GUJARAT TECHNOLOGICAL UNIVERSITY

BE-3 SEMESTER – PAPER SOLUTION – WINTER 2024

Subject Name & Code:
Material Science and Metallurgy- 3131904

			Marks
Q.1	**(a)**	What are engineering materials, and how are they classified?	**03**

Answer:

Engineering Materials are materials used in the manufacturing of machines, structures, components, and tools in engineering applications. They are selected based on properties like strength, ductility, hardness, corrosion resistance, etc.

Classification of Engineering Materials:

1. **Metals and Alloys**
   - *Ferrous*: Steel, cast iron
   - *Non-ferrous*: Aluminum, copper, zinc
2. **Ceramics**
   - Inorganic, non-metallic (e.g., alumina, glass)
3. **Polymers**
   - Plastics and rubber (e.g., PVC, nylon)
4. **Composites**
   - Mixture of two/more materials (e.g., FRP)
5. **Smart Materials**
   - Respond to external stimuli (e.g., piezoelectric)

	(b)	Calculate the atomic packing factor for a BCC and FCC crystal structure. How does the APF affect the density of the material?	**04**

Answer:

Atomic Packing Factor (APF) =

$$\frac{\text{Volume of atoms in a unit cell}}{\text{Total volume of unit cell}}$$

1. FCC (Face Centered Cubic):

- Atoms per unit cell = 4
- $a = 2\sqrt{2}r$

$$APF_{FCC} = \frac{4 \times \frac{4}{3}\pi r^3}{(2\sqrt{2}r)^3} = 0.74$$

2. BCC (Body Centered Cubic):

- Atoms per unit cell = 2

- $a = \frac{4r}{\sqrt{3}}$

$$APF_{BCC} = \frac{2 \times \frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{3}}\right)^3} = 0.68$$

Effect on Density:

- **Higher APF → more atoms per volume → higher density**
- FCC has higher density than BCC if atomic mass is the same.

(c) Consider a situation where you need to select a material for a high-temperature furnace lining. Based on the properties of metals, ceramics, and composites, which material would you choose and why? **07**

Answer:

Requirements for furnace lining:

- High **melting point**
- **Thermal stability**
- Resistance to **thermal shock** and **corrosion**
- Low **thermal conductivity** to reduce heat loss

Comparison:

Property	**Metals**	**Ceramics**	**Composites**
Melting point	Moderate	**Very High**	Depends on matrix
Thermal stability	Poor–Moderate	**Excellent**	Good
Corrosion resistance	Poor	**Excellent**	Good
Brittleness	Ductile	**Brittle**	Moderate
Cost	High	Moderate–Low	High

✅ **Best Choice: Ceramics**

Why?

Ceramics like **alumina (Al_2O_3)**, **silicon carbide (SiC)** are ideal for furnace lining due to:

- High melting point
- Chemical inertness
- Excellent thermal resistance

Q.2 **(a)** Define Macro examination & micro Examination and, State its uses in the field of Material Science. **03**

Answer:

Macro Examination:

- Involves observing a material's **structure with the naked eye** or **low magnification** (up to 10x).
- **Reveals:** Surface defects, grain flow, weld flaws, segregation.

Micro Examination:

- Involves observing the **internal structure** of materials using a **microscope** at **high magnification** (100x to 1000x).
- **Reveals:** Grain boundaries, phases, microcracks, inclusions.

Uses in Material Science:

- Identify material defects
- Evaluate heat treatment effects
- Determine grain size and phase distribution
- Quality control and failure analysis

(b) Using the concept of solute strengthening, explain how the addition of elements like carbon in steel or aluminum in copper improves the strength and mechanical properties of the base metal. **04**

Answer:

Solute Strengthening (Solid Solution Strengthening):
A process where **alloying elements (solute)** are added to **base metal (solvent)** to improve mechanical properties.

Mechanism:

- Solute atoms distort the crystal lattice and **hinder dislocation motion**.
- This increases the **yield strength and hardness** of the metal.

