanium alloys may be preferable for the presentation however; plastics, ceramics and composites should be greatly appreciated, too. Various images showing the wear traces can give rise to improved visualisation of wear mechanisms with regards to micro and macro level degeneration processes. The basic principles of wear processes, e.g. abrasion, adhesion and erosion should be separately introduced to students as they are considered main causes and the corrosion should be separated from those of three mechanisms but jointly introduced in tribo-corrosion. Tribo-corrosion processes were partly introduced in previous section but it should be given again in relation to corrosion amongst other corrosively induced wear mechanisms. All the mechanisms should be explained using many examples from literature in great detail and students should be presented formulations that includes wear rate of substrate in addition to wear loss in opposing hard ball or surface, and adhesive wear, stick slip interactions, contact fatigue wear due to repeated loads, abrasive wear by hard particles with details of low and high stress abrasion conditions, rolling or sliding wear with effect on the substrate that causes defacing or de-layering of affected part of the surface. A list of reading material should be provided to students to understand the matter deeper as they will be dealing a great number wear issues in industry. Fatigue wear, even though lubrication exists, is more problematic than other mechanisms since the machine parts contain ball rollers that have a pointed load distribution or slides in the same context. Hence, the last part of the topic should be spared to explain such incidents and many examples from industry and solution based approach should be implemented. A discussion on the effective lubrication on high speed rotational or linear motions should be initiated and students should be able to define the mechanisms active in those processes.

3. Learning outcomes

Students can explain the formation of lubrication films on opposing surfaces and load bearing surface to surface interactions; define the mechanisms active in the most wear processes and differentiate between adhesive, abrasive and fatigue wear processes; explain types of wear on different materials based on their surface and general properties; suggest a solution to the most of the wear problems appearing in industry.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Chapter 4 Classification of Wear Processes, Tribology Series, Volume 10, 1987, Pages 80-131

6. Additional notes

Topics 5

1. The subject of the lecture

WEAR OF CERAMICS AND POLYMERS

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic aims to introduce basics of overall structural and surface properties of polymeric materials and ceramics as an introduction to the tribological properties. Students should be introduced to general wear behaviour of non metallic materials as oppose to metallic materials with a condensed table of properties. Student should also be presented differences in atomic structures of both polymers and ceramics starting from atomic bonding and their effect on wear behaviour and main wear modes. In ceramics, there are three main wear modes occurring during the sliding action of the load on the surface, depending on the magnitude of contact load: microfracture on a sub-grain scale at low loads, grain-boundary fatigue at intermediate loads and macroscopic fracture at high loads. The main causes for these types of wear mode in ceramics appear to be low tensile strength coupled with low ductility and high friction in addition to low thermal conductivity and thermal expansion coefficient. Tensile stresses occurring at each pass of the load initiate cracks that propagate along grain boundaries which is weakened by decohesion. The grains and large pieces of ceramics debonded from the substrate leave the surface in the form of microfracture wear debris that is further attrited during continued sliding. Students should be given a brief introduction of grain boundaries in ceramics and metallic materials in order to show the difference in grain boundary cohesion behaviour. Students should be given of the principal wear modes in polymers. The principal wear modes likely to occur in polymers should be briefly described. In general, the wear mechanisms of materials include adhesion, abrasion, fatigue, impact, electrical and chemical wear. Wear mechanisms are classified under three broad approaches for polymeric materials; adhesion, abrasion and fatigue wear are the dominant mechanisms. It is demonstrated here that the wear of polymers is influenced by the contact conditions, the bulk mechanical properties of the polymer and the properties of the 'third body', which generally appears in the form of transfer film or degraded polymer particles between two sliding surfaces. Further, this topic establishes a link between the different contact and material parameters and shows how they are important in elucidating the generic wear mechanisms for polymers. The effects of environment and lubrication upon polymer wear should be briefly explained in terms of the chemical interactions between the liquid phase and the polymer. A discussion should be initiated on the capabilities and limitations of current predictive wear models for polymeric contacts. Many practical examples and images should be presented.

3. Learning outcomes

Students can explain the difference in wear mechanisms of polymeric materials and ceramics from the atomistic point of view; comparatively differentiate wear behaviours of metallic materials and both polymeric and ceramic materials; recognise the principal wear mechanisms of microfracture, grain-boundary fatigue and macroscopic fracture in ceramics based on the examination of worn specimens; recognise the wear types of adhesion, abrasion and fatigue wear based on the examination of worn specimens.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. G. Stachowiak, Chapter 14 - Friction and Wear of Polymers, Ceramics and Composites in Biomedical Applications, Composite Materials Series, Volume 8, 1993, Pages 509-557

6. Additional notes

Topics 6

1. The subject of the lecture

SURFACE PROTECTION TECHNOLOGIES 1

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the deformities of surfaces and show the difficulty to protect surfaces from the impact, loose hard particles and sliding action of third body or surfaces, in response, it aims to present that some technologies are available to protect the surface form such effects and by utilising chemical, thermochemical and heat treatment based applications. This topic is the first to treat surface anomalies by electron and laser beam surface hardening, microstructural treatment and mechanical straining of surfaces. Students can be accustomed to the attributes of rapid cooling and in some cases rapid solidification processes on surfaces where hardening is the main aim to fight against the wear process. Students should be given detailed information about the hardening processes through high energy beam processes and the mechanisms behind the hardening at atomic and crystallographic level. Students should be explained how to apply these techniques by giving extensive examples from literature and industrial applications. Students should be aware of principal parameters of these high energy beam processes when used on materials such as steel. Students should be given basic information on heat treatments for hardening of alloys and the effect of grain refining on increasing the hardness of the alloy in addition to the changing the morphology of grains e.g. martensite formation. Microstructural treatment should follow the application of local heat treatment such as laser spot heating which relatively milimeter level, and, if gas burner or arc or more precisely induction heating can be used to create a larger affected or hardened surface area comparaed to high energy beam treatment. Induction heating is more widely used for surface hardening, ,hence students should be given a good introduction which should be supported by industrial examples. A list of alloys can be given in the form of table to help students understand why some alloys are used for induction heating and some are not. Mechanically induced hardening processes are effective some non allotropic metals and alloys and most allotropic metals and alloys as well. The action of steel or WC balls is very efficient in producing a hard layer where the minute deformation is ignored. The advantages and disadvantages and limits of high energy beam local hardening, hardening by local heat treatment by arc, gas flame and induction heating and also microstructural treatment in addition to mechanically induced hardening on the surface should be presented to students. At the end of the lecture topic, there should be a discussion on conventional and new uses of these methods of hardening surfaces and which one is more effective for bcc and fcc based metals and alloys.

3. Learning outcomes

Students can explain how strain hardening and mechanical surface hardening processes can produce surfaces against wear and their mechanisms in achieving such hard surfaces at atomic and crystallographic level; suggest a process by which a hard surface can be generated on what type of metallic material against wear; explain the mechanism by which hard surface is obtained through high energy beam hardening, mechanical straining, local heat treatment such as induction heat treatment.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. S. Singh, S. Kumar, V. Khanna, A review on surface modification techniques, Materials Today: Proceedings, 2023

2. Part 4, Surface Engineering: Surface Modification of Materials, edited by R. Kossowsky, S.C. Singhal, proceedings of the NATO Advanced Study Insitute on Surface Engineering, Les Arc, France, 1983

6. Additional notes

Topics 7

1. The subject of the lecture

SURFACE PROTECTION TECHNOLOGIES 2

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to introduce the second part of previous topic's continuation. In this part of topic there should be an introduction to thermochemical processes such as nitriding, carburising and most importantly boriding processes which produces the hardest surface hardness amongst three of the methods. Students should be accustomed with fundamental concepts of heat treatment processing routes for many metallic systems including ferrous and non ferrous alloys with a special attention to the gas metal reactions occurring in both low atmosphere and high pressure containers. Students should be given a list of reactions that are relevant to the deposition of nitrogen, carbon and boron in gas, solid and liquid mediums. A list of temperature and durations should be also provided so that students can use this information a guide for their study or work when they needed. The emphasis should be mainly focused on nitriding and caburising of a medium, gas exchange or gas shift, reaction equilibria relevant to nitriding, nitro – carburising, carburising and carbonitriding. Such chapters on oxidation reactions in gas phase, water gas – exchange reaction, methane gas – exchange reaction, and hydrogen cyanide gas – exchange reaction need to be explained to students with suitable illustrations. Gibbs free energy rules should be used to employ equilibria for gas – solid reactions: Nitrogen transfer by ammonia, nitrogen transfer by nitrogen gas, carbon transfer from Boudouard reaction, carbon transfer via heterogeneous water – gas reaction, carbon transfer by hydrocarbons, carbon and nitrogen transfer by hydrogen cyanide. After a detailed explanation of thermodynamic concepts involved, a discussion on kinetics of gas – exchange reactions should be presented with phase stabilities in Fe – N, F – C, Fe – C – N systems. The development of an interstitial solid solution involving Fick's laws of diffusion, precipitation of second phase particles in a super saturated matrix, and product – layer growth (single and double layers) at the surface should be explained to students. A discussion on the methods of different heat treatment processing routes producing similar outcomes will be made at the end of the lecture topic. The lecture topic will finally end with extensive exemplary study on the processes requiring subsequent hardening (e.g.,carburizing), processes not requiring subsequent hardening (e.g., nitriding), process not requiring but allowing for subsequent hardening (e.g., boriding). A discussion should be held on the efficieny of these methods of surface hardening based on the treatment temperature and duration and finally the cost of the operation.

3. Learning outcomes

Students can elaborate on the efficiency of processes of nitriding, carburising and boriding and their varieties of applications; suggest a thermochemical surface hardening process for any type of materials based on the composition of substrate and other physical properties;

analyse the hardness and microstructure of the deposited layer and determine whether the process is successful for the proposed application.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. S. Singh, S. Kumar, V. Khanna, A review on surface modification techniques, Materials Today: Proceedings, 2023

2. Part 4, Surface Engineering: Surface Modification of Materials, edited by R. Kossowsky, S.C. Singhal, proceedings of the NATO Advanced Study Insitute on Surface Engineering, Les Arc, France, 1983

3. H. Amani et al, Controlling Cell Behavior through the Design of Biomaterial Surfaces: A Focus on Surface Modification Techniques, Advanced Materials Interfaces, Volume 6, Issue 13, 2019, 1900572

6. Additional notes

Co-funded by the European Union

Topics 8

1. The subject of the lecture

HIGH TEMPERATURE TRIBOLOGY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce high temperature tribology principles and methods by which materials are tested at high temperatures to find out if the materials is sufficiently viable for the proposed application. Initially, the high temperature tribology is introduced to the students with detailed principles of working of the measurement system. Students then should be given information about the high temperature behaviour of materials at especially temperatures above the 30% - 50% of melting points (warm deformation range), where the rigidity is preserved for deformation ability. The behaviour of surfaces at high temperatures should also be elaborated with illustrations of how atoms are acting on the surface with a reference to cohesion energies and diffusion capacities. Tabulated information can be presented to compare the low, medium and high temperature surface deformation capacity, diffusivity on the surface, the evaporation from the surface and grain boundary and surface diffusion of atoms in rigid solid. Students can be reminded of diffusion and principal diffusion equations at this stage. The equipment of tribology for high temperatures are different to low temperature ones, hence, students should be given a detailed knowledge on how high and low temperature wear systems are measuring the coefficient of friction differently. A special emphasis should be given to the surface to surface interactions and ball to surface interactions at atomic and micro level deformation mechanisms. An atomistic approach can be preferred to simulate the various reactions on the surface such as chemical reactions between sliding ball and surface and wear mechanisms such as stick slip behaviour. The effects of alloying element additions and starting microstructure in steels and in various alloys on mechanical and physical properties of target material should be mentioned with the interaction between the atoms of alloying additions and matrix atoms at different testing temperatures. Students should be involved in a discussion on how the alloying elements in different concentrations would influence the surface deformation at high temperatures and even the type of microstructure and carbide type and formation would affect the surface wear at warm and high temperatures. In the final part of the lecture, students will be given examples of worn surface images from different types of tests of high temperature tribology on different materials. Finally, students should be introduced to effect of test medium where gas or vacuum is used in order to control the type and thickness of tribolayer occurring on the surface of tested material.

3. Learning outcomes

Students can explain the effect of alloying elements and starting microstructure of substrate metallic material on the variation of friction behaviour and hence the coefficient of friction; define the mechanisms of wear on the surface at high temperatures and the mechanical and chemical interaction between the sliding surface or ball and substrate surface; elaborate on the effect of microstructure and its ingredients e.g. carbide or precipitate presence on the variation of surface friction behaviour and friction coefficient.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. Part 3, Surface Engineering: Surface Modification of Materials, edited by R. Kossowsky, S.C. Singhal, proceedings of the NATO Advanced Study Insitute on Surface Engineering, Les Arc, France, 1983

2. A.P. Semenov, Tribology at high temperatures, Tribology International, volume 28, Issue 1, February 1995, Pages 45-50

6. Additional notes

Topics 9

1. The subject of the lecture

EFFECT OF SURFACE AND MANUFACTURING CONDITIONS FOR FRICTION

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present an advanced treatment on the effect of surface roughness based on manufacturing conditions such as turning, polishing and grinding and their impact on the wear properties of different materials and wear volume changes based on different surface roughness and different materials with a treatment of advanced calculation methodology of wear volume and wear coefficient. This topic will also cover the wear properties of porous surfaces which acts differently compared to bulk materials and friction reduction techniques such as filler body suction and coating with resin etc.. A brief introduction to powder metallurgy and its manufacturing methods with a special interest to surface properties in terms of wear and protection of surfaces by various methods such as hardening and other heat treatment and also coating with thermochemical processes should be given in detail from literature sources. In addition to powder metallurgy process using actual powders, mechanical alloying is also similar to powder metallurgy using pre using flakes produced by deformed powders. Mechanical alloying is suitable for alloying of two dissimilar metallic or non metallic powders that are not practically possible or extremely difficult to produce. Sintered products are mostly products of powder metallurgy process, having the low volume porous structure with an average size of 1-20 micron max. Wear of manufactured structures such as machine body or more precisely joints of arc and high energy beams are also the concern of this topic. A generalised definition of joining can be introduced to students with a special interest to the third body abrasive wear of steel and non ferrous welds. In an environment such as oil rigs, petrol refineries and also heavy duty building vehicles working in harsh environments should be covered in this topic. The hardfacing of Arc welds are more prone to wear as they consist of three different parts of heat affected zone, which should be briefly given to students. Other methods of joining such as diffusion bonding may not be commonly found working against wear but can be covered in the topic with high deformation joining techniques as well. Mechanical joining components may be included into this topic. Finally, this topic should end with exemplary images from worn surfaces from many materials which work in harsh environments. Students should involve a discussion regarding the porous structures and mechanisms underlying the wear of these materials.

