

Engineering Materials (BSC2031)

Internal Assessment Test – I

QB SOLUTION BY SYNTAX SYNDICATE

| Q1(a) [6 Marks] — Numerical on Tensile Stress of an Alloy

Answer:

Concept

Tensile stress (σ) is defined as the internal resisting force developed per unit cross-sectional area of a material when it is subjected to a tensile (pulling) load.

Formula

$$\sigma = F / A \quad (\text{Unit: Pa or N/m}^2 \text{ or MPa})$$

$$\text{For circular cross-section: } A = \pi/4 \times d^2$$

Solved Numerical

Problem: A circular rod of an alloy, 20 mm in diameter, is subjected to a tensile force of 50,000 N. Calculate the tensile stress developed in the rod.

Solution

Given:

$$\text{Diameter (d)} = 20 \text{ mm} = 0.020 \text{ m}$$

$$\text{Tensile Force (F)} = 50,000 \text{ N}$$

Step 1 – Cross-sectional Area

$$A = \pi/4 \times d^2$$

$$A = (3.14159 / 4) \times (0.020)^2$$

$$A = 0.7854 \times 4 \times 10^{-4}$$

$$A = 3.1416 \times 10^{-4} \text{ m}^2$$

Step 2 – Tensile Stress

$$\sigma = F / A$$

$$\sigma = 50,000 / (3.1416 \times 10^{-4})$$

$$\sigma = 1.5916 \times 10^8 \text{ Pa}$$

$$\sigma = 159.16 \text{ MPa} \quad \leftarrow \text{Answer}$$

Additional Formulas (for complete 6-mark answer)

- Strain $\epsilon = \Delta L / L_0$ (dimensionless)
- Young's Modulus $E = \sigma / \epsilon$ (Unit: GPa)
- Example: If $\Delta L = 0.5 \text{ mm}$, $L_0 = 500 \text{ mm}$ $\rightarrow \epsilon = 0.001$, $E = 159.16 \text{ GPa} / 0.001 = \dots$ (compute accordingly)
- Factor of Safety = Ultimate Stress / Working Stress

| Q1(b) [2 Marks] — Numerical on Density of an Alloy

Answer:

Concept

The density of an alloy can be estimated by the Rule of Mixtures using weight fractions of each component element.

Formula

$$1 / \rho_{\text{alloy}} = (w_1 / \rho_1) + (w_2 / \rho_2) + \dots$$

where w_1, w_2 = weight fractions; ρ_1, ρ_2 = densities of constituent elements.

Solved Numerical

Problem: Brass contains 70 wt% Cu and 30 wt% Zn. Given: $\rho(\text{Cu}) = 8960 \text{ kg/m}^3$, $\rho(\text{Zn}) = 7133 \text{ kg/m}^3$. Find density of brass.

$$\begin{aligned} 1/\rho &= (0.70 / 8960) + (0.30 / 7133) \\ &= 7.8125 \times 10^{-5} + 4.2061 \times 10^{-5} \\ &= 12.0186 \times 10^{-5} \end{aligned}$$

$$\begin{aligned} \rho_{\text{alloy}} &= 1 / (12.0186 \times 10^{-5}) \\ &= 8320 \text{ kg/m}^3 \quad \leftarrow \text{Answer} \end{aligned}$$

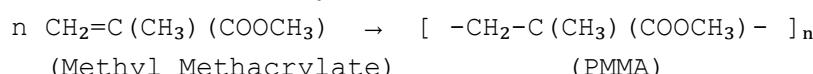
| Q1(c) [2 Marks] — Preparation, Properties, and Uses of PMMA / Teflon

Answer:

A. PMMA (Polymethyl Methacrylate) — Trade names: Plexiglas, Lucite, Perspex

Preparation:

PMMA is synthesized by free-radical addition polymerization of methyl methacrylate (MMA) monomer using initiators such as benzoyl peroxide.



Properties:

- Excellent optical transparency — transmits ~92% of visible light (more than glass)
- Hard, rigid, lightweight thermoplastic — density 1.19 g/cm^3
- Good UV and weathering resistance
- Good electrical insulator
- Relatively brittle; low impact strength

Uses:

- Optical lenses, spectacles, contact lenses
- Aircraft windows, automotive tail-lights, skylights
- Display panels, aquariums, signage
- Bone cement in orthopaedic surgery

B. Teflon (PTFE — Polytetrafluoroethylene)

Preparation:

PTFE is prepared by free-radical polymerization of tetrafluoroethylene (TFE) monomer under high pressure and temperature.