Examples:

- **Carbon in Steel (Fe–C):**
  Carbon atoms occupy interstitial spaces → restrict dislocation movement → increase strength
- **Aluminum in Copper (Cu–Al):**
  Substitutional atoms create internal stress → improve strength

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Conclusion:
Solute atoms act as barriers, preventing plastic deformation, thus enhancing strength and hardness.

(c) Discuss the mechanism of crystallization, focusing on the nucleation and growth processes. What factors influence nucleation and growth in materials? **07**

Answer:

Crystallization:
Crystallization is the process of formation of a **crystalline solid** from a liquid or vapor phase.

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1. Nucleation:

- **Initiation step** in crystallization.
- Tiny stable clusters (nuclei) of atoms form when the liquid is **supercooled** below melting point.
- **Types:**
  - *Homogeneous nucleation:* Nucleation in bulk without any impurity.
  - *Heterogeneous nucleation:* Occurs at surfaces or impurities; more common.

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2. Crystal Growth:

- Atoms deposit onto existing nuclei.
- Growth continues until the entire liquid becomes solid.
- Crystal size depends on cooling rate.

Factors Influencing Nucleation and Growth:

Factor	Effect
Undercooling	More undercooling → more nucleation
Impurities	Act as nucleation sites → promotes crystallization
Cooling Rate	Slow cooling → larger grains; fast → fine grains
Surface energy	High surface energy → less nucleation
Viscosity	Affects atomic mobility for growth

Sketch Suggestion:

OR

(c) Define the Dislocation and Differentiate Edge Dislocation and Screw Dislocation. **07**

Answer:

Dislocation:

A **dislocation** is a linear crystallographic defect or irregularity within a crystal structure where atoms are misaligned.
Dislocations are the **main reason** behind plastic deformation in metals.

Types of Dislocations:

1. Edge Dislocation:

- Occurs when an extra half-plane of atoms is inserted in a crystal.
- **Strain field:** Above plane – compressive, Below plane – tensile.
- **Burgers vector** is ⊥ (perpendicular) to dislocation line.

Sketch:

A rectangular crystal lattice with an extra half-plane showing stress regions.

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2. Screw Dislocation:

- Formed by a shear stress that causes a helical ramp in the crystal structure.
- The atoms shift in such a way that the structure looks "screwed".

- **Burgers vector** is ∥ (parallel) to dislocation line.

Sketch:
Crystal planes forming a helical step around the dislocation line.

✅ **Comparison Table:**

Feature	Edge Dislocation	Screw Dislocation
Direction	Perpendicular to Burgers vector	Parallel to Burgers vector
Formation	Extra half-plane	Shear distortion
Movement	Slip occurs perpendicular	Slip occurs parallel
Stress Field	Tensile-compressive zones	Pure shear zones

Q.3 **(a)** What are Hume-Rothery rules. **03**

Answer:

Hume-Rothery Rules are guidelines that predict the **formation of solid solutions** between two metals.

✅ **Rules for Substitutional Solid Solution:**

1. **Atomic Size Difference**:
   - Should be less than **15%**.
2. **Crystal Structure**:
   - Both metals should have the **same crystal structure** (e.g., both FCC).
3. **Electronegativity**:
   - Should be **similar**, otherwise intermetallic compounds form.
4. **Valency**:
   - The metal with **higher valency** dissolves more in the metal with **lower valency**.

Example:
Copper and nickel form solid solutions because they satisfy these rules.

(b) In Iron carbon diagram, which phases are presents at 0.4% carbon contain steel at 600^0C. and find out the % of Phases presents using lever rule. **04**

Answer:

From the **Iron–Carbon phase diagram**:

- At **0.4% C and 600°C**, the alloy lies in the **α + Fe_3C (ferrite + cementite)** region.
- Use **lever rule** between **0.02% (ferrite end)** and **6.67% (cementite)**.