3. Learning outcomes

Students can describe the effects of surface roughness on the outcome of wear and tribological behaviour of materials, e.g. friction coefficient and wear volume; define the wear mechanisms in porous materials and sintered products; elaborate on the wear of the arc, high energy beam welds, deformation/impact welded and diffusion bonded structures and related wear mechanisms for each of the weld type.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. C.J. Hooke, The effect of roughness in EHL contacts, (Pages 15-28), Life Cycle Tribology, Edited by D. Dowson, M. Priest, G. Dalmaz, A.A. Lubrecht, Tribology and Interface Engineering Series, Volume 48, Pages 1-933, 2005

2. I. Křupka, M. Hartl, M. Liška, The influence of slide-to-roll ratio on lubricant film thickness distribution in the vicinity of real roughness features passing through EHD point contact (Pages 57-64), Life Cycle Tribology, Edited by D. Dowson, M. Priest, G. Dalmaz, A.A. Lubrecht, Tribology and Interface Engineering Series, Volume 48, Pages 1-933, 2005

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 10

1. The subject of the lecture

FRICTION AND ADHESION MEASUREMENT DEVICES

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the friction force and friction coefficient measuring devices and their working principles. Students should be explained how to measure the friction force in a static and dynamic conditions using appropriate devices produced for the purpose. Students should be well informed on static and dynamic friction concepts and testing parameters, too. The devices for the measurement of friction force are relatively easy to setup and contains a strain gauge that measures the dragging force along the surface where as to measure the friction coefficient, one needs to measure both dragging force with respect to weight and coefficient of friction is recalculated using both values that is multiplied with a correction factor determined by the user or method. As the friction force is closer to the force applied by the weight on to specimen surface, the friction coefficient will be higher and if the force is much smaller than the force applied by the weight then the friction coefficient will be smaller as in the case of hard steel surface. Based on this concept a simple tribotester can be built using strain gauge, a known weight and revolving plate. Students should be familiar with a tribometer that is an instrument that measures tribological quantities, such as coefficient of friction, friction force, and sometimes wear volume in real time, between two surfaces in contact. A tribotester is the general name given to a device used to perform tests and simulations of wear, friction and lubrication which are the subjects of the study of tribology. Tribotesters are sometimes very specific in their place of use and are manufactured by companies that wish to test and analyse the service life performance of their products. For example, orthopedic implants are robustly tested by manufactures to develop a model for their product to predict their service life. These devices should be produced in such a way that it should accurately reproduce the motions and forces that occur in human hip joints so that they can perform accelerated wear tests of their products. Students are already aware of the concepts of dry and lubricated sliding wear from previous topics however the advantage of such measurements should be explained to students and the effect of testing temperature and gradual heating of specimens during the friction testing should be discussed with students in the classroom.

3. Learning outcomes

Students can describe the effects of testing temperature and gradual increase of specimen temperature during the testing on the friction force and coefficient of friction; explain how tribotester works and elaborate the mechanism of measuring friction force and coefficient of friction; elucidate the static and dynamic friction measurements and calculate the tribological quantities.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

1. riction and adhesion: fundamentals. In: Attachment Devices of Insect Cuticle. Springer, Dordrecht. (2002), https://doi.org/10.1007/0-306-47515-4_1

2. K. Komvopoulos (2003) Adhesion and friction forces in microelectromechanical systems: mechanisms, measurement, surface modification techniques, and adhesion theory , Journal of Adhesion Science and Technology, 17:4, 477-517,

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 11

1. The subject of the lecture

DESIGN OF SURFACES AGAINST WEAR

2. Thematic scope of the lecture (abstract, maximum 500 words)

The lecture aims to provide an extensive insight to design of working surfaces against wear and make them tribologically safe and resistant in practical applications. It also aims to boost the understanding of the tribological approach to surface design using various treatments on metallic materials with many exemplary study or application results and specimens from industry. Students should be aware of the design criteria and minimum criteria should be to establish a minimum acceptable lifetime by which degree of wear resistance is determined. The design phase will also lay out any other product constraints, like the presence or absence of an external lubricant, or the types of surfaces the product will need to slide against. Optimal surface design regarding both friction and wear can be achieved by multi-layer techniques which can provide properties such as reduced stresses, improved adhesion to the substrate, more flexible coatings and harder and smoother surfaces. Depending on their specific design constraints, certain designs can be developed by designers. For example, tires come in all kinds of shapes, sizes, and tread patterns depending on their application, which must be rounded so that the driver can handle the bike smoothly, but the tire compounds and tread patterns producers choose can have a significant impact on the tire's resistance to wear and performance. This topic will also concentrate on the wear resistant surface preparation (e.g. planar, wavy, cross wave, perpendicular etc..) and consecutive coatings applications including, HVOF, arc deposition and electro spark deposition, and their application parameters as well as design of deposition route on the surface to be wear resistant. Students should be introduced to naturally occurring wear processes and where they occur such as mining and sugar cane processing and typical problems observed in these application including solutions to overcome such problems. Students should be well aware of the tribological problems and explained that design is also as important as material used for the machine part. Similar to the material selection process, there is a very wide range of unique finishing options available to improve wear performance. These could include various protective coatings, metal hardfacing, or hardening treatments. However, all of these surface finishing treatments provide a great way to improve performance without using a more expensive base material or compromising other properties. For example, the steel bucket teeth on mining equipment can be hardfaced with a layer of much harder materials like VC, NbC, Cr_7C_3 and tungsten carbide or mixture of these carbides even carbide containing alloys such as M42 steel. This treatment significantly improves the abrasion resistance of the bucket teeth, while still taking advantage of the ductility and lower cost of the steel. A discussion on achieving the wear resistant required by bucket teeth in mining industry and plastic extrusion machine parts can be initiated by the instructor and possible solutions to various cases such as machine parts in powder processing and hydraulics can follow for further knowledge and experience sharing. Finally, students should be given extensive examples of coatings and applications generated for preventive measures should also be given in detail.

3. Learning outcomes

Students can explain the necessity of wear resistant patterns generated by techniques such as HVOF, arc deposition, electro spark deposition and hardfacing processes, on surfaces where wear resistance is desired; describe the advantages and disadvantages of the processes available in industry; define working mechanisms of wear resistive patterns and coatings and how these patterns act during the wear action in practice; elaborate on the design requirements of different industries and applications.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

K. Holmberg, A. Matthews, H. Ronkainnen, Coatings tribology—contact mechanisms and surface design, Tribology International, Volume 31, Issues 1–3, Pages 107-120, 1998

6. Additional notes

Topics 12

1. The subject of the lecture

WEAR RESISTANT MATERIALS AND COATINGS TRIBOLOGY, THIN (FILM) COATINGS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present the fundamentals of coating tribology by using a generalised approach to the friction and revisit the wear mechanisms of coated surfaces in dry sliding contacts. Students should be given information on the wear resistant materials in tabulated form and classification of the tribological contact processes: macromechanical, micromechanical, nanomechanical and tribochemical contact mechanisms, and material transfer. Students should be introduced the characteristics of thin layers such as low angle Xray and microscopic characterisation. The importance of thin tribo and transfer layers formed during the sliding action should also be shown to students interactively. The differences between contact mechanisms in dry, water and oil lubricated contacts with coated surfaces is also illustrated, although mentioned earlier, by experimental results from carbo-nitrides and diamond-like coatings sliding against a steel, WC and an alumina ball. Thin surface coatings for wear protection and friction reduction by multilayered and metastable coatings with extreme mechanical and chemical properties are being studied by both the scientific community and industry; in this respect, plasma and ion-based vacuum coating techniques received great attention. Multilayer coatings allow the coating/substrate system to be designed in such a way that the combination performs in an optimal manner. This objective is further aided by improvements in our fundamental understanding of contact mechanisms between surfaces, at the macro, micro and nano level. This topic should also presents a review of the present level of understanding of contact mechanisms, especially for thin coated surfaces, which includes a consideration of stress states, mechanical properties and chemical influences in the substrate and layer system. Students should be critically introduced to the formation of layering in thin coated surfaces and how to test using conventional tribological devices. The multiple layers of coatings created new possibilities in industry; this includes the possibility to categorise the functional properties from the surface to the interface between coating and substrate. Extra effort should be made to cite and elaborate recent developments in carbon based coatings which combine excellent frictional properties with good wear resistance in dry and lubricated conditions. A discussion on the comparative behaviour of thin coated surfaces and conventionally coated surfaces or the production advantages of thin layer of coating over multilayer coatings should be held in the classroom.

3. Learning outcomes

Students can explain how tribological contact processes work in dry and lubricated conditions on non coated and coated surfaces; differentiate the difference between N and B containing coatings, DLC and other C based coating for special applications and suggest one these coatings for the purpose of application; elaborate on the purpose of layering and multilayering of coatings on the surface; explain the classification and purpose thin coatings and their characterisation.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

W. Zhai et al., Recent Progress on Wear-Resistant Materials: Designs, Properties, and Applications, Advanced Science, volume 8, issue 11, 2003739, 2021

H. Frey, Applications and Developments of Thin Film Technology (Chapter 1), Handbook of thin film technology, Editors: H. Frey and H. R. Khan, Springer, 2015

6. Additional notes

Topics 13

1. The subject of the lecture

LIFE CYCLE AND SURFACE WEAR: COST AND ASSUMPTION

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to provide a detailed treatment of economics of surface modification processes in metal processing sectors such as die making which is, in general, categorised in sheet metal processing and machine manufacturing industries. Students should be accustomed to life cycle and wear cycle concepts which are detrimental in determining the service life or sometimes for the regular maintenance of a product such as jet engines and diesel or petrol engines. Students should also be given the details of how to estimate the total cost each process and also make a reliable assumption on cost calculations in surface modification processes of nitriding and carbo nitriding, carburising, pack boriding, paste boriding, physical vapour deposition, chemical vapour deposition and high velocity arc and high velocity oxy fuel flame coating, hardfacing or alloying of bucket teeth used in mining industry etc... A detailed tabulated information regarding the cost of processes should be given to students as itemised according to each category such as consumables for coating including electrodes for hardfacing, chemicals for PVD, CVD, nitriding and carbonising and equipment maintenance for the processes and finally labour if necessary. At this stage, students should be encouraged to choose an application from industry and select a substrate e.g. ferrous or non ferrous metal and discuss the costs of possible substrate and process and make an estimation based on these inputs. Coating parameters such as duration, type of chemical and temperature, and also service conditions such as dry sliding, lubricated sliding or hazardous or corrosive environment are prime factors in determining the coating thickness which could be very important for cost fixing. Such factors should be explained in detail. Students should involve a discussion regarding the effect of design of machine parts and how product developers and designers work. Product developers can experiment with multiple different approaches to their design to find one that meets their other performance criteria while improving wear resistance and extending product lifetime. Instead, designers should know that most material classes have special formulations designed to improve performance in a particular area like wear or corrosion. If you need to use steel, for example, you can consider using an abrasion-resistant steel alloy to prolong the service life of the selected material while staying within predetermined design constraints. However, simply using the most wear-resistant material that is available to designer appears to be mostly unlikely to meet the most design needs. You would never use metal tires on a car or tungsten carbide knives have the benefit of staying sharper for longer, they weigh nearly twice as much as steel knives and are very brittle. At the end of the lecture, students can suggest a coating process for Tungsten working in high temperature neutron radiation environment to prevent hardening due to defect formation if exists.

3. Learning outcomes

Students can explain how cost effective are the surface modification processes involving gaseous and solid medium that are carried out on a metallic specimen; suggest a method of coating methods of those mentioned in this topic with respect to the materials being offered and its final surface requirements; most importantly suggest a more cost effective process based on the information provided in this topic; relate the cost itemising and process outputs in any of the method mention in this topic.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

G.H. Isaac, Life Cycle Aspects of Total Replacement Hip Joints (Pages 147-160), Life Cycle Tribology, Edited by D. Dowson, M. Priest, G. Dalmaz, A.A. Lubrecht -Volume 48, Pages 1-933, 2005

A. Nakajima, T. Mawatari, Rolling Contact Fatigue Life of Bearing Steel Rollers Lubricated with Low Viscosity Traction Oil (pp. 351-362), Life Cycle Tribology, Edited by D. Dowson, M. Priest, G. Dalmaz, A.A. Lubrecht, Tribology and Interface Engineering Series, Volume 48, Pages 1-933, 2005

G.W. Poll, Life Cycle Engineering and Virtual Product Development – the Role of Tribology (Pages 15-28), Life Cycle Tribology, Edited by D. Dowson, M. Priest, G. Dalmaz, A.A. Lubrecht, Tribology and Interface Engineering Series, Volume 48, Pages 1-933, 2005

6. Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

MATERIALS FOR ELECTRONICS AND SENSORS

Code: MES

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO ELECTRONIC MATERIALS AND ROLE OF DEFECTS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the theoretical and structural principles of electronic materials and their applications, such as sensors, to students in an instructive manner. The importance of electronic materials is highlighted through popular applications, starting with radios and ending with smartphones. A chronological historical background of electronic materials is provided to students. The history of electronics begins with the invention of capacitors and resistances, followed by the development of diodes. In the late 1940s, Bardeen, Brattain, and Shockley revolutionised the electronics industry with the invention of transistors. This progression of technological advancements has had a significant impact on modern society. Students should also be informed about mechanical switches and electron transfer control devices, commonly known as vacuum tubes, which were used to create electronic circuits using closely spaced metal elements such as electron-emitting filaments, grids, and electrodes contained within a glass vacuum envelope. The transition from vacuum tubes to transistors occurred over a decade, during which time ideas about solid-state devices emerged. Semiconductor electronic materials, such as silicon and germanium, made from single crystals are essential for the development of reliable discrete transistors. The production of electronic materials should be emphasized, including the methods of producing single crystals using conventional methods. It is important to provide students with information on the advantages and disadvantages of these production methods. These crystals needed to be produced in large quantities with high crystalline perfection and chemical purity, which was a significant departure from the laboratory-sized production of the past. The invention of diodes and transistors brought about a massive change in the electronics industry, enabling the development of modern electronic devices such as portable radios, computers, and smartphones. Transistors are commonly used in modern electronics and integrated circuits due to their durability, small size, and low power consumption compared to vacuum tubes. The electronic structure of materials can be affected by defects in crystals caused by atoms, and the thermodynamic basis of these defects can be explained by the statistics of point defects. The speed of plastic deformation in solids is controlled by line defects, such as dislocations. Mobile dislocations in solids are mainly of two types: edge and screw dislocations. These dislocations allow atoms to slide over each other at low stress levels. Polycrystalline solids contain planar defects, such as grain boundaries and twin boundaries, which separate regions of different crystalline grains. Understanding the mechanisms, factors, and limitations of diffusion processes in solids at various temperatures can lead to new possibilities for innovation and advancements in electronic properties and devices. It is important to discuss the production of various electronic compounds and their impact on the environment with students.

3. Learning outcomes

Students can describe the historical background of electronic materials, starting from capacitors and resistances to the invention of diodes and transistors, and their impact on the electronics industry; explain the production methods of electronic materials, including the methods of producing single crystals, their advantages, disadvantages, and the impact of their production on the environment; discuss and analyse the impact of defects in crystals on the electronic structure of materials and their thermodynamic basis, as well as the mechanisms, factors, and limitations of diffusion processes in solids at various temperatures; emphasize the importance of semiconductor electronic materials, such as silicon and germanium, in the development of modern electronic devices like portable radios, computers, and smartphones.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Kasap, S.O., (Chapters 1, 4), Principles of electronic materials and devices, McGraw Hill 1221 Avenue of the Americas New York, NY 10020, 2002

6. Additional notes

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Topics 2

1. The subject of the lecture

ELECTRONIC STRUCTURE OF SOLIDS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic presents a detailed treatment of the electronic structures of solids used in electronic material production. Fundamental concepts in physics, such as waves, electrons, and wave functions should be discussed with students and probing questions should be directed to the students, especially to find out how much structural knowledge exists and, particularly in the field of solid-state physics. It is important to mention the fact that understanding the behaviour of electrons in solids requires knowledge of the energy band structure, which describes the relationship between energy and momentum in a solid. The types of bands and their relationship to electronic properties should also be mentioned again. A definition of range of energy levels existing with electrons in a solid may emphasized with relation to the electronic properties such as energy bands which can be categorized as empty, filled, mixed, or forbidden bands, depending on whether they are occupied by electrons or not. Detailed definitions of valance, conduction, insulation and Fermi energies should be revisited. The valence band is the highest energy band that contains electrons. Depending on the material, it can be fully or partially occupied. The conduction band, on the other hand, is the lowest energy band with unoccupied states. In materials, the conducting bands of empty, filled, or allowed states can interfere with forbidden bands, also known as band gaps. The type of material, whether it is an insulator, semiconductor, or metal, is determined by the width of the band gap. The Fermi energy is the energy level at which electrons are most likely to be found in a solid. It is a crucial parameter in determining the electrical properties of a material. Understanding the energy band structure is essential for explaining the electrical conductivity, insulation, and semiconducting properties of various materials. The band structure of energy is affected by various factors, including the arrangement of atomic orbitals, the degree of overlap between these orbitals, and the temperature of the material. A discussion should be held with students on the electron and diffusion relationships and their uncalled behaviours at high temperatures.