Properties:

- Chemically inert — resistant to almost all acids, solvents, and bases
- Extremely low coefficient of friction (non-stick surface)
- Wide service temperature: -200°C to $+260^{\circ}\text{C}$
- Non-flammable and hydrophobic
- Excellent electrical insulator; density $\sim 2.2 \text{ g/cm}^3$

Uses:

- Non-stick coatings for cookware
- Gaskets, seals, O-rings in chemical plants
- Electrical cable insulation
- Plumber's PTFE tape; medical implants and catheters

| Q1(d) [2 Marks] — Effect of Alloying Elements (Cr, Co, W, V, Mo) in Steel

Answer:

Alloying elements are added to plain carbon steel to modify specific mechanical, thermal, or chemical properties. Their effects are as follows:

1. Chromium (Cr)

- Forms a thin, stable Cr_2O_3 oxide layer → imparts corrosion resistance
- Increases hardness, tensile strength, and wear resistance
- Improves hardenability (depth of hardening)
- Above 12% Cr: steel becomes stainless steel
- Applications: Stainless steel, tool steels, ball-bearing steels

2. Cobalt (Co)

- Retains hardness at elevated temperatures (red hardness)
- Improves magnetic properties
- Refines grain size, increasing toughness
- Applications: High-speed steels (HSS), permanent magnets (Alnico)

3. Tungsten (W)

- Strongest carbide former — produces very hard WC (tungsten carbide)
- Imparts red hardness and high-temperature strength
- Increases wear resistance and hardness
- Applications: High-speed tool steels, dies, cutting tools

4. Vanadium (V)

- Strong carbide former → fine vanadium carbide particles
- Refines grain size, improving toughness and fatigue resistance
- Increases strength and hardness
- Applications: Spring steels, structural steels, HSS

5. Molybdenum (Mo)

- Increases hardenability and depth of hardening
- Improves high-temperature creep resistance
- Reduces temper brittleness in alloy steels
- Applications: High-strength structural steels, boiler steels, tool steels

| Q1(e) [2 Marks] — State the Drawbacks of Natural Rubber

Answer:

Natural rubber (*cis*-1,4-polyisoprene) is obtained from the latex of *Hevea brasiliensis*. Despite its high elasticity, it suffers from several drawbacks:

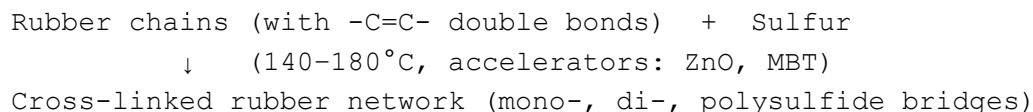
- Poor resistance to oxidation and ozone — undergoes ozone cracking and degradation in air
- Swells and softens in contact with oils, solvents, and organic chemicals
- Narrow service temperature range: brittle below 0°C and sticky/soft above 60°C
- Low mechanical strength in raw (unvulcanized) form
- Poor resistance to heat aging and UV radiation (photo-oxidation)
- High water absorption compared to synthetic rubbers
- Poor electrical insulation compared to synthetic alternatives
- Agricultural dependence: supply dependent on tropical climate and plantation availability

| Q1(f) [2 Marks] — What is Vulcanization?

Answer:

Vulcanization is the chemical process of treating natural or synthetic rubber with sulfur (or other cross-linking agents such as peroxides) at elevated temperature (140–180°C) to form covalent cross-links (sulfide bridges) between adjacent polymer chains.

Chemical Reaction



Properties Improved by Vulcanization

- Increased tensile strength and elongation at break
- Improved elasticity, resilience, and snap-back
- Reduced stickiness and cold flow (creep)
- Better resistance to heat, oxidation, oils, and solvents
- Improved hardness and abrasion resistance

Types of Vulcanized Rubber

- Soft rubber: 1–3% sulfur — used for tyres, tubes, hoses, gloves
- Hard rubber (Ebonite): 30–50% sulfur — used for battery cases, electrical equipment

| Section A [5 Marks] — What is Compounding of Plastics? Explain the Role of Any Two Ingredients in the Compounding of Plastics with Examples.