Lever Rule:
Let:

- C0=0.4%,
- Cα=0.02%,
- CFe3C=6.67%

%Ferrite (α):

$$\frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_\alpha} = \frac{6.67 - 0.4}{6.67 - 0.02} \approx \frac{6.27}{6.65} \approx 94.3\%$$

%Cementite (Fe_3C):

$$\frac{C_0 - C_\alpha}{C_{Fe_3C} - C_\alpha} = \frac{0.4 - 0.02}{6.67 - 0.02} \approx \frac{0.38}{6.65} \approx 5.7\%$$

✅ **Answer:**
At 600°C, **0.4% C steel** contains:

- ~94.3% **ferrite (α)**
- ~5.7% **cementite (Fe_3C)**

(c) Explain the eutectic and eutectoid reactions in detail. Discuss their differences and give examples of alloy systems where each reaction occurs. **07**

Answer:

1. Eutectic Reaction:

- A **liquid** transforms into **two solid phases** at a fixed temperature.

$$L \rightarrow \alpha + \beta$$

- **Occurs at eutectic point** in binary alloy systems (e.g., Pb–Sn).
- **Example:**
  In Fe–Fe_3C system at 4.3% C and 1147°C:

$$L \rightarrow \gamma + Fe_3C \quad \text{(Ledeburite)}$$

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2. Eutectoid Reaction:

- A **solid phase** transforms into **two new solid phases**.

$$\gamma \rightarrow \alpha + Fe_3C$$

- **Occurs at eutectoid point**, 0.8% C at 727°C in iron-carbon system.

✅ **Differences:**

Feature	Eutectic	Eutectoid
Phases involved	Liquid → 2 solids	Solid → 2 solids
State before reaction	Liquid	Solid
Example Alloy System	Pb–Sn, Al–Si	Fe–C (steel)
Microstructure	Lamellar (eutectic structure)	**Pearlite** in steel

OR

Q.3 **(a)** What is Gibbs' phase rule? **03**

Answer:

Gibbs Phase Rule:
It gives the number of **degrees of freedom (F)** in a system at equilibrium:

$$F = C - P + 2$$

Where:

- **F** = Degrees of freedom (independent variables like T, P, composition)
- **C** = Number of components
- **P** = Number of phases

At Constant Pressure:
For solid-liquid-metal systems, pressure is often constant, so:

$$F = C - P + 1$$

Example:
At the eutectic point in a binary system (C = 2, P = 3):

$$F = 2 - 3 + 1 = 0$$

→ **Invariant system** (no degree of freedom)

(b) Differentiate between homogeneous nucleation and heterogeneous nucleation. **04**

Answer:

Feature	Homogeneous Nucleation	Heterogeneous Nucleation
Location	Occurs within the bulk liquid	Occurs at surfaces like mold walls, impurities
Energy Required	Higher	Lower (due to favorable surface interaction)
Occurrence	Less common	More common in practical systems
Control	Hard to control	Easier to promote (by adding nucleants)

Explanation:

- **Homogeneous** nucleation needs large undercooling. Nuclei form randomly.
- **Heterogeneous** nucleation is easier as impurities act as sites.

(c) Draw Iron Carbon Diagram with all notations like Phases and Reactions Nomenclature. **07**

Answer:

The Iron–Iron Carbide (Fe–Fe_3C) Diagram shows phases formed in steels and cast irons (0 to 6.67% C). For steel, focus on up to 2.1% C.

✅ **Important Phases:**

Phase	Description
Ferrite (α)	BCC, low carbon solubility
Austenite (γ)	FCC, higher solubility of carbon
Cementite (Fe_3C)	Hard, brittle iron carbide
Pearlite	α + Fe_3C (eutectoid mixture)
Ledeburite	γ + Fe_3C or L + Fe_3C

✅ **Key Reactions:**

1. **Eutectoid:**
   $\gamma \rightarrow \alpha + Fe_3C$ at 0.8% C and 727°C
2. **Eutectic:**
   $L \rightarrow \gamma + Fe_3C$ at 4.3% C and 1147°C
3. **Peritectic:**
   $L + \delta \rightarrow \gamma$ at 0.16% C and 1493°C

✅ **Diagram Requirements:**

Q.4 **(a)** Define Heat Treatments. States its purpose. **03**

Answer:

Heat Treatment:
Heat treatment is a **controlled process of heating and cooling metals** to alter their physical and mechanical properties without changing the product shape.