3. Learning outcomes

Students can explain the fundamental concepts in physics, including waves, electrons, and wave functions; comprehend the energy band structure, emphasizing the relationship between energy and momentum in a solid and uUnderstand the different types of bands (empty, filled, mixed, or forbidden) and their relationship to electronic properties; define how the type of material (insulator, semiconductor, or metal) is determined by the width of the band gap and explain the essential role of the energy band structure in determining the electrical conductivity, insulation, and semiconducting properties of various materials.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)**

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

Students are expected to read below texts related to the lecture:

U. Bovensiepen, S. Biermann, and L. Perfetti, The Electronic Structure of Solids, Dynamics at Solid State Surfaces and Interfaces: Volume 2: Fundamentals, First Edition. Edited by Uwe Bovensiepen, Hrvoje Petek, and Martin Wolf, 2012 Wiley

6.	**Additional notes**

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Topics 3

1. The subject of the lecture

DIFFUSION IN SOLIDS AND ELECTRONIC MATERIALS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to give detailed information about the diffusion processes in solids in general and particularly in electronic materials. Solid-state diffusion is a fundamental process in materials science that refers to the movement of atoms or molecules through a solid material, driven by temperature and concentration gradients. Diffusion in electronic materials refers to the process by which charge carriers (electrons or holes) in a semiconductor move from a region of higher concentration to a region of lower concentration due to the random motion of the carriers. This process occurs in semiconductors and is responsible for maintaining thermal equilibrium. The atomistic theory of diffusion describes the movement of particles through a medium and can be modelled using the diffusion equation or the random walk problem. Other mass transport mechanisms include convection and migration. Diffusion can occur in both steady and unsteady states. The diffusion process is driven by a concentration gradient in the semiconductors, resulting in a net movement of carriers from areas of high carrier concentration to areas of low carrier concentration. In conductors, diffusion can affect the conductivity by changing the carrier concentration. The effect of temperature on diffusion coefficients in semiconductors and the failure of electronic devices at high and low temperatures should be explained to students. Students should also be introduced to thin film deposition and forming in the context of the production of electronic components in smaller sizes. In microelectronic devices and circuits, semiconductors, metals and insulators coexist (usually in a multilayer scheme), leading to a constant concern about mixing and the consequent loss of desired functional behaviour. Diffusion barriers that are typically thin layers of metal or other materials placed between two other materials to protect them from corrupting each other in semiconductors are used to prevent the inter-diffusion of different materials, such as metals and semiconductors, which can degrade the performance of electronic devices. The choice of diffusion barrier depends on the specific application, anticipated operating temperature, and service life, such as nickel, nichrome, tantalum, hafnium, niobium, zirconium, vanadium, tungsten, and conductive ceramics like tantalum nitride, indium oxide, copper silicide, tungsten nitride. A table of properties for thin layer materials should be provided, outlining their specific characteristics. At the last part of the lecture, Electronic properties of metals should be presented and the focus should be on the conduction and superconductivity. Superconductivity is characterized by two features: the conduction of electrons with zero electrical resistance and the repelling of magnetic field lines. In a superconductor, electrons occupy specific electronic states, leading to unique electrical properties. A discussion should be held with students on the efficiency of interlayer thickness and its impact on the functioning of electronic components and different applications areas of superconductivity.

3. Learning outcomes

Students can elaborate on the concept of solid-state diffusion processes and their effect on the formation and properties of solid materials and gain knowledge on the role of lattice defects, such as vacancies, interstitials, and impurities, in diffusion processes; explain the process of diffusion in electronic materials, specifically the movement of charge carriers (electrons or holes) in semiconductors, and elaborate on the effect of temperature on diffusion coefficients in semiconductors and the failure of electronic components at high and low temperatures; explain on the types of diffusion barrier materials based on specific applications, anticipated operating temperature, and service life.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Chapters 1 and 2, Diffusion Processes in Advanced Technological Materials, edited by Devendra Gupta, William Andrews Publishing, NY, 2005

6. Additional notes

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Topics 4

1. The subject of the lecture

ASSEMBLY, MINIATURISATION, HYBRIDISATION IN MICROELECTRONICS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic introduces the processes of miniaturisation and hybridisation in microelectronics and their impact on the limitations of electronic materials and material selection. It also covers assembly problems associated with these processes. To provide students with a historical overview of miniaturisation in electronics, visuals with selective explanations should be used, avoiding excessive detail. Additionally, hybridisation should be connected to this part of the presentation. A tabulated list of information on historical development may also be prepared. Hybrid integrated circuits are electronic circuits that combine semiconductor devices and passive components on a substrate or printed circuit board. Students should be presented with the importance of miniaturisation and hybridisation in electronics, and how these processes have affected the selection of materials in the field. An introduction to the areas where these processes are most commonly used can also be provided. Miniaturisation involves reducing the size of electronic components and circuits, while hybridisation combines different types of components and technologies to create more efficient and effective systems. These trends are particularly important in fields such as space electronics, electronic warfare, and precision-guided weapons, where size and weight constraints are critical. The miniaturization of electronic circuits is achieved through the development of hybrid integrated circuits (HICs), which are constructed by soldering or bonding individual devices and passive components to a substrate or printed circuit board. Techniques such as thin film technology and active laser trimming are used to fine-tune hybrid circuits. Furthermore, techniques such as photolithography and deposition are employed to create miniaturized electronic devices. All of these techniques should be presented to students with sufficient detail for them to understand the processes. Students should be able to distinguish between the two processes: miniaturization, which reduces the size of electronic components and circuits, and hybridization, which combines different types of components and technologies to create more efficient systems. These trends are significant in various applications, such as electronic warfare, precision-guided weapons, and space applications. It is essential to inform students about the assembly issues in electronic circuits, particularly those observed in soldering. However, miniaturisation brings about different assembly problems that should also be explained to students. Assembly issues in electronics can significantly impact the functionality and reliability of the final product, particularly during the miniaturisation and hybridisation phases. During the assembly process, common issues may arise, such as problems with the incorrect PCB footprints, errors in component placement, soldering defects, thermal issues, lack of testability, inadequate silkscreen markings, incomplete or unclear assembly documentation, supply chain shortages and delays, rapidly changing technology, short product life cycles, and PCB layout problems. It is important to discuss the future of miniaturisation and hybridisation processes with students.

3. Learning outcomes

Students can distinguish between miniaturization, which involves reducing the size of electronic components and circuits, and hybridization, which combines different types of components and technologies to create more efficient systems; explain the assembly problems associated with miniaturization and hybridization, including issues in soldering, component placement, and thermal concerns; identify the areas where miniaturization and hybridization processes are commonly (to be) used, such as space electronics and electronic warfare.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Atherton, W.A. (1984). Miniaturization of Electronics. In: From Compass to Computer. Palgrave, London.

Charles, H.K., Miniaturized Electronics, Johns Hopkins APL Technical Digest, 26(4), 402-413, (2005)

6. Additional notes

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Topics 5

1. The subject of the lecture

SEMICONDUCTORS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic introduces semiconductor materials commonly used in modern equipment and communication devices. The text adheres to conventional structure and formatting features, including consistent citation and footnote style. It provides examples of diodes and transistors and defines coding to show the type of doping. Students should be taught about the concepts of self-resistance and its dominant factors, such as cold work, wire length, thickness or diameter, ambient temperature, and the amount of alloying elements. It is important to give special emphasis to the production of semiconductors and their historical development. Semiconductors are materials with resistivity between conductors and insulators. Semiconductor materials exhibit a decrease in resistance as temperature increases and vice versa. There are two types of semiconductors: intrinsic and extrinsic. Intrinsic semiconductors are pure, while extrinsic semiconductors contain impurities to enhance conductivity. Extrinsic semiconductors are further classified into two types: n-type and p-type semiconductors, depending on the type of doping. Doping is the deliberate introduction of impurities into an intrinsic semiconductor to modify its electrical properties. Doping semiconductors with pentavalent impurities results in n-type semiconductors, which have an excess of conduction electrons, and with trivalent impurities results in p-type semiconductors, which have a surplus of gaps called 'holes' that behave like positive charges. Intrinsic semiconductors, such as those doped with germanium and silicon, have a perfectly balanced number of free electrons and holes. Their conductivity increases exponentially with temperature. In contrast, extrinsic semiconductors have high electrical conductivity due to the intentional introduction of impurities. It is important to note that the language used in this text is clear, objective, and value-neutral, adhering to the characteristics outlined in the assignment. The conductivity of intrinsic semiconductors depends solely on temperature, whereas the conductivity of extrinsic semiconductors depends on both temperature and the level of doping. Extrinsic semiconductors, which are doped with impurities, have a significantly higher concentration of free electrons or holes, resulting in a substantial increase in their conductivity. This makes them useful for electronic devices. Semiconductor research also encompasses the study of the electronic behaviour of organic materials. Production methods for semiconductors are well-documented, and while doping can be localized to specific areas, temperature has a more widespread effect. A discussion should be held with students on the importance of ambient temperature on the functioning of semiconductors. The discussion should also include the knowledge gained in the previous topic to analyze and propose solutions for defects that tend to form during service with respect to n and p type doping.

3. Learning outcomes

Students can distinguish between the difference between n-type and p-type semiconductors and explain the two types of semiconductors: intrinsic and extrinsic based on the working mechanisms; define the doping, its effects on semiconductor properties, and the factors that influence self-resistance of semiconductors; explain the relationship between temperature and semiconductor conductivity for both intrinsic and extrinsic semiconductors and discuss the importance of ambient temperature on the functioning of semiconductors and its impact on electronic devices.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Oba, F., and Kumagai, Y., Design and exploration of semiconductors from first principles: A review of recent advances, Applied Physics Express 11 060101 (2018)

Morin, F.J., Semiconductors, Digest of Literature on Dielectrics, Washington, DC, USA, 1949, pp. 58-71

6. Additional notes

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Topics 6

1. The subject of the lecture

JUNCTIONS AND DEVICES

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic provides a detailed explanation of the junctions and devices used in advanced semiconductors for high power and high-speed switching applications. These components and phenomena are crucial for modern electronic devices and have applications in various fields, including radio frequency and microwave power generation, public or device display technology, lighting, and renewable energies such as solar power, wind power, and wave power stations as voltage and current regulator parts. The principles of Zener breakdown and resistance changes can be explained using concepts from metal-semiconductor junctions. This can be applied to control voltage and limit current in rectifying circuits. The collective use of P and N junctions, such as semiconductor PN junctions, can be described using basic technical terms. The commercial applications of semiconductor junctions include BJT (normal transistors), JFET transistors, LEDs, MOSFETs, and Schottky junctions. Solar cells and their production can also be discussed, along with common problems in establishing and running the junctions and cells. Furthermore, piezoresistivity, ohmic contacts, and thermoelectric coolers are important concepts in electronic materials and devices. These materials aid in comprehending electronic behaviour and designing and producing electronic devices. Metal semiconductor junctions are utilized in the fabrication of diodes and transistors, while PN junctions are employed in the production of solar cells and some special diodes. Zener breakdown is a phenomenon that occurs in diodes when a high reverse voltage is applied in a regulating circuit. BJT and JFET transistors are commonly used for amplification and switching, whereas LEDs are frequently used for lighting and display applications. MOSFETs are used for switching and amplification. Students should be mentioned of Schottky effect in semiconductors materials and the working mechanisms should be extensively explained as this is observed in other materials, too. Schottky junctions are utilized in the production of diodes and solar cells, whereas piezoresistivity is employed to measure mechanical stress. Ohmic contacts are utilized to create low resistance electrical contacts to semiconductors, while thermoelectric coolers are utilized for cooling applications, such as car coolers and thermic coolers used in tight spaces. Students should discuss the defect mechanisms and ambient temperature effects in advanced semiconductors and compare them to those mentioned in previous topics.

3. Learning outcomes

Students can define the junctions and devices used in advanced semiconductors for high power and high-speed switching applications and describe the principles of Zener breakdown and resistance changes and their application in controlling voltage and limiting current in rectifying circuits; explain the collective use of P and N junctions, such as semiconductor PN junctions, and their commercial applications in BJT (normal transistors), JFET transistors, LEDs, MOSFETs, and Schottky junctions; explain the working principle of solar cells and their production, along with common problems in establishing and running the junctions and cells; define the piezoresistivity, ohmic contacts, and thermoelectric coolers and their importance in electronic materials and devices with the phenomenon of Zener breakdown in diodes when a high reverse voltage is applied.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Milnes, A.G., Chapter 2 and 4, Heterojunctions and Metal Semiconductor Junctions, Elsevier, (2012)

Sharma, B. L. and Purohit, R. K., Chapters 1 and 3, Semiconductor Heterojunctions, Elsevier, (2015)

6. Additional notes

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Topics 7

1. The subject of the lecture

MAGNETIC PROPERTIES AND SUPERCONDUCTIVITY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the self-magnetic properties of metallic materials under the influence of a magnetic field. It provides an extended view of the types of magnetism, Curie temperature, and magnetic domains, as well as their theoretical principles. Students should be familiarized with the concepts of hard and soft magnetic properties, as well as saturation magnetization of materials commonly used in the production of sensors and electronic devices. The students should be introduced to the selection criteria for detecting magnetic properties in a tabulated form, with links to external magnetic fields and signals. It is important to explain the concept of magnetic domains briefly and reference the sensors. The magnetization of matter is a complex phenomenon that involves the alignment of atomic magnetic moments in a material. The creation of magnetic domains is responsible for the material's response to an external magnetic field. Metallic and non-metallic magnetic materials have specific applications, such as high-frequency manipulation and signal generation in radio frequency applications. These materials can be classified according to their magnetism types, such as ferromagnetism and paramagnetism. Ferromagnetic materials, including iron, nickel, and cobalt, exhibit a unique behaviour called ferromagnetism, where the atomic magnetic moments are aligned, resulting in a strong magnetic response. One valuable property of magnetic materials is their saturation in a magnetic field. Saturation magnetization is the maximum magnetization that can be achieved when all magnetic domains are aligned in ferromagnetic materials. The Curie temperature is the temperature at which ferromagnetic materials lose their ferromagnetic properties and become paramagnetic. The temperature at which a ferromagnetic material becomes non-magnetic is unique to each material. For instance, iron's Curie temperature is approximately 1043 K. Magnetic materials of the latest generation, such as powder, sheet, film, and highly cooled amorphous structures, can be categorized based on their magnetic behaviour, including ferromagnetic, paramagnetic, antiferromagnetic, and ferrimagnetic. Soft and hard magnetic materials have different applications based on their magnetic properties. Soft magnetic materials are easily magnetized and demagnetized, while hard magnetic materials retain their magnetization. Superconductivity is another fascinating phenomenon observed in certain materials, where they exhibit zero electrical resistance when cooled below a critical temperature. Hall effect and sensors based on this property should also be explained to the students. Typical sensors for magnetic field measurements (direction, strength etc…) and flux should be introduced to students and these should be linked to magnetic properties of materials and earth. A discussion on the use of magnetic materials in different working environments should be initiated and students should be asked to contribute to the topic with their knowledge on the topic.