Answer:

Definition of Compounding

Compounding of plastics is the process of intimately mixing a base polymer (plastic) with various additives in definite proportions to obtain a compound that has the desired processing characteristics (flowability, moldability) and end-use properties (strength, flexibility, colour, stability).

Purpose of Compounding

- Improve processability during moulding/extrusion
- Enhance mechanical, thermal, or electrical properties
- Reduce cost by using fillers
- Improve service life by adding stabilizers

Ingredients Used in Compounding

The major ingredients are: Plasticizers, Fillers, Stabilizers, Lubricants, Colorants, Flame Retardants, and Blowing Agents.

Ingredient 1 — Plasticizers (detailed explanation)

Definition: Plasticizers are high-boiling organic liquids or low-melting solids that are incorporated into a plastic to reduce its brittleness, lower the glass transition temperature (T_g), and increase flexibility and workability.

Mechanism: Plasticizer molecules insert themselves between polymer chains, reducing intermolecular forces (van der Waals forces), increasing chain mobility.

Examples:

- Dioctyl phthalate (DOP) — most widely used plasticizer for PVC
- Tricresyl phosphate (TCP) — used in PVC, also acts as flame retardant
- Camphor — classical plasticizer for cellulose nitrate

Effect: Rigid PVC (unplasticized) → addition of DOP → flexible PVC used in electrical cable insulation, raincoats, flooring.

Ingredient 2 — Fillers (detailed explanation)

Definition: Fillers are solid materials (organic or inorganic) incorporated into plastics to reduce cost, improve mechanical properties, and modify processing behavior.

Types:

- Reinforcing fillers — improve mechanical strength: carbon black (in PE, rubber), glass fibres (in nylon, epoxy)
- Non-reinforcing fillers — mainly cost reduction: chalk (CaCO_3), talc, wood flour, silica

Examples:

- Carbon black added to polyethylene: increases tensile strength by 2–3× and provides UV resistance
- Glass fibre added to nylon 6,6: increases flexural strength from ~80 MPa to ~200 MPa
- Wood flour in phenol-formaldehyde (Bakelite): reduces cost and improves impact strength

Other Ingredients (brief mention for completeness)

- Stabilizers: Prevent thermal (heat stabilizers for PVC: lead stearate) and UV degradation (HALS, carbon black)
- Lubricants: Internal (stearic acid, reduces melt viscosity); External (waxes, prevent sticking to dies)
- Colorants: Pigments (TiO_2 for white, carbon black for black) or dyes for transparent colouring
- Flame Retardants: Antimony trioxide + halogenated compounds in polypropylene

Section B [5 Marks] — Define Alloy. Numerical on Atomic Percentage of Each Element.

Answer:

Definition of Alloy

An alloy is a homogeneous or heterogeneous mixture of two or more elements, of which at least one is a metal, prepared by mixing them in the molten state and allowing solidification, to obtain a material with properties superior to those of its individual components.

Purpose of Making Alloys

- Improve mechanical properties: hardness, tensile strength, toughness
- Improve corrosion and oxidation resistance
- Improve casting and machining characteristics
- Obtain special properties: magnetic, electrical, or thermal

Classification

- Binary alloy — 2 components: Brass (Cu + Zn)
- Ternary alloy — 3 components: German Silver (Cu + Zn + Ni)
- Quaternary alloy — 4 components: Duralumin (Al + Cu + Mg + Mn)

Numerical: Calculation of Atomic Percentage

Formula:

$$\text{Atomic \% of element A} = \frac{(\text{Wt\% A} / \text{Atomic Mass of A})}{\sum [\text{Wt\%}_i / \text{Atomic Mass of element } i]} \times 100$$

Problem: An alloy (Brass) contains 70 wt% Cu and 30 wt% Zn. Calculate the atomic percentage of each element.