Purpose of Heat Treatment:

1. Improve hardness and strength
2. Increase ductility and toughness
3. Relieve internal stresses
4. Refine grain structure
5. Improve machinability
6. Enhance wear, corrosion, and fatigue resistance

(b) Explain the Grey cast iron. **04**

Answer:

Grey Cast Iron:
A type of cast iron in which **carbon is present as graphite flakes**, giving the fractured surface a grey appearance.

Composition:
- Carbon: 2.5–4%
- Silicon: 1–3%
- Manganese, Phosphorus, Sulphur (trace)

Properties:
- Good castability
- Excellent vibration damping
- High compressive strength
- Brittle due to flake graphite

Applications:
- Engine blocks
- Machine bases
- Pipes
- Brake drums

(c) Classify the Heat Treatments Process and Explain the Normalizing Heat Treatments. **07**

Answer:

Classification of Heat Treatment Processes:
1. **Annealing** – Softens metal, improves ductility
2. **Normalizing** – Refines grain size, improves strength
3. **Hardening** – Increases hardness and strength
4. **Tempering** – Reduces brittleness after hardening
5. **Surface Hardening** – Hardens only the surface (e.g., flame, induction)

Normalizing:
A heat treatment process for **refining grain structure** and improving toughness.

Procedure:
1. Heat steel to **30–50°C above upper critical temperature** (~850–950°C)
2. Soak to allow full austenite formation
3. **Cool in air** (not furnace-cooled)

Effects:
- Produces fine pearlite and ferrite
- Improves mechanical properties compared to annealing
- Used after forging, casting, or welding

OR

Q.4 **(a)** Classify the Plain carbon Steel. **03**

Answer:

Plain Carbon Steels are iron–carbon alloys with **no significant alloying elements**, classified based on **carbon content**:

Type	Carbon %	Characteristics
Low Carbon Steel	Up to 0.3%	Soft, ductile, good weldability
Medium Carbon Steel	0.3–0.6%	Higher strength, less ductility
High Carbon Steel	0.6–1.5%	Very hard, wear-resistant, brittle

Applications:

- **Low C steel**: Sheets, auto bodies
- **Medium C steel**: Shafts, gears
- **High C steel**: Springs, tools

(b) Explain the characteristics of Powder material used in Powder metallurgy. **04**

Answer:

Essential Characteristics of Metal Powders:

1. **Particle Size & Distribution:**
   - Affects compressibility and sintering. Fine particles give better surface finish.
2. **Particle Shape:**
   - Spherical for good flow; irregular for better compressibility.
3. **Purity:**
   - High purity reduces contamination and improves properties.
4. **Apparent Density:**
   - Affects die filling and green strength.
5. **Flowability:**
   - Easy and uniform die filling during compaction.
6. **Compressibility:**
   - Powder must densify under pressure to form strong green compact.

(c) Write full name of TTT Diagram. Draw TTT diagram for eutectoid steel with necessary notations. and Describe How Rate of Cooling is affect the Microstructure of Steel. **07**

Answer:

Full Name:
Time–Temperature–Transformation (TTT) Diagram

Use:
Shows the transformation of **austenite** into **pearlite, bainite, or martensite** at constant temperatures.

Sketch of TTT Diagram for Eutectoid Steel (0.8% C):

- X-axis: Time (log scale)
- Y-axis: Temperature
- Shows start/finish curves for pearlite, bainite
- Vertical line for martensite (no time required)

Cooling Rate Effect on Microstructure:

Cooling Rate	Microstructure Formed	Properties
Slow cooling	Coarse Pearlite	Soft, ductile
Moderate cooling	Fine Pearlite	Harder, stronger
Intermediate	Bainite	Harder than pearlite, tough
Rapid Quenching	Martensite	Very hard, brittle

Conclusion:
The **faster the cooling**, the **harder** and **brittle** the structure becomes due to martensitic formation.

Q.5 (a) Define Powder metallurgy. State its Advantages and Limitation. **03**

Answer:

Definition:
Powder Metallurgy (PM) is a metal forming technique where **metal powders** are compacted into desired shapes and then **sintered** (heated below melting point) to form solid parts.