3. Learning outcomes

Students can define types of magnetism, Curie temperature, magnetic domains, hard and soft magnetic properties, saturation magnetization, and selection criteria for detecting magnetic properties; classify the types of magnetic field sensors and the production of sensors and electronic devices with specific effects such as Hall effect; define the magnetism and determine the type of magnetic materials for a specific application.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Slusarek B., Zakrzewski, K., Przegląd Elektrotechniczny (Electrical Review), ISSN 0033-2097, R. 88 NR 7b/2012

J. Lenz and S. Edelstein, "Magnetic sensors and their applications," in *IEEE Sensors Journal*, vol. 6, no. 3, pp. 631-649, June 2006

6. Additional notes

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Topics 8

1. The subject of the lecture

OPTICAL PROPERTIES OF MATERIALS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the light radiation detecting and/or analysing sensors which are sensitive to wavelength or intensity of the incident light. In addition, the optical properties of materials and types of measurements of important optical properties should also be included in a tabulated form in order to inform students in a collective manner. Students should be made aware of optical properties of both commonly known inorganic and organic materials and their capacity of reflecting and/or absorbing the light in different mediums such as liquid and solids. Engineers and scientists study optical materials to control properties of materials effectively, measuring optical parameters to design devices with specific functionalities. The conception of light waves, refractive index, dispersion effects, magnetic fields, and optical materials forms the foundation for advancements in technology of optical devices. Students should be informed about the internal reflection that is the phenomenon involving the reflection of the entire incident light. Students should be given information about the commercial sensors for various light radiation such as UV, Infrared, white light or specific colour sensor. Light-detecting sensors or photo-detectors are devices that convert light energy into electrical signals. These sensors are widely used in various applications, ranging from simple consumer electronics to complex scientific instruments and systems. The semiconductor materials that are sensitive to light radiation should be categorised based on their functionalities such as photo resistors change the resistance of the circuit e.g. increases or reduces the total resistance for applications such as automatic lighting control in streetlights or outdoor security lights. Photodiodes are one of the most used components in electronics especially in light meters, cameras, and optical communication systems. Phototransistor sensors amplify the current and voltage with high sensitivity. Photovoltaic or solar cells convert light energy directly into electrical energy through the photovoltaic effect generated by the light sensitive components. Photonic sensors use the interaction of light with materials to measure various physical quantities such as pressure, temperature, or chemical composition. Fiber optic sensors fall into this category. (CCDs) and CMOS Sensors in imaging devices are used to capture and convert light into electrical signals. Pyro-electric Sensors detect changes in infrared radiation and are commonly used in motion detectors and thermal imaging devices. Light Emitting Diodes can be used as sensors reverse-bias as photodiodes to detect light. This property is known as the "photo-electric effect”. The choice of a light-detecting sensor depends on factors such as sensitivity, response time, spectral range, and application requirements. These sensors play a crucial role in a wide range of fields, including electronics, telecommunications, medicine, astronomy, and environmental monitoring. Light waves play a fundamental role in optics, where their behaviour is influenced by factors such as refractive index and dispersion effects. The wavelength behaviour is crucial in optical studies, as different materials display unique dispersion patterns. Furthermore, the interaction of light waves with magnetic fields introduces a fascinating dimension to optics. Students should involve a discussion regarding the type of light and sensitivity of sensors available in market.

3. Learning outcomes

Students can explain the role of light-detecting sensors in various fields, including electronics, telecommunications, medicine, astronomy, and environmental monitoring; elaborate about the optical properties of materials, including commonly known inorganic and organic materials, and their capacity to reflect and/or absorb light in different mediums such as liquids and solids; explain the concept of light radiation detecting and analyzing sensors, which are sensitive to wavelength or intensity of incident light; explain the functionality of different semiconductor materials sensitive to light radiation, including photo resistors, photodiodes, and phototransistor sensors.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Naseer Sabri et al, Toward Optical Sensors*:* Review and Applications*,* J. Phys.: Conf. Ser. **423** 012064, 2013

Haus, J., Part 2, Optical Sensors: Basics and Applications, John Wiley & Sons, Jan 12, 2010

6. Additional notes

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Topics 9

1. The subject of the lecture

DIELECTRIC MATERIALS AND INSULATION

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to inform about the dielectric materials that are used in electronic components and electrical circuits. Students should be informed about the dielectric materials in the form of tabulated form and the use of such materials in making capacitors, circuits and cables etc... Students should also be aware of the common and special dielectric materials used for special applications and theoretical principles behind. Detailed information regarding the electronic properties of materials and mostly related to dielectric properties such as polarisation, frequency dependence of dielectric materials should be given to students. A short list of common insulators should be sufficient. Various properties such as Dielectric polarization which occurs when a dipole moment is formed in an insulating material due to an externally applied electric field. Electronic polarization is always inherent in a dielectric material and is a mechanism that contributes to the relative permittivity of a material, particularly in covalent solids. It is due to the displacement of electrons in the covalent bonds and is one of the polarization mechanisms that determine the total dielectric behaviour of a material. Students should be given information regarding the frequency response as it is important for high frequency transformers and coils and also ceramics. The frequency dependence of the real and imaginary parts of the dielectric constant is influenced by various polarization mechanisms, including electronic polarization. Gauss's Law relates to dielectric polarization by being modified to account for the presence of bound charges in dielectric materials. When a dielectric material is placed in an electric field, it becomes polarized, leading to the displacement of charges and the creation of bound charge surfaces. This polarization gives rise to an induced electric field, which opposes the external electric field. This reduction of the electric field is proportional to the dielectric constant of the material. Students can also be given information about the high voltage puncture current of insulator and hence the effectiveness in preventing the voltage drop and conductivity in critical applications. These applications may cover the use of these materials in high voltage transmission lines and high voltage cathode tubes. Students should involve a discussion regarding the use of dielectric and insulating materials in electronic circuits where human injury risk is present and propose a solution for locations in circuits.

3. Learning outcomes

Students can explain the theoretical background of dielectric materials and insulators that are used in electronics; elaborate the basic terms regarding the dielectric properties of materials and insulators; propose a solution to insulation and dielectric problems that humans face during the control of electric and electronic circuits; also differentiate between the different insulations and dielectric materials with respect to their potential use.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

https://www.matsusada.com/column/dielectrics_vs._insulators.html,

Kao, K.C., Dielectric Phenomena in Solids. London: Elsevier Academic Press. pp. 92–93, (2004).

6. Additional notes

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Topics 10

1. The subject of the lecture

PIEZOELECTRICITY, FERROELECTRICITY AND PYROELECTRICITY SENSORS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to give extensive information about the Piezoelectricity and its practical effect of some materials and theoretical background about Piezoelectricity. Students should also be given common materials that show Piezoelectricity and commercial materials that are actively used in sensors for vibration and its frequency measurement. It is also important to mention the fact that most of the electronic equipments employ these materials to generate vibration, sound and ultrasound to measure distances and even to reveal defects inside bulk materials. Some applications can go as far as sonar devices to visualise the sea bed or fish schools in the sea. These sensors can also be used to measure relative density of gases or generate water vapour to humidify the room. The piezoelectric effect is also used in applications of the production and generation of high voltages, electronic frequency generation, microbalances, and ultra-fine focusing of optical assemblies. These sensors or materials deserve more recognition. Another important group of materials is pyroelectric materials, not as wide spread as Piezoelectricity, these materials also find good use in industrial applications especially in thermal measurement. Students should be given these materials in a tabulated form. As a short, Piezoelectricity is the indication of potential electric charge effect in response to applied mechanical stress in certain solid materials, e.g. crystals, ceramics, and biological matter like bone, and proteins. Materials like quartz, ferroelectric and pyroelectric crystals, and polymer composites show such behaviours. When a piezoelectric material is mechanically stressed, it generates an external electrical field between the opposing faces of the crystal due to the shift of positive and negative charge centres. Ferroelectric and pyroelectric crystals are two types of materials with distinct electrical properties that differ from piezoelectric materials. Ferroelectric crystals have an internal electric field that can be reversed by an external polarising field. This results in a reversal of nonlinearity for certain light polarizations, as seen in optical microscope filters. They also have a spontaneous electric polarization that can be reversed by an electric field, making them useful in various applications, including capacitors, sensors, and actuators. Pyroelectric crystals have a spontaneous electric polarization that changes with temperature, generating an electric field. It is important to note that while all ferroelectric materials are pyroelectric, the reverse is not always true. These crystals have unique properties that make them valuable for various technological applications. It should be noted that their field of use is not limited to the applications mentioned above. There are various applications, including specific military and laser interferometry. Students should discuss the extent to which these materials can be combined in equipment to measure the thickness of a light beam and coatings on non-metallic materials.

3. Learning outcomes

Students can explain the effect of piezoelectricity and list the materials that show Piezoelectricity, such as quartz, ferroelectric and pyroelectric crystals, and polymer composites with extensive therotecial background; elaborate on the effect of pyroelectricity and ferroelectricity with common applications and potential applications fields; suggest and select a proper sensor for an exemplary industrial application based on their knowledge obtained in this topic.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Gautschi, G., Piezoelectric Sensorics: Force, Strain, Pressure, Acceleration and Acoustic Emission Sensors, Materials and Amplifiers, Springer (2002)

Damjanovic, D., Ferroelectric, dielectric and piezoelectric properties of ferroelectric thin films and ceramics, Reports on Progress in Physics, 61 (9): 1267–1324, (1998).

Migliorato, M. et al., A Review of Non Linear Piezoelectricity in Semiconductors. AIP Conference Proceedings. AIP Conference Proceedings. 1590, 32–41, (2014).

Wu, J., Perovskite lead-free piezoelectric ceramics, *Journal of Applied Physics*, **127** (19), (2020).

6. Additional notes

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Topics 11

1. The subject of the lecture

SENSORS: MORE INFORMATION, STRAIN AND PRESSURE SENSORS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to provide more information on the working principles of sensors in the first stage, and then to introduce the sensors that detect and respond to physical stimuli such as mechanical strain, force and pressure. Sensors are critical components in a wide range of systems such as industrial automation, medical equipment, transportation and consumer electronics. Active sensors have the advantage of operating in low power conditions, such as low light, and measuring various target parameters in adverse conditions. However, they consume more power and can be affected by interference. Passive sensors, on the other hand, are more covert, consume less power and are not affected by weather conditions. However, they are dependent on natural radiation and have limitations in measuring target parameters. The choice between active and passive sensors depends on the specific application and the environmental conditions in which they will be used. As mentioned in other topics, there are other different types of sensors that detect different physical parameters and respond to physical effects. These types of sensors are very common in domestic appliances and in high-precision equipment such as thermal analysis devices, which measure the exact weight of the substance under investigation to an accuracy of a tenth of a milligram. Students should be informed about the use of simple and extreme measurements using different force and strain sensors. For example, strain gauges measure the deformation or elongation of an object under external forces. They can be made of metal foil, which is the case for most sensors, or carbon strips, which are sensitive enough to measure strain. Load cells, measure force based on the deflection of load carrying metal bar and, are commonly used in weighing scales with a conversion. Interferometry and fibre optic methods are utilised to measure strain and displacement with high accuracy. Measuring ambient and confined volume pressure is also very important for industrial applications. Pressure of a cabin or vacuum level of a container requires sensitive sensors with a high precision output. Pressure gauges, such as Bourdon gauges and diaphragm gauges, are commonly used to measure pressure. Ionisation gauges, on the other hand, are typically used to measure low pressures. It is recommended that students discuss the use of vacuum gauges for force measurements in space applications. Additionally, they could suggest an application example that utilises a combination of force and strain sensors to replace complicated sensors in various sectors.

3. Learning outcomes

Students can understand the working principles of sensors and their role in various systems such as industrial automation, medical equipment, transportation, and consumer electronics; explain the advantages and disadvantages of active and passive sensors, and their choice based on specific applications and environmental conditions; elaborate on different types of sensors that detect various physical parameters and respond to physical effects; propose sensors for a specific application regarding the measurement of force and strain in a structure under a load; emphasize the importance of measuring ambient and confined volume pressure in industrial applications, and the use of pressure gauges and ionisation gauges for pressure measurements.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Gautschi, G., Piezoelectric Sensorics: Force, Strain, Pressure, Acceleration and Acoustic Emission Sensors, Materials and Amplifiers, Springer (2002)

6. Additional notes

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Topics 12

1. The subject of the lecture

POSITION, DIRECTION, DISTANCE AND MOTION SENSORS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to give detailed information about the position, direction, distance and motion sensors and their working principles. Examples of use of these sensors should be introduced to the students in applications where precision is important. It is also important to mention that these sensors are extremely common in many devices and even in watches and mobile phones. Position (linear or rotational), direction sensors and Hall effect sensors are in general a group of sensors that are used to refer to a variety of sensor technologies used for measuring distance between objects or from a reference point, for direction to and from a reference point in space, and magnetic fields. Hall effect is slightly different than other because of its double use in both magnetic field measurement but also in determination of pole position by using magnets and earth pole magnetic field. These specific sensors have many diverse industrial applications, including distance measurements in open and closed or confined areas with or without the aid of energy beams, rotational position sensing such as in angle measurement in a cylindrical route as in step motors, and motion tracking as in line tracer etc... Students should be able to explain the working principles of these sensors and then metallurgical and electronic structures of these sensors should be explained to students based on the type of sensor materials. The Hall effect sensor, for instance, is a type of magnetic sensor that can detect the strength and direction of a magnetic field, and it is commonly used for position sensing, revolution counting, and current sensing, as given in topic or lecture 7. Background information and working principle of hall effect sensors can be re-given to the students. Other sensor technologies such as LVDT (Linear Variable Differential Transformer) sensors, accelerometers, and encoders are also used for similar purposes. For example, LVDT sensors are commonly used for measuring displacement in system with the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal, while accelerometers are used to measure acceleration of a moving object and detect changes in velocity in any direction. Encoders, on the other hand, are used to convert motion into an electrical signal for various applications as in tensile test machines to count the revolution of tensile screws. Overall, these sensor technologies play a crucial role in a wide range of industries, including automotive, aerospace, and manufacturing, and they enable the precise measurement of physical quantities for control and monitoring purposes. Students should involve a discussion regarding the use of these sensors in cooperation with piezoelectric sensors to build a free fall impact tester to measure various parameters.

3. Learning outcomes

The students can explain the basic working principles of distance, direction and motion sensors and their structural properties; classify the distance, motion and direction sensors based on their properties and elaborate the limits and advantages and disadvantages in use; describe the practical applications of these sensors and critically analyse any given application and suggest a proper sensor for the given application.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Wilson, J.S., Chapter 15, Sensor Technology Handbook, Elsevier, 2005.

6. Additional notes

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Topics 13

1. The subject of the lecture

RADIATION SENSORS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to provide a thorough overview of radiation and radiation detecting sensors. Students should be introduced to radiation as one of the forms of energy released directly from the atomic level interaction of nuclear materials. Students should be introduced to the history of the study of radiation and its effects on biological tissues. Students should also be aware of the relationship between the energy of radiation and the type of radiation, and precautions for the safety of personnel from all types of radiation should also be mentioned. A specific mention of ionising radiation should be emphasised, as this is the more common form of radiation that has an effect. Ionising radiation and its interaction with matter, focusing on the energy absorbed, is quantified by radiation dosimetry. Since the detection and measurement of radiation is based on the detection and measurement of its effects in a medium, several properties of materials need to be reviewed in terms of their radiation response characteristics. The potential health risks associated with ionising radiation depend on factors such as the type of radiation, the dose, the duration of exposure and the sensitivity of the exposed tissues. In some industrial sectors, such as medicine and defence, the use of sensors is critical, for example the need to detect and control X-rays produced in medical imaging and α, β and γ radiation. The working principle of radiation sensors should be given to students based on material-energy beam interaction, such as the half-life concept, radiation damage to the detection material, etc. Radiation sensors or detectors convert a portion of the energy lost by incident radiation into an electrical signal, i.e. each radiation detector can detect a specific type of radiation. However, the energy range of the detector determines which sensors are best suited to a particular application. Nevertheless, there are certain radiation detectors, called nucleonic detectors, which can detect both nuclear particles and electromagnetic radiation. Students should be given information about dosimeters, commonly referred to as radiation dosimeters. These sensors are made for many different purposes and by many different compounds that are selectively good for certain ionising radiation; which can be checked at certain duration. Dosimetry is concerned with the techniques for calculating the dose of radiation that has been absorbed by material or body components. Personnel who are likely to be exposed to hazardous radiation wear portable dosimeters on their skin or clothing. Students should also be informed that ionisation chambers, proportional counters, Geiger-Muller tubes, scintillation counters and semiconductor detectors are used to monitor and quantify α, β, γ and neutron radiation in the environment. Students should be involved in a discussion on the impact of disasters such as Chernobyl and its effect on neighbouring countries.