Given:

$$\begin{aligned}\text{Wt\% of Cu} &= 70, & \text{Atomic Mass (A_Cu)} &= 63.5 \text{ g/mol} \\ \text{Wt\% of Zn} &= 30, & \text{Atomic Mass (A_Zn)} &= 65.4 \text{ g/mol}\end{aligned}$$

Step 1 — Mole fractions (per 100 g of alloy):

$$\begin{aligned}n_{\text{Cu}} &= 70 / 63.5 = 1.1024 \text{ mol} \\ n_{\text{Zn}} &= 30 / 65.4 = 0.4587 \text{ mol} \\ \text{Total} &= 1.1024 + 0.4587 = 1.5611 \text{ mol}\end{aligned}$$

Step 2 — Atomic %:

$$\begin{aligned}\text{at\% Cu} &= (1.1024 / 1.5611) \times 100 = 70.62 \text{ at\%} \\ \text{at\% Zn} &= (0.4587 / 1.5611) \times 100 = 29.38 \text{ at\%}\end{aligned}$$

Answer: Cu = 70.62 at%, Zn = 29.38 at%

Section C [5 Marks] — Composition, Properties, and Uses of (i) Wood's Metal (ii) German Silver

Answer:

(i) Wood's Metal

Composition:

Element	Percentage (wt%)
Bismuth (Bi)	50%
Lead (Pb)	26.7%
Tin (Sn)	13.3%
Cadmium (Cd)	10%

- Type: Fusible eutectic alloy | Melting Point: ~70°C

Properties:

- Extremely low melting point (~70°C) — melts in hot water
- Good fluidity and excellent castability
- Expands very slightly on solidification (unusual — resists shrinkage)
- Good corrosion resistance; non-toxic (modern Bi-based variants)

Uses:

- Fire sprinkler systems — fusible plug melts at 70°C to activate water spray
- Safety plugs in boilers and pressure vessels
- Holding optical lenses during grinding/polishing (acts as low-melt fixture material)
- Low-temperature soldering, casting, and electroforming mandrels

(ii) German Silver (Nickel Silver / Alpaca)

Composition:

Element	Percentage (wt%)
Copper (Cu)	60%
Zinc (Zn)	20%
Nickel (Ni)	20%

- Note: Contains NO actual silver — only silvery appearance due to nickel
- Melting Point: ~1060°C | Color: Bright silvery-white

Properties:

- Bright, lustrous silvery-white appearance
- Good corrosion resistance due to nickel content
- Good mechanical strength, ductility, and formability
- Excellent base for silver electroplating (EPNS — Electroplated Nickel Silver)
- Good spring properties

Uses:

- Cutlery, spoons, forks — base metal for silver-plated utensils (EPNS)
- Keys, zippers, coins, ornamental hardware
- Musical instrument valves and keys
- Electrical contacts and resistors

Section D [5 Marks] — Composition, Properties, and Uses of (i) Dutch Metal (ii) Duralumin

Answer:

(i) Dutch Metal (Tombac / Dutch Gold)

Composition:

Element	Percentage (wt%)
Copper (Cu)	80%
Zinc (Zn)	20%

- Type: High-copper brass | Color: Brilliant golden-yellow

Properties:

- Brilliant gold-like color — closely resembles gold in appearance
- High ductility — can be rolled into extremely thin sheets or beaten into foil
- Lower cost than gold
- Susceptible to tarnishing in moist air — requires lacquering for protection

Uses:

- Decorative gold-colored foil for gift wrapping and packaging
- Imitation gold leaf for gilding picture frames, furniture, and art
- Costume jewelry and decorative craft items
- Gold-colored printing in publishing and packaging industries

(ii) Duralumin

Composition:

Element	Percentage (wt%)
Aluminium (Al)	94% (balance)
Copper (Cu)	4%
Magnesium (Mg)	~0.5%
Manganese (Mn)	~0.5%

- Type: Age-hardenable (precipitation-hardening) aluminium alloy
- Density: ~2.79 g/cm³ | Tensile Strength (aged): 400–450 MPa

Age Hardening / Heat Treatment:

- Solution treatment: Heat to ~500°C → dissolves CuAl₂ → quench in water
- Ageing: Hold at room temperature (natural ageing) or 150–180°C (artificial ageing)
- CuAl₂ precipitates uniformly → blocks dislocation movement → strength greatly increases

Properties:

- High strength-to-weight ratio (comparable to mild steel at one-third the density)
- Good machinability and workability
- Good fatigue resistance
- Moderate corrosion resistance (Alclad coating applied for aircraft use)

Uses:

- Aircraft fuselage, wings, and structural frames — primary aerospace alloy
- Automobile engine components and body panels

- Railway coach bodies and structural members
- Rivets, fasteners, and bolts in aerospace applications