Advantages:

1. Near net-shape production → **minimal machining**
2. **Less material wastage**
3. Ability to produce **complex and porous shapes**
4. Suitable for **mass production**
5. **Uniform properties** in parts

Limitations:

1. **High cost** of powder production
2. Limited to **brittle/non-reactive** metals
3. **Lower mechanical strength** than forged parts
4. **Size limitations** due to press capacity

(b) States the various Non Destructive methods. State the Advantages of RT over UT techniques. **04**

Answer:

Non-Destructive Testing (NDT) Methods:

1. **Visual Inspection (VI)**
2. **Ultrasonic Testing (UT)**
3. **Radiographic Testing (RT)**
4. **Dye Penetrant Testing (DPT)**
5. **Magnetic Particle Testing (MPT)**
6. **Eddy Current Testing**

✅ **Advantages of Radiographic Testing (RT) over Ultrasonic Testing (UT):**

Feature	RT Advantage over UT
Permanent Record	RT provides a **radiograph** (film/digital)
Interpretation	Easier for non-experts to analyze
Complex Shapes	RT can inspect **irregular geometries**
Surface Preparation	Less critical than UT

(c) Explain the various methods used to prevents the Corrosion. **07**

Answer:

Methods to Prevent Corrosion:

1. Barrier Protection (Coatings):

- **Paint, varnish, plastic coating**
- Blocks exposure to air/moisture

2. Galvanization:

- Coating iron/steel with **zinc layer**
- Zinc corrodes preferentially (sacrificial protection)

3. Cathodic Protection:

- Metal made cathode by attaching **sacrificial anode** or **external current**

4. Alloying:

- Adding elements like **chromium in stainless steel** to form passive films

5. Anodizing:

- Used for **aluminum** to form **protective oxide layer**

6. Design Improvements:

- Avoid crevices, ensure proper drainage, use corrosion-resistant joints

7. Corrosion Inhibitors:

- Chemicals added to fluid to **suppress corrosion reactions**

OR

Q.5 **(a)** Define Corrosion. Classify the corrosion. **03**

Answer:

Corrosion:
Corrosion is the **deterioration of a material**, usually metal, **due to chemical or electrochemical reaction** with its environment.

Classification of Corrosion:
1. Dry Corrosion (Chemical):
- Direct oxidation (e.g., scaling at high temperature)

2. Wet Corrosion (Electrochemical):
- Involves electrolytes (e.g., rusting of iron)

Types of Wet Corrosion:
- **Uniform corrosion**
- **Galvanic corrosion**
- **Pitting corrosion**
- **Crevice corrosion**
- **Intergranular corrosion**
- **Stress corrosion cracking (SCC)**

(b) State the various metal powder production methods. Explain any one method among them. **04**

Answer:

Metal Powder Production Methods:
1. **Atomization (most common)**
2. **Reduction of metal oxides**
3. **Electrolytic deposition**
4. **Mechanical pulverization**
5. **Chemical precipitation**

Atomization Method (Explained):
- Molten metal is forced through a nozzle.
- A **high-pressure gas or water jet** breaks it into droplets.
- Droplets cool and solidify into fine metal powders.

Advantages:
- High production rate
- Spherical particles
- Suitable for many metals

(c) Define Non Destructive Testing. Explain the Dye Penetrant Testing with principle, procedure, advantages and Limitations. **07**

Answer:

Definition:
Non-Destructive Testing (NDT) is the method of **inspecting materials for internal and surface flaws** without damaging or altering them.

Dye Penetrant Testing (DPT):
Used to detect **surface cracks/defects** in **non-porous materials**.

Principle:
Capillary action draws penetrant dye into surface flaws. After cleaning and applying developer, dye flows out of cracks, making them visible.

Procedure:
1. **Pre-cleaning:** Remove grease, dirt, oxide layers
2. **Apply Penetrant:** Let it dwell (~10–20 mins)
3. **Remove Excess Penetrant:** Clean surface
4. **Apply Developer:** White powder draws dye out
5. **Inspection:** Cracks appear as colored lines
6. **Post-cleaning:** Remove chemicals

Advantages:
- Inexpensive
- Easy to use
- Detects **fine surface cracks**

Limitations:
- Only for **surface defects**
- Not for **porous** materials
- Requires proper cleaning
- Health & environmental concerns (chemical use)

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