3. Learning outcomes

Students can discuss the radiation effect on materials and explain how radiation detecting sensors work in general; relate the radiation(s) as a form of energy released from atomic level interaction of nuclear materials, and their effects on biological tissues; explain the precautions necessary for safety, and potential health risks associated with ionizing radiation; describe working priniples of normal and specific types of radiation detectors and their applications, including dosimeters, ionization chambers, proportional counters, Geiger-Muller tubes, scintillation counters, and semiconductor detectors.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

Dhanekar, S., Rangra, K., (2021) Wearable Dosimeters for Medical and Defence Applications: A State of the Art Review. Adv. Mater. Technol. 6, 2000895

K.A. Pradeep Kumar, G.A. Shanmugha Sundaram, B.K. Sharma, S. Venkatesh, R. Thiruvengadathan, (2020). Advances in gamma radiation detection systems for emergency radiation monitoring. Journal of Nuclear Engineering and Technology, 52, 2151-2161

6. Additional notes

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Co-funded by the European Union

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

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SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SUSTAINABLE WASTE AND RECYCLING MANAGEMENT IN MANUFACTURING PROCESSES

Code: SWRMMP

UNIVERSITY OF SILESIA IN KATOWICE

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Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO RECYCLING AND WASTE MANAGEMENT

2. Thematic scope of the lecture (abstract, maximum 500 words)

Recycling and waste management are essential components of modern manufacturing and environmental sustainability. The concept of recycling revolves around converting waste materials into new products, reducing the consumption of fresh raw materials, decreasing energy usage, limiting air and water pollution, and lowering greenhouse gas emissions. In essence, recycling helps to sustain the environment for future generations by efficiently managing resources. In the manufacturing industry, the recycling process generally involves several key steps. Firstly, waste materials are collected and transported to recycling facilities. This is followed by sorting and cleaning, where waste is categorized, and contaminants are removed to ensure the quality of the end product. The next step involves processing and converting these sorted materials into raw formats like sheets, pellets, or fibers. These materials are then used to manufacture new products. The final step encompasses selling and purchasing these recycled goods, completing the cycle. Recycling has a profound impact on the manufacturing industry. It conserves natural resources like wood, water, and minerals and significantly reduces the energy expenditure typically required in the production process. This energy efficiency is mainly because manufacturing with recycled materials often requires less energy than producing the same goods with virgin materials. Furthermore, recycling helps industries to reduce their carbon footprint, contributing to environmental protection and sustainability. It also opens up economic opportunities, creating jobs in the recycling sector and fostering a market for recycled products. Waste production is an inevitable byproduct of manufacturing, but effective waste management strategies are crucial. These strategies involve reducing waste generation at the source, optimizing resource usage, and implementing recycling practices. Proper waste management helps conserve natural resources and minimizes environmental pollution. Effective waste management plays a vital role in environmental conservation by reducing landfill usage and decreasing the release of harmful gases. The impact of recycling and waste management on the manufacturing industry is multifaceted. It promotes environmental stewardship, enhances resource efficiency, and encourages the development of green technologies. It also pushes industries towards more sustainable practices, aligning with global efforts to combat climate change and environmental degradation. Additionally, it influences consumer behavior, with a growing preference for products made from recycled materials. In sum, recycling and waste management are not just environmental imperatives but also key factors driving the evolution of the manufacturing industry towards more sustainable and responsible practices.

3. Learning outcomes

Students can elaborate on the basics of recycling, including its purpose of converting waste into new products, reducing raw material consumption, energy usage, and environmental pollution; explain the recycling stages in the manufacturing industry, encompassing collection, sorting, processing, and the manufacture and sale of recycled products; show how recycling conserves natural resources, reduces energy expenditure, and lowers carbon footprints, contributing to environmental sustainability and economic growth; recognize the importance of effective waste management in manufacturing, focusing on waste reduction, resource optimization, and pollution minimization; explain the multifaceted influence of recycling and waste management, including promoting sustainable practices, advancing green technologies, and shaping consumer preferences for recycled products.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 2

1. The subject of the lecture

Sustainability Issue and Manufacturing

2. Thematic scope of the lecture (abstract, maximum 500 words)

Sustainability in manufacturing has become a critical issue in the contemporary industrial landscape. This concept involves creating products in ways that are environmentally friendly, economically viable, and socially responsible. The core challenge in sustainable manufacturing lies in balancing these three aspects – often called the triple bottom line of sustainability: planet, profit, and people. From a cost perspective, sustainable manufacturing seeks to minimize resource use and waste, leading to long-term cost savings and operational efficiency. This approach often involves investing in energy-efficient technologies, reducing material waste through lean manufacturing processes, and recycling or reusing materials. While the initial investment in sustainable practices might be high, the long-term savings in resources and the potential increase in market share due to consumer preference for sustainable products can lead to significant financial benefits. Additionally, sustainable practices can protect companies from the volatility of raw material prices and the increasing costs associated with waste disposal. Labor in sustainable manufacturing focuses on ensuring fair practices, safety, and well-being of the workforce. It involves creating a working environment that respects workers' rights and promotes development. This aspect is crucial as it not only affects the ethical standing of a company but also influences productivity and product quality. A committed and healthy workforce is more likely to produce high-quality products and contribute to the innovation necessary for sustainable manufacturing. The relationship between product design and sustainability is also paramount. Sustainable products are designed with their entire lifecycle in mind, including recyclability and biodegradability. This approach reduces the environmental impact of products both during their use and at the end of their life. Moreover, companies are increasingly adopting the principles of the circular economy, whose goal is to eliminate waste and keep resources in use for as long as possible. Sustainable materials are central to this approach. Using renewable, recycled, or biodegradable materials reduces the environmental footprint of products. However, there are challenges in ensuring that these materials meet the required quality standards and performance criteria. Research and innovation in materials science are crucial to overcoming these challenges, allowing for the broader adoption of sustainable materials in manufacturing. In summary, sustainability in manufacturing involves a holistic approach that considers environmental, economic, and social factors. It encompasses efficient use of resources, responsible labor practices, sustainable product design, and eco-friendly materials. While there are challenges in implementation, particularly in terms of cost and maintaining product quality, the move towards sustainable manufacturing is essential for the industry's long-term viability and the planet's well-being.

3. Learning outcomes

Students can explain the concept of sustainable manufacturing, which involves environmentally friendly, economically viable, and socially responsible production practices, aligning with the triple bottom line of sustainability; comment on long-term cost savings and operational efficiency gains from sustainable practices despite potentially high initial investments; recognize the importance of fair, safe, and respectful labor practices in sustainable manufacturing and their impact on productivity and product quality; explain the significance of designing products with sustainability in mind, focusing on their entire lifecycle, including recyclability and biodegradability; identify the challenges of using sustainable materials that meet quality standards and the role of research and innovation in overcoming these challenges for wider adoption in manufacturing.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

IAssimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 3

1. The subject of the lecture

Waste Production in Industry and Recycling Methods

2. Thematic scope of the lecture (abstract, maximum 500 words)

Waste production in the industrial sector is a significant concern due to its environmental impact and resource depletion. The causes of industrial waste production vary but commonly include inefficient production processes, lack of product design for recyclability, overproduction, and use of non-renewable materials. The classification of industrial waste involves categorizing it based on its nature and potential for recycling or disposal. This can include hazardous wastes (chemicals, metals), non-hazardous wastes (paper, wood), and special wastes (electronic, medical). The complexity of this classification stems from the diverse range of materials and processes used across different industries. Sustainable waste reduction methods are increasingly being adopted to mitigate the environmental impact of industrial waste. These methods focus on reducing waste at the source, optimizing production processes, and designing products with their end-of-life in mind. Reducing material usage, improving process efficiency, and incorporating eco-friendly materials are crucial strategies in this approach. Additionally, implementing lean manufacturing principles can significantly minimize waste by optimizing resource usage and reducing overproduction. The emphasis is on creating a circular economy, where the waste of one process becomes the input for another, thereby maximizing resource efficiency and sustainability. Recycling is a crucial component in managing industrial waste effectively. Recyclable products include metals, plastics, glass, paper, and certain types of electronic waste. However, recycling these materials involves challenges related to separation, contamination, and the economics of recycling processes. The cost issues associated with recycling can be significant, especially when dealing with complex materials or low-value waste. Despite these challenges, recycling remains a preferred option due to its potential to conserve resources, reduce landfill use, and lower the carbon footprint associated with material production. Innovation in recycling technologies and methods continues to evolve, aiming to make the process more efficient and cost-effective. The best practices in recycling and sustainable waste management involve an integrated approach that combines technology, policy, and consumer behavior. This includes developing efficient collection and sorting systems, investing in advanced recycling technologies, and encouraging industry-wide standards for waste management. Policies that promote extended producer responsibility, where manufacturers are accountable for the end-of-life management of their products, can significantly enhance recycling rates. Public awareness and participation are also crucial, as informed consumers can drive demand for sustainable products and recycling services. Ultimately, the goal is to transition towards a circular economy model, where waste is minimized, resources are optimally used, and recycling becomes a natural part of the industrial process.

3. Learning outcomes

Studnets can recognizing various sources of industrial waste and comprehending the classification system based on waste type, including hazardous, non-hazardous, and special wastes; comment on strategies to reduce waste at the source, optimizing production processes, and designing products for end-of-life recyclability to promote environmental sustainability; explain different recyclable materials and understanding the complexities and cost issues involved in recycling processes; recognizing the significance of recycling in conserving resources, reducing landfill usage, and lowering carbon footprints; describe the importance of an integrated approach that combines technology, policy, and consumer behavior for effective recycling and sustainable waste management.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 4

1. The subject of the lecture

Sustainable Waste Utilization in Heavy Metal Industry

2. Thematic scope of the lecture (abstract, maximum 500 words)

Sustainable waste utilization in the heavy metal industry, particularly in iron production, is an area of growing importance. This industry, fundamental to modern infrastructure and manufacturing, faces significant environmental challenges due to the large volumes of waste it generates. Addressing these challenges involves innovative waste management and recycling approaches, specifically focusing on the byproducts of iron production, such as slag and pig iron waste. Iron production facilities, primarily blast and electric arc furnaces, are the primary iron and steel production sources. Iron ore is reduced to pig iron in the blast furnace process, generating a by-product known as blast furnace slag. This slag, composed of silicates and aluminates of calcium and other bases, is typically granulated and used in cement production, road construction, and soil stabilizers. Pig iron waste, on the other hand, includes off-gases and particulate matter, which are often treated and recycled internally within the plant. Electric arc furnaces, used in recycling scrap steel, also produce slag, though of a different composition, along with dust and gas emissions. Melting furnaces in iron and steel manufacturing, including blast and electric arc furnaces, contribute significantly to waste generation. Classifying these wastes depends mainly on their composition and potential for recycling. For instance, slag can be categorized based on its metallic content, potential for hazardous leaching, and suitability for various secondary uses. Other wastes include refractory materials, furnace linings, and emissions captured during the melting process. Proper classification is crucial for effective recycling and waste management strategies. Recycling of blast furnace waste primarily involves the reutilization of slag. Methodologically, this process includes the cooling and processing of slag to form granules or aggregates. These materials are then used in various applications, such as road bases, concrete, and asphalt binders in the construction industry. An example of successful recycling is seen in using slag in cement production, where it replaces Portland cement, reducing the environmental impact of cement manufacturing. Another example is the recovery of metals from slag, which can be reused in the steelmaking process. This conserves resources and reduces the need for landfilling, thereby contributing to environmental sustainability. In summary, sustainable waste utilization in the heavy metal industry, particularly in iron production, involves the innovative recycling and management of various by-products like slag and emissions. These efforts not only mitigate the environmental impacts of the industry but also contribute to resource conservation and economic efficiency. The success of these recycling initiatives depends on effective waste classification, innovative processing techniques, and finding viable secondary uses for these materials.

3. Learning outcomes

Students can elaborate on the types of waste generated in iron production facilities, including blast furnace slag and pig iron waste; comment on the different wastes produced by melting furnaces, such as slag and emissions, and their classification based on composition and recycling potential; acquire insights into the methods and processes involved in recycling blast furnace waste, particularly slag; explain the importance of sustainable waste utilization in the heavy metal industry and its impact on environmental conservation and resource efficiency.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 5

1.	The subject of the lecture

Sustainable Waste Utilization in Light Metal Industry

2.	Thematic scope of the lecture (abstract, maximum 500 words)

Sustainable waste utilization in the light metal industry, focusing on aluminum, titanium, and magnesium, is gaining significant attention due to environmental and economic benefits. Due to their favorable strength-to-weight ratios and corrosion resistance, these metals and their alloys are essential in various sectors, including automotive, aerospace, and construction. However, their production routes often lead to substantial waste generation, prompting a need for efficient recycling and waste management strategies. Aluminum is primarily produced through the Bayer process for alumina extraction, followed by the Hall-Héroult process for smelting. This production route generates red mud and spent pot lining (SPL) as major waste products. Red mud, a byproduct of the Bayer process, is a primary environmental concern due to its alkalinity and large volume. SPL, a waste from the Hall-Héroult process, contains hazardous materials like cyanides and fluorides. Titanium production, mainly through the Kroll process, generates chlorides and other chemical waste. Magnesium is commonly produced using the Pidgeon process, leading to the generation of slag and off-gases containing greenhouse gases. The wastes from these processes pose challenges regarding safe disposal and environmental impact. Recycling in the light metal industry offers a path to mitigate these environmental impacts. Aluminum recycling is well-established, with scrap aluminum being remelted and reused, significantly reducing the energy requirement compared to primary production. Recycling aluminum also lessens the volume of red mud and SPL generated. Titanium recycling, though more complex due to its reactive nature, is becoming increasingly important in reducing the environmental footprint of its production. Scrap titanium is often recycled through remelting or blended with virgin titanium in alloy production. While less common, magnesium recycling is gaining traction due to its energy efficiency and reduction in greenhouse gas emissions. The impact of recycling on producing aluminum, titanium, and magnesium alloys is profound. Recycling helps in conserving natural resources and reducing energy consumption. For instance, recycling aluminum saves about 95% of the energy required for primary production. It also helps in reducing the environmental impact of waste disposal. Introducing recycled materials into the production of alloys can sometimes alter their properties. For aluminum and magnesium alloys, careful control of the recycling process is essential to maintain quality. For titanium, the challenge lies in preventing contamination during recycling to preserve the desirable properties of the alloy. In conclusion, sustainable waste utilization in the light metal industry is crucial for environmental conservation and resource efficiency. While producing aluminum, titanium, and magnesium generates significant waste, recycling offers a viable solution to reduce this impact. Recycling conserves resources and energy and helps maintain the quality of these light metals in their alloy forms, contributing to a more sustainable future in metal production.

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3. Learning outcomes

Students can elaborate the types of waste generated in producing aluminum, titanium, and magnesium, including red mud and spent pot lining (SPL) for aluminum, chlorides from titanium, and slag from magnesium; explain the environmental and energy-saving benefits of recycling aluminum, titanium, and magnesium and how it reduces the volume of hazardous waste; show how recycling impacts the quality and properties of light metal alloys; explain the role of recycling in conserving natural resources and reducing energy consumption in the light metal industry.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**.