Section E [5 Marks] — Preparation, Properties, and Uses of (i) Silicone Rubber (ii) Polyurethane Rubber

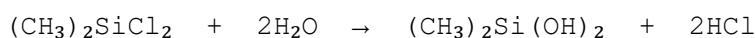
Answer:

(i) Silicone Rubber (Polysiloxane Rubber)

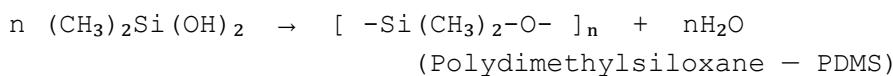
Preparation:

Silicone rubber is a synthetic elastomer with an inorganic siloxane backbone ($-\text{Si}-\text{O}-\text{Si}-$). It is prepared in two steps:

Step 1 — Hydrolysis of organochlorosilane:



Step 2 — Condensation polymerization:



Cross-linking (vulcanization) is achieved using organic peroxides or platinum catalysts.

Properties:

- Excellent thermal stability: service range -60°C to $+300^{\circ}\text{C}$
- Good weathering, UV, and ozone resistance
- Low surface energy — non-stick and hydrophobic
- Excellent electrical insulator
- Biocompatible and chemically inert — suitable for medical use
- Good flame resistance

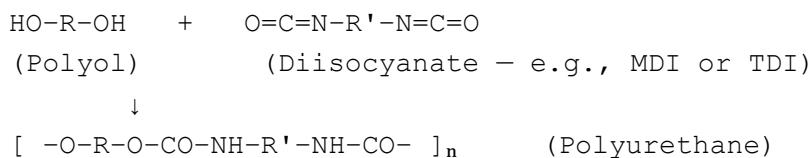
Uses:

- Medical implants, prosthetics, catheters, and surgical tubing
- Aerospace and automotive gaskets, seals, and O-rings
- Electrical insulation for high-voltage cables and equipment
- Oven-safe kitchen bakeware and food-grade moulds
- Sealants for buildings, glass, and electronics

(ii) Polyurethane Rubber (PU)

Preparation:

Polyurethane is formed by the addition polymerization reaction between a polyol (multi-functional alcohol) and a diisocyanate.



Common raw materials: MDI (methylene diphenyl diisocyanate), TDI (toluene diisocyanate), polyester/polyether polyols.

Properties:

- Outstanding abrasion resistance — superior to most rubbers and plastics
- High tensile strength and tear resistance
- High load-bearing capacity

- Good resistance to oils, fuels, and oxygen
- Available in a wide range of hardness (soft foam to rigid solid)
- Good adhesion to many substrates

Uses:

- Solid tyres and wheels for forklifts and industrial vehicles
- Shoe soles and sports footwear
- Flexible foam for cushions, mattresses, and car seats
- Rigid foam for thermal insulation (walls, refrigerators)
- Industrial conveyor belts, rollers, and linings
- Adhesives, coatings, and sealants

Section F [5 Marks] — Composition, Properties, and Uses of (i) Gunmetal (ii) Tinman's Solder

Answer:

(i) Gunmetal (Admiralty Gunmetal)

Composition:

Element	Percentage (wt%)
Copper (Cu)	88%
Tin (Sn)	10%
Zinc (Zn)	2%

- Type: Copper-based alloy (special bronze) | Melting Point: ~900°C

Properties:

- High strength and hardness due to tin content
- Excellent resistance to seawater and marine corrosion
- Good anti-friction / bearing properties
- Resistant to steam under high pressure and temperature
- Good castability and machinability
- Dense material: ~8.7 g/cm³

Uses:

- Gun and cannon parts (historical origin of the name)
- Marine fittings: ship propeller bushings, pump casings, valves
- Steam-operated valves, taps, and hydraulic fittings
- Bearings, bushings, and gear wheels in heavy machinery

(ii) Tinman's Solder (Soft Solder)

Composition:

Element	Percentage (wt%)
Tin (Sn)	60–70%
Lead (Pb)	30–40%

- Most common grade: Sn60/Pb40 | Melting range: 183–190°C

- Note: Lead-free solder (Sn-Ag-Cu / SAC) used in modern electronics (RoHS compliance)

Properties:

