MATERIAL SCIENCE
ENME 201

Lecture : 3 **Year : II**
Tutorial : 1 **Part : I**
Practical : 1.5

Course Objectives:
The objective of this course is to equip students with a solid foundation in materials science and characterization, enabling them to analyze the relationship between the structure and properties of ferrous and non-ferrous alloys, polymers, ceramics, and composite materials and help students make informed decisions on selecting appropriate materials for various applications based on their structural properties.

1 Introduction (1 hour)

1.1 Classification of materials
1.2 Material selection for design

2 Atomic Structure, Interatomic Bonding and Crystalline Structure (6 hours)

2.1 Relationship among structures, processing, and properties
2.2 Atomic structure and atomic bonding
2.3 Crystal Structures, crystalline and non-crystalline materials
   2.3.1 Crystal structures
   2.3.2 Crystalline and non-crystalline materials
2.4 Miller indices and anisotropy
   2.4.1 Miller indices
   2.4.2 Miller-Bravis indices
   2.4.3 Anisotropy
2.5 Imperfections in solids
   2.5.1 Theoretical strength
   2.5.2 Point defects
   2.5.3 Line defects or dislocations
   2.5.4 Interfacial defects
   2.5.5 Bulk or volume defects
   2.5.6 Atomic vibrations
   2.5.7 Schmid's law
2.6 Movement of atoms in materials
   2.6.1 Fick's First law
   2.6.2 Fick's Second law

3 Mechanical Properties and Their Tests (7 hours)

3.1 Tensile test
- 3.1.1 Elastic and plastic deformation
- 3.1.2 Interpretation of engineering tensile stress-strain curves for different materials
- 3.1.3 True stress-strain diagram
- 3.1.4 Yield criteria, equivalent stress, plastic strain

3.2 Hardness test
- 3.2.1 Types of hardness measurements
- 3.2.2 Comparison among hardness methods and scales
- 3.2.3 Nanoindentation

3.3 Impact test
- 3.3.1 Toughness
- 3.3.2 Types of impact test, Charpy and Izod test
- 3.3.3 Significance of transition – temperature curve, notch sensitivity

3.4 Fatigue test
- 3.4.1 Metallurgical aspects of fatigue failures
- 3.4.2 S-N curve, endurance limit, linear elastic fracture mechanics in fatigue factors affecting fatigue life
- 3.4.3 Preventions

3.5 Creep test
- 3.5.1 Types of creep
- 3.5.2 Metallurgical aspects of creep failures
- 3.5.3 Creep curve for different materials
- 3.5.4 Factors affecting creep life
- 3.5.5 Preventions

4 Solidification, Phase Relations and Strengthening Mechanism (6 hours)

4.1 Solidification
- 4.1.1 Nucleation and grain growth
- 4.1.2 Dendrite formation
- 4.1.3 Cooling curve
- 4.1.4 Under-cooling cast structure
- 4.1.5 Solidification defect
- 4.1.6 Solid solutions, solid solutions strengthening

4.2 Phase relations and equilibrium
- 4.2.1 Phase and Structure Constituents
- 4.2.2 Cooling curves and under-cooling cast structure
- 4.2.3 Unary and binary phase diagrams
- 4.2.4 Gibbs's phase rule, lever rule

4.2.5 Eutectic, eutectoid, peritectic and peritectoid systems
4.2.6 Iron-Iron carbon equilibrium diagram: Different mixtures and phases, classification of steels and cast iron referring to diagram

4.3 Strengthening mechanism
4.3.1 Solid solutions strengthening
4.3.2 Strengthening by grain size reduction
4.3.3 Strain hardening, recovery, recrystallization, and grain growth
4.3.4 Alloys strengthening by exceeding the solubility limit
4.3.5 Age or precipitation hardening and dispersion strengthening
4.3.6 Cold work, hot work, residual stress in cold worked metal, comparison between hot and cold work

5 Heat Treatment (3 hours)

5.1 Principles and purpose of heat treatment

5.2 Heat treatment process
5.2.1 Annealing, normalizing, tempering, their types, and applications
5.2.2 Carburizing, nitriding, cyaniding, flame and induction hardening processes
5.2.3 Stress relieving
5.2.4 Allotropic transformation of iron and steel
5.2.5 Quenching process, quenching medium, hardenability, Jominy test, TTT diagram, CCT diagram

6 Metals and Alloys (3 hours)

6.1 Ferrous materials
6.1.1 Steels: Low carbon steels, medium carbon steels, high carbon steels, stainless steels
6.1.2 Cast irons: Gray cast iron, white cast iron, nodular or ductile cast iron, malleable cast iron

6.2 Non-ferrous materials: Aluminum alloys, copper alloys, magnesium alloys, titanium alloys, nickel alloys, cobalt alloys, titanium alloys, refractory metals, noble metals