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 6

1. The subject of the lecture

Plastic Waste Treatment and Sustainability Issue

2. Thematic scope of the lecture (abstract, maximum 500 words)

Plastic waste treatment and its sustainability issues are critical to environmental management, given the widespread use and persistent nature of plastics. The production of plastics involves various manufacturing routes, each with its own ecological footprint and waste generation profile. These routes primarily include polymerization processes, such as addition polymerization for plastics like polyethylene and polypropylene and condensation polymerization for polyesters and nylons. The choice of manufacturing route influences the type and amount of waste produced, as well as the physical and chemical properties of the plastics, which in turn affect their recyclability and environmental impact. The manufacturing processes of plastics significantly contribute to waste production. For instance, addition polymerization often involves significant energy consumption and the generation of by-products that may be hazardous. In contrast, condensation polymerization produces water as a by-product, which is less harmful but still contributes to waste. The production methods also determine the type of plastic made –thermoplastic or thermosetting. Thermoplastics, being remeltable, are more amenable to recycling, whereas thermosetting plastics, which cannot be remelted, pose a more significant challenge in waste treatment. The types of additives used in plastics, like plasticizers, fillers, and colorants, further complicate their recycling and environmental impact. Recycling of plastics is a significant issue in addressing the sustainability challenges posed by plastic waste. While mechanical recycling, where plastics are melted and remolded, is the most common method, it is often limited to certain types of plastics and can lead to degradation in quality. Chemical recycling, which breaks down polymers into their monomers, offers a potential solution for a broader range of plastics but is more energy-intensive and technologically demanding. Globally, the challenges in plastic recycling include the lack of infrastructure for efficient waste collection and sorting, technological limitations in processing mixed or contaminated plastics, and the economic viability of recycling processes compared to the production of new plastics. The sustainability issues related to plastic waste treatment are further exacerbated by the sheer volume of plastic waste generated globally and its environmental impacts. Not recycled plastics end up in landfills or the natural environment, where they can persist for hundreds of years, releasing toxins and microplastics that harm wildlife and ecosystems. The global challenge lies in developing more sustainable production methods, improving recycling technologies and systems, and reducing reliance on single-use plastics. Efforts towards these goals include the promotion of biodegradable plastics, advancements in recycling technologies, and policies aimed at reducing plastic consumption and waste. In conclusion, treating plastic waste and the associated sustainability issues requires a multifaceted approach. This involves reconsidering plastic production methods, improving recycling processes, and addressing global waste management infrastructure and technology challenges. The urgency of these issues calls for collective efforts from governments, industry, and individuals to mitigate the environmental impact of plastic waste.

3. Learning outcomes

Students can acquire knowledge about different plastic manufacturing routes and how they influence the type and volume of waste generated; explain the distinctions between thermoplastic and thermosetting plastics and their respective challenges in waste treatment; recognize the complexities and global challenges associated with the recycling of plastics, including technological and infrastructural limitations; elaborate on the broader environmental impact of plastic waste and the need for sustainable waste management practices.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier- Related chapters.

6. Additional notes

Topics 7

1. The subject of the lecture

Wood Waste Management

2. Thematic scope of the lecture (abstract, maximum 500 words)

Wood waste management is an essential aspect of environmental sustainability and resource efficiency, especially given the extensive use of wood in various industries. Wood is a versatile material widely used in construction, furniture making, and paper production due to its strength, durability, and ease of working. However, wood processing and usage generate considerable waste, including offcuts, shavings, and sawdust. Effective management of this waste is crucial in reducing environmental impact and maximizing resource utilization. Wood waste typically arises from manufacturing processes such as cutting, shaping, and finishing wood products in industrial settings. These activities generate various forms of waste, including large offcuts and smaller chippings. One standard method of managing this waste is through wood chipping. Chipping reduces the volume of wood waste and transforms it into a form that can be more efficiently utilized for other purposes. Wood chips are often used as a biomass fuel, providing a renewable energy source that can help reduce reliance on fossil fuels. They are also used in producing particleboard and other engineered wood products, contributing to the circular economy in the wood industry. Composting is another sustainable method of wood waste management, particularly for more negligible and less contaminated wood waste like sawdust and shavings. When mixed with other organic materials, wood waste can decompose and transform into compost, a valuable soil amendment that enriches soil fertility and structure. This process not only diverts wood waste from landfills but also creates a useful product for agriculture and landscaping. However, the suitability of wood waste for composting depends on factors like the type of wood, the presence of chemicals or treatments, and the composting method used. From a materials science perspective, wood presents unique challenges and opportunities in waste management. Wood's structural and chemical properties influence how it can be recycled or repurposed as a natural composite material made of cellulose fibers embedded in a lignin matrix. For example, treated wood or wood composites may require different handling processes than untreated solid wood waste. Advances in material science have led to innovative uses of wood waste, such as in the creation of new composite materials and bio-based polymers and even as a raw material for 3D printing applications.

In summary, wood waste management is vital to sustainable practices in industries utilizing wood. Techniques like chipping and composting help reduce the waste volume and enable the repurposing of wood waste into valuable products. Understanding wood from a materials science perspective is critical to developing innovative and effective strategies for its recycling and reuse, contributing to both environmental sustainability and economic efficiency in the wood industry.

3. Learning outcomes

Students can explain the various industrial applications of wood and the types of waste generated during wood processing; elaborate on the methods of managing wood waste, including chipping and composting, and their applications; recognize the potential uses of processed wood waste, such as in biomass fuel and soil enrichment; determine wood's structural and chemical properties and explain how they influence recycling and repurposing efforts.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 8

1. The subject of the lecture

Waste Management and Recycling in Textile Industry

2. Thematic scope of the lecture (abstract, maximum 500 words)

Waste management and recycling in the textile industry are critical due to the substantial environmental footprint of textile production and disposal. The sector utilizes various textile types for industrial use, including natural fibers like cotton and wool, synthetic fibers such as polyester and nylon, and specialized fabrics for technical applications. Each kind of textile has unique properties and recycling challenges. Home textile wastes, including bedding, carpets, and curtains, add significantly to the overall waste. These household textiles often blend different fibers, complicating recycling processes. Disposal methods typically involve landfilling or incineration, but with growing environmental concerns, more sustainable practices are being explored. Recycling textiles in different manufacturing industries involves various processes depending on the type of textile. Natural fibers can often be mechanically recycled, though the process may reduce the fiber quality. Synthetic fibers present a more significant challenge due to their plastic-based composition, but they can be chemically recycled, reverting them to basic polymers for reuse. Innovative techniques are being developed to handle blended fabrics, which traditionally are difficult to recycle due to their mixed composition. Recycling textiles reduces waste, conserves resources, and decreases reliance on virgin materials, thereby lowering the environmental impact of textile production. Recycling textiles into usable material is an evolving field with numerous applications. Recycled textiles find uses in fashion, industrial applications, and non-textile products. For instance, recycled polyester is widely used in clothing and home textiles, while recycled cotton may find its way into insulation materials, paper products, and automotive industries. These practices contribute to a circular economy and open new markets and opportunities for innovative products. Exciting case studies highlight the potential of textile recycling. One example is using recycled ocean plastics to create sportswear, turning a pollution problem into a resource. Another is the development of textile composites, where recycled textiles are combined with other materials to create products with enhanced properties. Textile composites are increasingly used in automotive, aerospace, and construction industries for their strength, lightness, and sustainability. These case studies demonstrate the feasibility of recycling textiles and inspire further innovation in waste management within the textile industry. As environmental awareness grows, the textile sector is poised to play a pivotal role in sustainable manufacturing and waste reduction.

3. Learning outcomes

Students can elaborate the range of textile materials used industrially and domestically and the specific recycling challenges associated with natural, synthetic, and blended fibers; show how different textiles are recycled and the diverse applications of recycled materials in various industries; comment and analyse the case studies about innovative recycling solutions, such as textile composites and recycled products, highlighting the potential and impact of sustainable practices in the textile industry.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6.	**Additional notes**

Topics 9

1. The subject of the lecture

Green Composites

2. Thematic scope of the lecture (abstract, maximum 500 words)

Green composites represent a class of materials that align with sustainability principles and environmental friendliness. Traditional composites are engineered materials made by combining two or more constituents with significantly different physical or chemical properties, where one constituent forms the matrix, and the other serves as reinforcement. Green composites, however, differentiate themselves by utilizing natural, renewable, and biodegradable materials as either the matrix, the reinforcement, or both. This approach significantly reduces the environmental impact of conventional composites made from synthetic materials. The concept of green composites encompasses a variety of types, including eco-composites and hybrid green composites. Eco-composites are typically made from natural fibers like hemp, flax, or jute, combined with biodegradable resins derived from plants or other renewable sources. These composites offer the advantage of being environmentally friendly, as they are derived from renewable resources and are often biodegradable or recyclable. Hybrid green composites take this further by combining natural fibers with small amounts of synthetic materials to enhance specific properties such as strength, durability, or resistance to environmental factors. The idea is to balance maintaining environmental benefits while achieving the desired performance characteristics. One of the innovative aspects of green composites is the incorporation of filler waste materials. These fillers, which can include agricultural waste like rice husk ash, wood chips, or recycled paper, are added to the composite matrix to enhance strength and thermal stability or reduce material costs. Using such waste materials contributes to waste reduction and adds value to otherwise discarded substances. This approach aligns with the circular economy model, where waste materials are effectively reused and recycled, minimizing environmental impact. Several case studies highlight the successful application and potential of green composites. For instance, automotive and aerospace industries have explored green composites for interior components, capitalizing on their lightweight and sustainable nature. In construction, green composites have been used for paneling, insulation, and structural components, offering an eco-friendly alternative to traditional materials. These case studies demonstrate the feasibility of using green composites in various industries and their potential to reduce manufacturing processes' environmental footprint significantly. In summary, green composites represent a significant advancement in materials science, combining the benefits of traditional composite materials with sustainability. By utilizing natural, renewable, and biodegradable components and incorporating waste materials, green composites offer a promising solution to reduce environmental impact across various industries. These materials' continued development and study are crucial in pursuing more sustainable manufacturing practices and products.

3. Learning outcomes

Students can show the fundamental differences between traditional composites and green composites, focusing on their composition and environmental impact; elaborate on the different types of green composites, including eco-composites and hybrid green composites, and their specific characteristics; recognize the role and importance of using filler waste materials in green composites for enhancing properties and supporting circular economy principles; explain the application and potential of green composites through real-world case studies in various industries like automotive, aerospace, and construction.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 10

1.	**The subject of the lecture**

Advanced Materials from Waste

2.	**Thematic scope of the lecture (abstract, maximum 500 words)**

The concept of "Advanced materials from waste" has emerged as a pivotal aspect of sustainable manufacturing, transforming waste products into valuable materials for various industrial applications. This approach addresses environmental concerns and creates economic value from otherwise discarded resources. The classification of wastes in terms of usability and ongoing research and development (R&D) in this area are crucial to understanding and advancing this field. Wastes can be classified based on their origin and potential for reuse in the manufacturing industry. Primarily, these include industrial waste, such as slag from metal processing, fly ash from power plants, and waste from chemical industries, and consumer waste, like plastic, glass, and rubber. These materials are assessed for their physical and chemical properties to determine their suitability for repurposing. Industrial waste often contains metals or other valuable components that can be recovered and reused. Consumer waste, particularly plastics, presents both a challenge and an opportunity, with research focused on transforming these polymers into high-value materials. R&D in waste utilization is highly interdisciplinary, combining material science, chemistry, and engineering to develop innovative solutions. One focus area is the conversion of waste into composite materials. For instance, fly ash and slag from industrial processes are being incorporated into cement and concrete, enhancing their properties and reducing the environmental impact of cement production. Similarly, recycled plastics are finding new life in composites for automotive and aerospace applications, contributing to weight reduction and energy efficiency. Another burgeoning area of research is the extraction of high-value elements from electronic waste (e-waste). As electronic devices increase, so does the volume of e-waste, which contains precious metals like gold, silver, and rare earth elements. Developing efficient and environmentally friendly methods to recover these materials is an essential research focus. Additionally, there is significant interest in converting organic waste into bio-based materials, such as bioplastics and biofuels, through processes like pyrolysis and fermentation. In conclusion, the development of advanced materials from waste is a rapidly evolving field with significant implications for both the environment and industry. Classifying wastes based on their potential reuse and investing in R&D makes it possible to transform waste into high-value materials. This mitigates the environmental impact of waste accumulation and contributes to a circular economy, where waste is seen as a resource rather than a liability. The ongoing advancements in this area are poised to redefine material sourcing and manufacturing practices in the future.

3. Learning outcomes

Students can elaborate about classifying various types of waste, including industrial and consumer waste, based on their potential for reuse in manufacturing; comment about the latest research and development in transforming waste into valuable materials, focusing on technological advancements and environmental impacts; suggest methods for extracting valuable elements from electronic waste, an essential aspect of resource conservation; explain the processes for converting organic waste into bio-based materials, such as bioplastics and biofuels, contributing to sustainable material production.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 11

1. The subject of the lecture

Sustainable Waste Utilization in Construction Materials

2. Thematic scope of the lecture (abstract, maximum 500 words)

Sustainable waste utilization in construction materials is an innovative approach aimed at reducing environmental impact, conserving natural resources, and promoting circular economy principles in the construction industry. This concept involves integrating recycled materials into construction materials, transforming waste into valuable resources. Construction materials are broadly classified into two categories: natural materials like stone, sand, and wood and manufactured materials such as concrete, bricks, and glass. The choice of material depends on factors like availability, cost, strength, durability, and environmental impact. The integration of sustainable practices in this sector focuses on reducing the reliance on natural resources by substituting them with recycled or waste materials without compromising quality and performance. Pavements form a critical part of infrastructure, traditionally made from asphalt, concrete, or a combination of both. However, the industry is now exploring using recycled materials like rubber from tires, reclaimed asphalt pavement (RAP), and plastic waste in pavement construction. These materials not only dispose of waste efficiently but also enhance the properties of the pavement, such as increased durability and resistance to weathering. Additives like fly ash, slag from steel manufacturing, and recycled glass can be mixed with traditional road-making materials to improve their performance and longevity. Using concrete and stone waste in road construction is a significant step towards sustainable development. Recycled concrete aggregates (RCA) from demolished structures can replace natural aggregates in road base and sub-base layers. This recycling reduces the demand for virgin materials and minimizes landfill waste. Similarly, stone waste from quarries can be processed and used in road construction, offering an eco-friendly alternative to natural crushed stone. Ceramics and plastics, often considered non-biodegradable wastes, pose a significant environmental challenge. However, in road construction, these materials can be repurposed effectively. Crushed ceramics can be used as a substitute for natural aggregates, providing strength and stability to the road structure. Similarly, plastic waste can be melted and mixed with asphalt, creating a more durable composite less prone to wear and tear than traditional asphalt. This innovative use addresses the issue of plastic waste and enhances the quality of roads. In conclusion, sustainable waste utilization in construction materials presents a promising solution to environmental challenges while maintaining the quality and safety of infrastructure. The construction industry's shift towards recycling and reusing waste materials is a step towards a more sustainable and eco-friendly future.