- Low melting point — easily applied with a soldering iron
- Good wetting and adhesion to tin, copper, and iron surfaces
- Adequate electrical conductivity in solidified joint
- Joints are mechanically strong enough for light tinsmithing work
- Low cost and easy to apply

Uses:

- Joining tin-plated iron sheets in tinsmithing and sheet metal work
- Electronic PCB assembly (soldering of components to circuit boards)
- Plumbing joints for low-pressure water pipes
- Sealing of food containers and tin cans
- Joining copper refrigeration tubes

| Section G [5 Marks] — Write a Note on Stainless Steel

Answer:

Definition

Stainless steel is a family of iron-based alloys containing a minimum of 10.5 wt% chromium, which confers excellent corrosion resistance by forming a thin, stable, self-healing passive film of chromium oxide (Cr_2O_3) on the surface, preventing further oxidation.

Essential Composition

- Fe: base metal (>50%)
- Cr: minimum 10.5% (typically 12–26%) — provides corrosion resistance
- Ni: 0–22% — stabilises austenite phase, improves ductility
- C: <0.08% — low carbon prevents sensitization (Cr carbide formation at grain boundaries)
- Mo, Ti, Nb, Mn — added in specific grades for special properties

Types of Stainless Steel

Type	Typical Composition	Key Features	Applications
Austenitic (304, 316)	18% Cr, 8–10% Ni	Non-magnetic, excellent corrosion resistance, most widely used	Kitchen equipment, pipes, chemical vessels
Ferritic (430)	17% Cr, no Ni	Magnetic, moderate corrosion resistance, lower cost	Automotive exhausts, appliances
Martensitic (410, 440C)	12% Cr, higher C	Magnetic, hardenable, high strength and hardness	Cutlery blades, surgical instruments, valves
Duplex (2205)	22% Cr, 5% Ni, 3% Mo	High strength + superior corrosion resistance	Chemical processing, offshore structures
Precipitation Hardening (17-4 PH)	17% Cr, 4% Ni, Cu	Very high strength via age hardening	Aerospace, shafts, structural parts

Properties

- Excellent corrosion and oxidation resistance (passive Cr₂O₃ film)
- High tensile strength and hardness (varies by grade and heat treatment)
- Good formability, weldability, and machinability (austenitic grades)
- Attractive, lustrous appearance — takes high mirror polish
- Hygienic surface — easy to clean, does not contaminate food
- Good performance at cryogenic temperatures and up to ~900°C

Uses

- Household: Cutlery, kitchen sinks, cookware
- Food and dairy industry: Processing equipment, tanks, pipelines
- Chemical industry: Reactors, heat exchangers, storage vessels
- Medical: Surgical instruments, orthopaedic implants, hospital furniture
- Architecture: Cladding panels, handrails, elevator doors
- Automotive: Exhaust systems (ferritic), decorative trim
- Aerospace: Structural and fastener components

| Section H [5 Marks] — Write a Note on Plain Carbon Steel

Answer:

Definition

Plain carbon steel is an iron-carbon alloy in which carbon (0.02–2.14 wt%) is the principal alloying element, with only residual amounts of Mn, Si, S, and P from the steelmaking process and no intentional addition of other alloying elements.

Effect of Carbon Content on Properties

- Increasing carbon → higher hardness, tensile strength, wear resistance
- Increasing carbon → lower ductility, toughness, weldability
- Carbon exists as Fe₃C (cementite) within the iron matrix — harder than ferrite

Classification of Plain Carbon Steel

Type	C Content	Key Properties	Typical Uses
Dead Mild Steel	< 0.15%	Very soft, highly ductile, good weldability	Wire, rivets, thin sheets, nails
Low / Mild Carbon Steel	0.15–0.30%	Soft, ductile, easily welded and formed, low strength	Structural sections, plates, pipes, bars
Medium Carbon Steel	0.30–0.60%	Higher strength and hardness, heat treatable, less ductile	Gears, axles, crankshafts, rails, bolts
High Carbon Steel	0.60–1.0%	High hardness and strength, brittle, poor weldability	Springs, cutting tools, files, drills, chisels
Very High Carbon	1.0–1.4%	Very high hardness, very brittle	Speciality tool steels, historical swords

Mechanical Properties of Mild Steel (most common grade)

- Tensile strength: 400–550 MPa
- Yield strength: ~250 MPa
- Elongation at break: ~25–35% (highly ductile)