7 Ceramics and Glasses (3 hours)

7.1 Ceramics and ceramics materials
7.1.1 Classification and applications of ceramic materials
7.1.2 Ceramic crystal structures: Wurtzite, zinc blende, rocksalt perovskite and spinel structure
7.1.3 Ceramic phase equilibrium diagrams
7.1.4 Fabrication and processing of ceramics: pressing and blowing processes, tape casting slip casting, extrusion process, injection molding, compaction process, cold iso-static pressing (CIP), hot isostatic pressing (HIP)

7.2 Glasses
  7.2.1 Basic concepts of glass structure
  7.2.2 Types and applications of glasses
  7.2.3 Basic concept of the glass manufacturing process
  7.2.4 Optical properties and optical application of glasses

8 Polymers (4 hours)

8.1 Structure of polymers
8.2 Types of polymers
  8.2.1 Plastics: thermosets and thermoplast
  8.2.2 Elastomer
8.3 Polymerization: Addition, condensation, and stereoregular polymerization
8.4 Frication processes of polymers: Compression molding, transfer molding, injection molding, extrusion, blow molding
8.5 Crystallization, melting, and glass transition of polymers
8.6 Mechanical behavior of polymers
8.7 Mechanisms of deformation and strengthening of polymers
8.8 Typical applications of thermoplastic and thermos setting polymers

9 Nanomaterials (4 hours)

9.1 Introduction of nanomaterials
  9.1.1 Nanomaterials
  9.1.2 Size and shape-dependent properties and their uniqueness
  9.1.3 Quantum confinement, zero, one, and two-dimensional nanostructures
9.2 Synthesis of nanomaterials
  9.2.1 Top-down and bottom-up approaches
  9.2.2 Physical nanofabrication techniques: PVD, CVD, self-assembly, lithographic techniques
  9.2.3 Wet chemical methods for the synthesis of zero, one, and two-dimensional nanostructures

10 Composite (5 hours)

10.1 Classification of composite materials
10.2 Particle-reinforced composites: Dispersion-strengthened composites and particulate composites
10.3 Fiber-reinforced composites
  10.3.1 Effect of fiber length, orientation, and concentration
  10.3.2 Continuous fiber composites
  10.3.3 Discontinuous and aligned fiber composites
  10.3.4 Discontinuous and randomly orientated fiber composites
10.4 Structural composite: Laminar composites and sandwich structures

- 10.5 Rule of mixture
  - 10.5.1 Weight and volume fraction
  - 10.5.2 Determination of longitudinal and transverse modulus of composite
- 10.6 Nanocomposite
  - 10.6.1 Mechanical, thermal, optical, and electrical properties of nanocomposite
  - 10.6.2 Synthesis methods of nanocomposites

11 Failure, Corrosion and Degradation of Materials (3 hours)

- 11.1 Different fracture modes
  - 11.1.1 Ductile and brittle fracture
  - 11.1.2 Ductile-to-brittle transition
- 11.2 Fatigue, crack initiation and propagation, crack propagation rate
- 11.3 Corrosion of metals
  - 11.3.1 Corrosion principles, emf series of metals and galvanic series
  - 11.3.2 Forms of corrosion: Uniform corrosion, galvanic corrosion, crevice corrosion, pitting, inter-granular corrosion, selective leaching, erosion-corrosion, stress corrosion
- 11.4 Corrosion of ceramics
- 11.5 Degradation of polymers

Tutorial (15 hours)

1. Numerical problems on the Fick’s first and second law
2. Convert engineering data to true data
3. Numerical problems on cold work and grain growth
4. Steels and non-ferrous alloys in industrial applications
5. Ceramics materials in drilling, cutting, and tribology
6. Nanomaterials characterization techniques
7. Numerical problems on the rule of mixtures

Practical (22.5 hours)

1. Macro examination of metals: Macrography to determine uniformity of composition, method of manufacture, and physical defects
2. Micro examination (Metallography)
3. Selection and preparation of the specimen
4. Application of heat treatment (Full annealing, normalizing, quenching, tempering), etching, and observation through a metallurgical microscope to different ferrous and non-ferrous alloy specimens
5. Examination of failure: Fatigue, creep
6. Tests: Hardness test (Brinell, Rockwell, micro-hardness)
7. Mechanical testing (Tensile, compressive, impact)
8. Strength testing of adhesives
9. Synthesis of nanoparticle

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Marks distribution*
1	1	8
2	6	
3	7	8
4	6	8
5	3	8
6	3	
7	3	10
8	4	
9	4	5
10	5	8
11	3	5
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Askeland, D. R., Haddleton, F., Green, P., Robertson, H. (2013). The Science and Engineering of Materials. Switzerland: Springer US.
2. Van Vlack, L. H. (1964). Physical Ceramics for Engineers. United Kingdom: Addison-Wesley Publishing Company.
3. Hull, D., Clyne, T. W. (1996). An introduction to composite materials. United Kingdom: Cambridge University Press.
4. Harper, C. A. (2002). Handbook of Plastics, Elastomers, and Composites. United Kingdom: McGraw-Hill.
5. Hertzberg, R. W. (1996). Deformation and fracture mechanics of engineering materials. United Kingdom: Wiley.