3. Learning outcomes

Students can explain the classification of construction materials and the importance of choosing sustainable alternatives for environmental conservation; show how to use recycled materials such as rubber, plastics, and reclaimed asphalt in pavement construction, enhancing durability and sustainability; show how to us recycled concrete, stone waste, ceramics, and plastics in road construction, promoting waste management and ecological sustainability.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) ***

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6.	**Additional notes**

Topics 12

1. The subject of the lecture

Thermal Power Plants and Recycling of Ash and Other Wastes

2. Thematic scope of the lecture (abstract, maximum 500 words)

Thermal power plants, primarily fueled by coal, natural gas, or oil, are a significant source of electricity generation worldwide. These plants burn fossil fuels to produce heat, which is then used to generate steam that drives turbines connected to electricity generators. The burning process of these fuels involves chemical reactions where carbon in the fuel combines with oxygen in the air to produce carbon dioxide (CO_2), water, and energy. For example, coal combustion typically follows the reaction: $C + O_2 \rightarrow CO_2$. This process significantly contributes to CO_2 emissions, a greenhouse gas impacting global climate change. The combustion of fossil fuels in thermal power plants also produces various wastes, including slag and fly ash. Slag, formed from the non-combustible components of coal, is a dense, glass-like material that can be used in road construction and as a soil amendment. Fly ash, on the other hand, is a fine particulate matter that rises with flue gases. It consists primarily of oxides like silica, alumina, and ferrous oxide. Fly ash can be classified into two types based on its composition: Class F, produced by burning anthracite or bituminous coal, and Class C, resulting from lignite or sub-bituminous coal combustion.

One of the most notable applications of fly ash is in cement making. Fly ash can be incorporated into concrete as a partial replacement for Portland cement or used to produce blended cement. This utilization helps manage the waste effectively and enhances the durability and strength of concrete. Adding fly ash to cement is a step towards sustainable construction practices as it reduces the reliance on cement, which is energy-intensive to produce, and minimizes CO_2 emissions associated with cement manufacturing. Several case studies highlight the successful recycling of ash and other wastes from thermal power plants. For instance, in some countries, over 50% of the fly ash produced is used in concrete production, significantly reducing waste sent to landfills. Another example is the use of slag in road construction, which has proven to be both durable and cost-effective. These case studies demonstrate the potential of turning waste from thermal power plants into valuable resources, contributing to environmental sustainability and circular economy initiatives. The challenge lies in increasing the scale of these recycling efforts and developing new technologies to enhance the usability of these by-products in various applications.

3. Learning outcomes

Students can explain the chemical reactions of burning fossil fuels in thermal power plants and their resulting carbon dioxide emissions; elaborate about the types and properties of waste generated in thermal power plants, particularly slag and fly ash, and their environmental implications; suggest the methods for recycling thermal power plant waste, especially in cement making, and its benefits in sustainable construction; analyze real-world examples of successful waste recycling from thermal power plants to understand practical applications and environmental impacts.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

Topics 13

1. The subject of the lecture

Electronic Waste and Regulations

2. Thematic scope of the lecture (abstract, maximum 500 words)

Electronic waste (e-waste) is a rapidly growing environmental concern due to the increasing consumption and shorter lifespan of electronic devices. The management and disposal of e-waste are governed by various regulations, notably the Restriction of Hazardous Substances (RoHS) Directive. These regulations limit certain hazardous materials in electronic and electrical equipment. One significant aspect of these regulations involves solders, which are essential in manufacturing electronic devices for joining components. Solders are fusible metal alloys used to create permanent bonds between metal workpieces. Soldering is a common practice for assembling components onto printed circuit boards (PCBs) in electronic equipment making. Two main types of solders are used in electronics: leaded and lead-free. Leaded solders, traditionally used for their favorable melting point and durability, are primarily composed of tin and lead. However, lead-free solders have become increasingly prominent due to lead toxicity and environmental impact, especially in regions adhering to RoHS regulations. These lead-free solders typically consist of combinations of tin, copper, silver, and other metals. The soldering process can be either automatic or handmade. Automated soldering, often used in mass production, ensures consistency and speed, whereas handmade soldering is standard in repair work or small-scale production. The choice of solder type significantly affects the formation of intermetallic compounds at the solder joints, which are crucial for joint strength and durability. The properties of solders, such as melting point, tensile strength, and thermal fatigue resistance, play a vital role in determining the reliability of electronic assemblies. The RoHS Directive, implemented in the European Union, restricts using specific hazardous substances in electronic equipment, including lead. This regulation has led to the widespread adoption of lead-free solders in the global electronics industry. Case studies demonstrate both the challenges and successes of transitioning to lead-free solders. For instance, some industries faced initial reliability issues due to differences in the properties of lead-free solders compared to traditional leaded solders. However, continuous research and development have led to the formulation of new alloys and improved soldering techniques, overcoming many of these challenges. These advancements not only comply with environmental regulations but also contribute to the sustainability of the electronics industry, highlighting the importance of regulatory frameworks in driving technological and environmental progress.

3. Learning outcomes

Students can explain electronic waste's environmental impact and challenges, emphasizing the need for effective management and disposal methods; elaborate about different types of solders, including leaded and lead-free, their properties, and their roles in electronic device manufacturing; explain the RoHS regulations and their influence on solder material selection and electronic manufacturing practices; analyze case studies to understand the industry's response to regulatory changes, focusing on the transition to lead-free solders and related technological adaptations.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods) *

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below sources related to the lecture:

-Pardeep Singh, Pramit Verma, Rishikesh Singh, Arif Ahamad, André C. S. Batalhão (Eds), Waste Management and Resource Recycling in the Developing World (2022 Edition), Elsevier-Related chapters.

6. Additional notes

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).

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University

Co-funded by the European Union

SUPPLEMENTARY MATERIALS

FOR THE FOUR-SEMESTER MASTER'S DEGREE PROGRAM

MATERIALS SCIENCE MA(S)TERS

TEACHERS' GUIDE

The Teachers' Guide is a supplement to the information contained in the course syllabus

SCIENTIFIC RESEARCH TECHNQIUES

Code: SRT

UNIVERSITY OF SILESIA IN KATOWICE

UNIVERSITY OF ŽILINA

Course content – lecture

Topics 1

1. The subject of the lecture

INTRODUCTION TO RESEARCH AND SCIENTIFIC THINKING

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic presents the concepts of scientific thinking, the importance of knowledge and research and their principle role in our daily lives. This topic should also mention about the researchers and their scientific activities based on the principles of acquisition, generation of knowledge and its dissemination. It is widely accepted that knowledge based on research and literature can now be generated and published at lightning speed. However, the extent to which scientific thinking is involved remains a question. Research and scientific thinking can be influenced by the media and publishing journals, which may lead scientists to focus on mainstream research subjects and reject non-conforming research. Research methodology is often influenced by prevailing trends in fields such as physics, biology, and computer science. These trends are frequently presented as common sense, shaping our approach to research. Scientific research is crucial for advancing knowledge and progress in various fields, including healthcare, education, technology, and social policy. It generates new knowledge, solves problems, and drives innovation. Technology is increasingly integral to scientific research, aiding in data collection, analysis, and dissemination. Technology has a significant role in enhancing the teaching and learning process in education. It makes the process more scientific, objective, clear, and effective. It also contributes to the development of educational methods and tools, ultimately improving the quality of education. Research education is essential for cultivating a new generation of researchers equipped with the necessary skills to conduct high-quality research and contribute to the advancement of knowledge. Technology plays a crucial role in scientific research, facilitating data collection, analysis, and dissemination. Educational technology enhances the teaching process by making it scientific, objective, clear, simple, and effective, ultimately contributing to the development of educational methods and tools. Research education is essential for cultivating a new generation of researchers equipped with the necessary skills to conduct high-quality research and contribute to the advancement of knowledge.

3. Learning outcomes

The students can explain the role of knowledge and producing knowledge through research using well known methods of scientific research; define the necessity of trendy approach in research based on technological advancement and future requirements for daily and other uses such as aerospace and military advances; differentiate between acquiring the knowledge and doing research using literature sources.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Chapter 3, Mikael Stenmark, The scientific explanation of morality, Scientism (1st Edition) 2001, Routledge
- Chapter 4, Mikael Stenmark, Debunking and replacing traditional ethics with science, Scientism (1st Edition) 2001, Routledge

6. Additional notes

Topics 2

1. The subject of the lecture

SCIENCE, SCIENTIFIC ETHICS AND MORALITY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic introduces an extended treatment of science, scientific ethics, and morality that can be easily correlated with everyday behaviour. It discusses the ethical issues in publishing and the scientific community, which are of prime importance as they involve the violation of basic rights of ownership of any kind of data generated during the course of research and scientific activity. Students should receive a chronological overview of the historical development of science and technological advancements. It is crucial for scientists to be transparent about the ethical and moral aspects of their research projects from the initial stages to the final conclusions. Ethics Committees have been established in numerous universities and research centres to approve or disapprove research projects before they are conducted. Intrusions into scientific output can be a means of censorship or balance, but plagiarism is a significant issue in science and technology. However, the plagiarism is a big issue in science and technological processes as the self citation which would be taking advantage of oneself's ownership of any research if it is many in amount. Self citation in high amounts should also be considered to fall into the same category as unethical as it would be considered as deceiving or fraudulence of research. Morality, which can be indication of mischievous ideas, is believed to be somehow linked to ethical activities since it reflects the capacity to steal or claim credit for another's idea by accomplishing it in a concealed or unobserved manner. Stealing one's idea and using it in a different way should also be mentioned in this topic. While they are sometimes used interchangeably, these words e.g. morality and ethical behaviour are slightly different but linked: ethics refer to rules provided by an external source, such as a code of conduct in the workplace, morality however refers to an individual's principles regarding right and wrong in a process of deciding.

3. Learning outcomes

Students can explain the role of ethics and ethical issues in science and technology especially in the course of generating knowledge; define the difference between ethics and morality and their impact on the research presentation such as publishing and ownership of an idea; analyse the ethics role in commercially important issues and explain the need for having a governing body to decide on the capacity of ownership of an idea or result.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

- Marchant, G.E., Pope, L.L. The Problems with Forbidding Science. *Sci Eng Ethics* **15**, 375–394 (2009). https://doi.org/10.1007/s11948-009-9130-9

- Jonas, H. (1984). *The imperative of responsibility: In search of an ethic for the technological age*. Chicago: University of Chicago Press.

- Jones, N. L. (2007). A code of ethics for the life sciences. *Science and Engineering Ethics, 13*, 25–43.

6. Additional notes

Topics 3

1. The subject of the lecture

GOOD AND BAD EXAMPLES OF ETHICAL ISSUES IN PUBLICATIONS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic is aimed to give a detailed view on good and bad examples of publishing with journals and other means of publishing the research results or literature searches. Scientific journals play an important role in the exposure and correction of research misconduct. Peer reviewers may detect fraud before publication of the results of a research; readers, after publication. Journals also perform a vital service by publishing corrections or retractions after research misconduct has been confirmed. A definition of scientific misconduct as fabrication, falsification, plagiarism, or other serious deviations from the scientific norm. Detection lies in the hands of editors, peer reviewers, coauthors, and readers. Students should be given examples from both natural and social sciences and given explanation for a such an outcome. Students should also be given a list of predator journals and why their practice of publishing is considered fraudulent and not ethical in the eye of a scientist and publisher. Open access journals are also another issue that scientists have to deal with as it requires a great deal of financial resources which could be spent on the research, as most of the journals find voluntary reviewers and referees for the evaluation of manuscripts. These ethical questions are pivotal for research publication and future of publishing however it may be treated differently in natural sciences and social sciences categories. Students should be aware of differences in publishing in the form of books and publishing in a well known journal or with well known publishers. Students should also be aware of journals that are voluntarily managed by researchers and scientists who are in academic positions such as universities or research institutions. The lecture should pose a question on the efficiency of these groups of journals and have deeper discussions on whether open access is opportunistic act or way forward.

3. Learning outcomes

Students can recognise good examples and bad examples of publishing in journals and books by the reference of ethical rules of conduct; differentiate between open access and normal publishing in journals with good reputation and average journals; explain the need for a regulatory body or affiliation in order to decide on whether the research published is genuine or trustworthy.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

Students are expected to read below texts related to the lecture:

- Proceedings of the retreat on The Journal's Role in Scientific Misconduct; A Council of Science Editors retreat with funding from the Office of Research Integrity, 7-9 November 2003, Lansdowne Resort and Conference Center, Lansdowne, Virginia

6.	**Additional notes**

Topics 4

1. The subject of the lecture

COPYRIGHT ISSUES AND (COMMON) PUBLICATION RULES IN RESEARCH: RESEARCH CONCEPTS, R&D CONCEPTS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to provide an advanced treatment of copyright issues that are closely linked to the publishing of one's own work and the work of others that is referenced. The rules for copyright are valid for anyone who is part of the academic publishing route. However, researchers should be particularly careful about what they use in their research and give appropriate recognition to the work of others. There are many types of publishing options for academics or practitioners in academic and industry. Open publishing or sometimes otherwise known as open access in addition to creative commons publishing is another way of overcoming the copyright issues and plagiarism issue in publishing academically, in which the publishing of material organized in such a way that there is no financial or other barrier to the reader. Non subscription journals and free journals are also part academic publishing and they deal with issues much more easily by relaxing the rules of keeping their copyright however similar challenges should be overcome with the authors's rights of use of their work after some amount of time. These issues are far more relaxed with these types of journals but financing of this type of journals is serious matter. In the second part of this topic, a series of common rules for writing in all types of journal should be considered for students and students should also be experiencing enough writing style for both project and manuscript writing. Students should be able to differentiate the writing styles of manuscript, project and thesis proposal in this topic. Students should be involved in a discussion in improving the quality of works carried out by scientists with a plausible suggestion. A good discussion would be on the publication rules in common and related content could help build substantial contribution to the field of study such as improving the academic or research and development quality of manuscript in a given field.

3. Learning outcomes

Students can differentiate between the writing styles of thesis, manuscript and project proposals with respect to the content and aims and sectioning of three styles; explain the copyright issues and plagiarism issue in science publishing and accustomed with the aversion of such problems; define and describe the paid and free or creative commons journal publishing in science and technology discipline.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- https://www.vu.edu.au/researchers/research-lifecycle/conducting-research/copyright-for-researchers

6. Additional notes

Topics 5

1. The subject of the lecture

SCIENTIFIC JOURNALS AND INDEXING

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the indexing concept in academic publishing and how they work in terms of classification of disciplines and classification of journals based on their citation numbers and citation qualities. This topic will also introduce journal impact factor concept and scientific indexing based on quartile of citation e.g. Q series and other indexing. A quartile is the ranking of a journal or paper definite by any database based on the impact factor (IF), citation, and indexing of that particular journal. It can divide into four different quadrants starting with Q1, Q2, Q3, and Q4. Institute for Scientific Information came into being in the year 1960. Following its acquisition by Thomson Reuters and merger into Clarivate Analytics, we now call it as "Web of Science". Scopus and ISI are two widely used citation databases that offer a range of services to researchers. While ISI is best known for its calculation of the journal impact factor, Scopus offers a more comprehensive citation database that covers a broader range of subjects and indexes more journals. The Journal Citation Indicator is a measure of the average Category Normalized Citation Impact (CNCI) of citable items (articles and reviews) published by a journal over a recent three year period. It is used to help you evaluate journals based on other metrics besides the Journal Impact Factor (JIF). The Journal Impact Factor (JIF) is a journal level metric calculated from data indexed in the Web of Science Core Collection. It should be used with careful attention to the many factors that influence citation rates, such as the volume of publication and citations characteristics of the subject area and type of journal. The Journal Impact Factor can complement expert opinion and informed peer review. In the case of academic evaluation for tenure, it is inappropriate to use a journal-level metric as a proxy measure for individual researchers, institutions, or articles.