- Vickers Hardness: ~120–160 HV

Heat Treatment of Plain Carbon Steel

- Annealing: Heat to austenitizing temperature → furnace cool (slow) — softens, relieves stress, maximum ductility
- Normalizing: Heat to austenitizing temperature → air cool — refines grain structure, slightly higher strength than annealed
- Hardening: Heat to austenitizing temperature → quench rapidly in water or oil — forms martensite, maximum hardness
- Tempering: Reheat hardened steel to 150–650°C → air cool — reduces brittleness, adjusts hardness/toughness balance
- Case Hardening (for low-C steel): Carburizing or nitriding surface → hard surface + tough core

Uses (by grade)

- Mild steel: Structural beams (I-beams), bridges, buildings, ships, automobile body panels, wire ropes
- Medium carbon: Gears, crankshafts, connecting rods, wheel axles, railway tracks
- High carbon: Cutting tools, springs, bearing races, milling cutters, chisels, punches

Section J [5 Marks] — Numerical on Polymer (Molecular Weight & Degree of Polymerization)

Answer:

Important Definitions

- Degree of Polymerization (DP): Number of repeat units (monomer units) in a polymer chain
- Number Average Molecular Weight (\bar{M}_n): Average based on number of molecules
- Weight Average Molecular Weight (\bar{M}_w): Average based on weight fraction of each species
- Polydispersity Index (PDI): Measure of molecular weight distribution breadth = \bar{M}_w / \bar{M}_n

Key Formulas

$$DP = M^-_{avg} / M_0 \quad (M_0 = \text{Mol. Wt. of monomer})$$

$$\bar{M}^-_n = \sum N_i M_i / \sum N_i \quad (\text{number average})$$

$$\bar{M}^-_w = \sum N_i M_i^2 / \sum N_i M_i \quad (\text{weight average})$$

$$PDI = \bar{M}^-_w / \bar{M}^-_n \quad (\text{ideal} = 1.0, \text{ typical} = 1.5-4.0)$$

Numerical 1 — Degree of Polymerization

Problem: The average molecular weight of PVC (polyvinyl chloride) is 1,11,500 g/mol. Calculate its degree of polymerization. [Molecular weight of vinyl chloride ($\text{CH}_2=\text{CHCl}$) = 62.5 g/mol]

Solution:

$$\begin{aligned} DP &= M^-_{avg} / M_0 \\ &= 1,11,500 / 62.5 \\ &= 1784 \end{aligned}$$

Answer: DP = 1784 (i.e., 1784 monomer units in one polymer chain)

Numerical 2 — Number Average & Weight Average Molecular Weight

Problem: A polymer sample has the following molecular weight distribution. Calculate \bar{M}_n , \bar{M}_w , and PDI.

M_i (g/mol)	N_i (no. of molecules)	$N_i M_i$	$N_i M_i^2$
5,000	2	10,000	5.0×10^7
10,000	4	40,000	4.0×10^8
20,000	3	60,000	1.2×10^9
30,000	1	30,000	9.0×10^8
TOTAL	$\sum N_i = 10$	$\sum N_i M_i = 1,40,000$	$\sum N_i M_i^2 = 2.55 \times 10^9$

$$\begin{aligned} \bar{M}_n &= \frac{\sum N_i M_i}{\sum N_i} \\ &= \frac{1,40,000}{10} \\ &= 14,000 \text{ g/mol} \end{aligned}$$

$$\begin{aligned} \bar{M}_w &= \frac{\sum N_i M_i^2}{\sum N_i M_i} \\ &= \frac{2.55 \times 10^9}{1,40,000} \\ &= 18,214 \text{ g/mol} \end{aligned}$$

$$\begin{aligned} \text{PDI} &= \frac{\bar{M}_w}{\bar{M}_n} \\ &= \frac{18,214}{14,000} \\ &= 1.30 \end{aligned}$$

Answers: $\bar{M}_n = 14,000 \text{ g/mol}$ | $\bar{M}_w = 18,214 \text{ g/mol}$ | PDI = 1.30

Interpretation of PDI

- PDI = 1.0: Perfect monodisperse polymer (all chains same length) — rare, only in lab conditions
- PDI 1.0–2.0: Narrow distribution — typical of living polymerization
- PDI 2.0–4.0: Broad distribution — typical of commercial free-radical polymers