3. Learning outcomes

Students can explain the role of indexing in academic publishing and how the indexing agents are important in determining the quality publication for scientists; recognise which indexes are good for their discipline of research and how they are used to grade the journals and as well as scientists; define citation ranking and journal quartile ranking and what they mean for indexing journals.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- https://blog.scholasticahq.com/post/index-types-for-academic-journal/

6. Additional notes

Topics 6

1. The subject of the lecture

THESIS PROPOSAL OR PROJECT PREPARATION: HYPOTHESIS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to introduce the thesis proposal preparation and its first stage that is preparing your hypothesis and make id validate by your supervisor or thesis jury. There is no single definitive method for selecting and gaining approval for a research topic. The approaches vary depending on the department within the university. While some departments mandate a proposal, others do not. Similarly, some departments require a detailed proposal, while others are content with a general preliminary outline. Some departments require students to present their proposals at a research seminar, while others circulate proposals among staff. Often, a student will have an interview with a potential supervisor. Despite this variety of procedures, there are still some general issues that all students should consider before starting their research, even if they do not have to write a proposal. Many students and novice researchers may not have a complete understanding of the meaning and significance of a research proposal, particularly in the early stages of their MSc or PhD studies. A research proposal is a comprehensive explanation of a proposed study aimed at investigating a particular problem. The purpose of a research proposal is to persuade others that you have a valuable research project and that you possess the skills and plan to complete it. Regardless of your research area and methodology, the research proposal should answer the following questions: What do you intend to achieve, why do you want to do it, and how do you plan to do it? Researchers typically ask curious questions and formulate research hypotheses. However, the effectiveness of a research study's conclusion depends on the quality of the research hypothesis. Examples of research hypotheses can assist researchers in developing a strong research hypothesis. A research hypothesis is a statement that introduces a research question and proposes an expected outcome. The construction of a research hypothesis is an essential aspect of the scientific method and forms the basis of scientific experiments. It is crucial to be careful and thorough in this process, as even minor flaws could have adverse effects on the experiment.

3. Learning outcomes

Students can explain the role and the impact of good and well prepared thesis proposal stage in their academic career and later on academic life; define the stages of preparing thesis proposal and can clearly recognise the need for doing a good research on choosing the subject; explain the need for strong research question and valid hypothesis leading to less problematic and with minor flaws during the course of study.

4.	**Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)**

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	**Recommended reading, pre-lesson preparation (required knowledge of students on the topics)**

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6.	**Additional notes**

Topics 7

1. The subject of the lecture

THESIS PROPOSAL OR PROJECT PREPARATION: LITERATURE SURVEY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to introduce the importance of literature survey prior to writing your thesis or manuscript even for the project that you are proposing to submit. The overall goals of the literature search are to refine your topic, and then find as much relevant information as possible on your topic, within reason. Talk to your advisor to get guidance on this. You may not need to do the full-fledged literature review for your proposal. Here are objectives that will help you meet the goals of the literature search. Determine the most important databases for your discipline and topic, search for all source types allowed or relevant for your topic, e.g., books, articles, reviews, dissertations and theses, websites, films, etc., find peer-reviewed empirical and theoretical literature. A previously published literature review related to your topic is an invaluable source for developing your topic and finding the important literature. Develop an understanding of the academic terminology for your topic, and determine the time frame for the literature review. Consider your specific area of study and think about what interests you and what interests other researchers in your field. Talk to your professor, brainstorm, and read lecture notes and recent issues of periodicals in the field. Limit your scope to a smaller topic area. Define your source selection criteria (ie. articles published between a specific date range, focusing on a specific geographic region, or using a specific methodology). Using keywords is a lifesaver and these keywords are used to search a library and ISI/Scopus database. Reference lists of recent articles and reviews can lead to other useful papers. Include any studies contrary to your point of view. Evaluate and synthesize the studies' findings and conclusions. Following information are good and needed to be collected in literature stage and later for your methodology of your thesis or project proposal: 1) Assumptions some or most researchers seem to make, 2) Methodologies, testing procedures, subjects, material tested researchers use, 3) Experts in the field such as names/labs that are frequently referenced, 4) Conflicting theories, results, methodologies, 5) Popularity of theories and how this has or has not changed over time.

3. Learning outcomes

Students can explain the role of literature survey in preparation of a good thesis prior and after thesis study, which may lead a way to start a good manuscript or be well informed about the subject for project defence; define a good way to start writing a literature survey and analyse and classify the information needed to be collected for a literature survey.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

Topics 8

1. The subject of the lecture

THESIS PROPOSAL OR PROJECT PREPARATION: WRITING AIM, CONTENT AND BENEFITS

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to present the form of writing aim, content and benefits sections of thesis or project proposal. This section should also present an answer to what benefits should public or scientific community get from this thesis or project proposal. Research objectives are the goals to be achieved by conducting the research. They may be stated as 'general' and 'specific'. The general objective of the research is what is to be accomplished by the research project, for example, to determine whether or not a copper based strain gauge sensor should be used to test the capacity of new machine part that was sand cast or arc melted on a piece of copper. The scope and content of the thesis is the section in which the thesis is described in detail. The student here should clearly illustrate the thesis design, the scope and the content of the thesis subject clearly. Questions should be answered here should be such as which problem the thesis deals with, which questions it will seek to answer in this study, under which limitations the study will be carried out, and the assumptions upon which it is based. However, there are also concepts which are related to the subject and what the student means with regard to these concepts. In this section, the student also writes which questions he/she will seek to answer. A thesis should have one or more essential questions and sub-questions related to it. It is important that these questions are written as points. If an empirical study will be made based on numerical data to be obtained from the field, a hypothesis related to each question will be developed and it will be included in this section. Every study has one or more purposes. Every study needs to reach an aim or serves some purpose. The selected thesis subject is also considered to serve a specific purpose. A thesis may have more than one purpose. The student should describe what he/she intends by choosing that particular thesis subject, which question will be answered, or which practical problem will be illuminated through this study.

3. Learning outcomes

Students can describe the aim of a project proposal or a thesis that is the main selling point of a thesis or project proposal; describe how to write an effective content of a thesis or a project proposal and elaborate on the main points to be cared for; analyse and explain the need for benefits in project proposal or thesis in order to clarify the outcomes of a project proposal or a thesis.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

- The topics will be covered in next week's lecture.

Topics 9

1. The subject of the lecture

THESIS PROPOSAL OR PROJECT PREPARATION: METHODOLOGY

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to introduce the writing and preparation principles of methodology in a thesis or project proposal or in a manuscript. In the simplest of terms, the methodology section in a proposal explains the research design and methods you'll use to complete your research, and why you chose that approach. In other words, if someone else wants to replicate your study to achieve the same results, what would they need to do, and how do you know that your approach is the best way to complete the research? The methodology section can include (but isn't limited to) 1) a description of the research design and methods, 2) a description of data-gathering instruments, 3) Methods of data collection, 4) ethical considerations, 5) analysis strategies and techniques, 6) potential participants, 7) rationale for your choice of methodological choices, 8) how the methodology is appropriate for the organization or participants, 9) the advantages and disadvantages of the methodology, 10) references to scholarly literature that support the chosen research design and methods. Your methodology comprises the various methods and material that you will use to obtain and analyze the information necessary to answer your research question. Be careful not to simply describe your methodology— you must also justify it. This means explaining why a particular choice of methodology will enable you to do a project that will produce results that are new or unique. What research methods will you use e.g. Qualitative or Quantitative and why?, what material will you use for your experiments e.g. materials, alloys, statistical and Analytical tools and why?, how do particular methodologies allow you to address different questions?, and what are the strengths of your methods for the best outcome of experiments? What are their weaknesses?; these are some of the questions that needed to be asked prior to writing and choosing your methodology. The method section is very important because it tells your research Committee how you plan to tackle your research problem. The guiding principle for writing the Methods section is that it should contain sufficient information for the reader to determine whether the methodology is sound. Some even argue that a good proposal should contain sufficient details for another qualified researcher to implement the study. Indicate the methodological steps you will take to answer every question or to test every hypothesis illustrated in the Questions/ hypotheses section.

3. Learning outcomes

Students can explain the role of good preparation of a methodology as it is the indication of a project or thesis being manageable or achievable; define the stages of writing methodology and describe the necessary content with necessary documentation such as equipments; analyse the best methodology for a given project and explain the need for each item given.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

Topics 10

1. The subject of the lecture

PREPARATION AND DESIGN OF CONCLUSION AND DISCUSSION WRITING/PRESENTATION

2. Thematic scope of the lecture (abstract, maximum 500 words)

This lecture aims to introduce the basics of writing conclusions of a research findings and how to conclude in presentations. The discussion section help you discuss your results with scientific basics and compare them with literature outputs, presenting the “so what,” or “why should the reader care” about your research. This is where you explain what you think the results show. Tell the reader the significance of your document by discussing how the results fit with what is already known as you discussed in your introduction, how the results compare with what is expected, or why are there unexpected results. Here are some words to get you thinking about this section: evaluate, interpret, examine, qualify, etc… Start by either summarizing the information in this section or by stating the validity of the hypothesis. This allows readers to see upfront your interpretation of the data. End the discussion by summarizing why the results matter. The discussion section of your manuscript can be one of the hardest to write as it requires you to think about the meaning of the research you have done. An effective discussion section tells the reader what your study means and why it is important. In this article, we will cover some pointers for writing clear/well-organized discussion and conclusion sections and discuss what should NOT be a part of these sections. Your discussion is, in short, the answer to the question “what do my results mean?” The discussion section of the manuscript should come after the methods and results section and before the conclusion. It should relate back directly to the questions posed in your introduction, and contextualize your results within the literature you have covered in your literature review. In order to make your discussion section engaging, you should include the following information a) major findings of your study, b) meaning of those findings, c) how these findings relate to what others have done, d) limitations of your findings, e) an explanation for any surprising, unexpected, or inconclusive results and f) suggestions for further research.

3. Learning outcomes

Students can identify the components of effective communication and research conclusion and discussion; systematically explain the underlying meaning of findings and state the most important outcomes of one’s research; relate the similar findings and studies in other research studies and hence compare them efficiently to make a contrast for the study carried out.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

Topics 11

1. The subject of the lecture

POSTER AND PRESENTATION OF RESULTS: APPLICATION

2. Thematic scope of the lecture (abstract, maximum 500 words)

PThe lecture aims to provide an extensive insight into presentation skills necessary for thesis or project appearance. The slides' theme should be relevant to your thesis, as it guides your selection of colours, typography, images, and style. These elements should support the main message of your slides and align with your concept visually and sociologically. After defining the concept, the next step is to structure the thesis content. A clear and logical structure is essential to showcase the organization behind your work and highlight your content. Prior to your thesis defence, it is recommended to welcome your audience and establish a connection with them through a well-delivered presentation. Remember to avoid subjective evaluations and maintain a balanced perspective throughout your presentation. Use a formal language register, avoiding informal language, while maintaining an approachable and natural tone. For instance, you could say, 'Welcome to the thesis defence on [the title of your thesis].' To begin, please introduce yourself by stating your name and providing a brief description of your background and occupation. If specific guidelines for the context of your presentation are not provided, follow the structure of your thesis or project proposal. For project presentations, assume a 20-30 minute presentation time, although this may be extended to 45-60 minutes for a thesis presentation. If you have more time to present, you can extend important sections or spend more time on certain slides. It is recommended to plan for approximately one minute per slide of information. Avoid overcrowding your slides with text and instead use bullet points and images to highlight key points. The lecturer should present an engaging topic to the students in the classroom for duration of 15 minutes. Students who were assigned to present a topic a week prior should also be given the opportunity to present. The class should provide feedback on the effectiveness and style of communication with the audience, and a mock jury can be used for evaluation.

3. Learning outcomes

Students can explain the role of choosing right theme for your presentation, which may positively affect the performance of presenter; define the stages of presentation based on their project proposal structure of thesis structure; arrange their time in each slide and have a chance to practice in the classroom in order to improve their presentation techniques.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

Topics 12

1. The subject of the lecture

DEFENDING YOUR THESIS OR MANUSCRIPT: TIPS AND TRICKS AND GENERAL RULES

2. Thematic scope of the lecture (abstract, maximum 500 words)

The topic aims to give an extensive introduction tips and tricks when defending your thesis or what one can do and prepare answer sheet of reply in some cases when you get a reviewers sheet of comments. A thesis defense is an oral presentation and discussion of a thesis study. The purpose is to share the results of the study and demonstrate to the committee and the academic community that the author has done work of sufficient quality to receive the master's degree and is able to speak to it in an open forum. It is expected that if the candidate speaks to their study as well as they have written about it, they will be successful in the defense. Thesis defences should be open to any interested members of the academic or professional community. Speaking about one's research is an academic skill that differs from writing the study. The format should reflect the most effective way to communicate with the audience. After the presentation, the thesis committee will ask questions to further explore the candidate's methods, findings, theoretical and practical applications of results, and to allow the candidate to demonstrate their knowledge of the general topic. The questions may range from specific to general and will probe what the candidate learned from conducting the study. Questionnaires can be retrospective, asking about something that was already done in the study, or prospective, prompting the candidate to consider future possibilities or uses for the findings. They may comprise open-ended questions, for which there is no known correct answer, as well as closed questions about specific literature, theory, methods, or findings. It is not inappropriate to ask challenging questions. The aim is for the candidate and all attendees to acquire as much knowledge as possible about the study, the new knowledge generated by the candidate's research, and the candidate's suitability for the degree.

3. Learning outcomes

Students can explain the need for a thesis defence following the completion of writing it and recognition of his or her study by being examined through a jury or committee; describe the procedures for a thesis defence or project proposal; explain the need for preparing an answer sheet against reviewer's comments in a timely and scientific manner.

4. Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5. Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

-- Writing A Thesis Proposal: Independent Learning Resources, The learning centre, The University of Sydney

6. Additional notes

Topics 13

1. The subject of the lecture

WHAT HAPPENS AFTER DEFENDING YOUR THESIS: FUTURE STUDIES AND COMPLETION OF YOUR RESEARCH

2. Thematic scope of the lecture (abstract, maximum 500 words)

This topic aims to provide a detailed summary of what do you do after completing your thesis defence and submit your final copy of thesis. It is also imperative to think about the future of your career to choose from following up your research beacon or go for more exotic projects. Many graduates find themselves in the office correcting their thesis after their oral examination or thesis defence but it is the until the moment when they submit their thesis to the registry, they realize that they have nothing to do in terms of research or is it not? This paragraph summrises many thoughts of a PhD candidate as it goes "...But I do have to think about what is next in terms of my research. I'd like to rework some sections of my dissertation for publication. I also have some other research interests that I haven't had the time or intellectual energy to pursue in the last year. While I am well versed in the literature relating to my dissertation topic, I've fallen shamefully behind on other literature in my field so I have reading to catch up on. I have some professional development money available to me, so I should probably also consider my options for conference travel and presentations, especially now that I can introduce myself as "Dr. Robinson"." There are many options available in academia, industry, or government. It is important to consider your personal and professional goals when deciding on your career path. After completing your PhD, you may be wondering about your next steps. It is important to consider your personal and professional goals when deciding on your career path. It is important to consider your personal and professional goals when deciding on your career path. If you are still interested in research, a postdoc or contract research position may be a good fit for you. Are you considering a transition from the research laboratory to the industry? This is an opportunity time for PhDs to make the move, as they possess both the technical skills highly valued by employers and transferable soft skills, including leadership and teamwork.

3. Learning outcomes

Students can explain the importance of having a valid and feasible plan after a successful PhD thesis examination; recognise the need for field changing attempt for a better future of their career such as going for industry rather than staying in academia; clearly comprehend the need for a publication after completing a thesis to be recognised by international scientific community.

Co-funded by the European Union

4.	Didactic methods used (description of student/teacher activities in the classroom/laboratory, taking into account didactic/teaching methods)

Assimilation methods/providing: **informative lecture**

problem methods: **problem-based lecture, activating methods: case study, presentation, show/demonstration**

5.	Recommended reading, pre-lesson preparation (required knowledge of students on the topics)

Students are expected to read below texts related to the lecture:

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6.	Additional notes

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Content preparation: Project Team of Materials Science Ma(s)ters, Afyon Kocatepe University