UNIT IX · LESSON 04

Engineering Materials & Testing

powder metallurgy · mechanical testing · semiconducting, magnetic & dielectric materials · ceramics · polymers · composites · nanomaterials · smart materials

20
questions in Unit IX
Mechanisms · SOM · Materials

P/M POWDER METALLURGY

- Steps: **powder production** → **blending/mixing** → **compaction (pressing)** → **sintering** → secondary operations (sizing, coining, infiltration, impregnation, heat treatment)
- Powder production: **atomisation** (most common, molten metal sprayed), reduction of oxides, electrolysis, mechanical comminution (milling), carbonyl process
- **Green compact**: pressed, fragile; **sintering** at **0.7–0.9 T_m** in protective atmosphere → bonding by diffusion
- Advantages: near-net shape, little waste, controlled **porosity** (self-lubricating bearings, filters), refractory metals (W, Mo), **cemented carbides** (WC + Co), composites
- Limits: high die cost, size limits, lower strength (porosity), uniform density hard to get
- Products: oil-impregnated bronze bearings, gears, cutting-tool inserts, filters, magnets, tungsten filaments
- Isostatic pressing (HIP/CIP), metal injection moulding (MIM)

DESTRUCTIVE MECHANICAL TESTS

Test	Measures
Tensile (UTM)	E, yield strength, UTS, % elongation, % reduction in area
Compression	compressive strength (brittle materials)
Brinell (BHN)	hardness: 10 mm steel ball, 3000 kgf; BHN = $2P/(\pi D(D - \sqrt{(D^2 - d^2)}))$
Rockwell	depth of indentation; scale B (1/16" ball, 100 kgf, soft) / **C (diamond cone 120°, 150 kgf, hard steels)**; minor load 10 kgf
Vickers (VHN)	136° diamond pyramid; VHN = $1.854\ P/d^2$; all materials, thin sections
Knoop, Shore scleroscope, Mohs	micro-hardness / rebound / scratch (talc 1 … diamond 10)
Impact — Charpy / Izod	toughness (energy absorbed); Charpy: simply supported, notch away from striker; Izod: cantilever, notch facing striker
Fatigue (rotating beam)	S–N curve, endurance limit

DESTRUCTIVE MECHANICAL TESTS (CONTD.)

Test	Measures
Creep	deformation under constant load at high temperature (primary, secondary/steady, tertiary)
Torsion, bend, shear tests	G, ductility

- **Ductile-to-brittle transition temperature (DBTT)**: BCC steels become brittle at low temperature (Titanic, Liberty ships); FCC metals do not
- Toughness = area under stress–strain curve; resilience = area up to elastic limit

ELECTRONIC SEMICONDUCTING MATERIALS

- Elemental: **Si** (E_g 1.12 eV), **Ge** (0.67 eV); compound: **GaAs** (1.43, direct gap → LEDs, lasers, high-speed), InP, GaN (blue LEDs, power), SiC (power devices)
- Direct band gap (GaAs) → efficient light emission; indirect (Si) → poor emitter
- Crystal growth: **Czochralski** (single-crystal Si ingots), float zone (purer); wafer, oxidation, photolithography, diffusion / ion implantation, metallisation
- Hall effect identifies carrier type and concentration

NON-DESTRUCTIVE NDT

Method	Detects
Visual	surface defects
Liquid (dye) penetrant	surface-breaking cracks (any non-porous material)
Magnetic particle	surface & near-surface cracks in **ferromagnetic** materials
Ultrasonic	internal flaws, thickness (pulse-echo, 0.5–25 MHz)
Radiography (X-ray, γ-ray)	internal porosity, inclusions, weld defects (permanent film record)
Eddy current	surface cracks, conductivity, coating thickness (conductive materials)
Acoustic emission, thermography	active crack growth / heat patterns

CLASSES MAGNETIC MATERIALS

Class	Susceptibility χ	Example
Diamagnetic	small **negative**	Cu, Bi, Ag, wate superconducto ($\chi = -1$)
Paramagnetic	small positive	Al, Pt, O_2
Ferromagnetic	large positive (domains)	Fe, Co, Ni, Gd
Antiferromagnetic	small positive (anti-parallel spins)	MnO, Cr

CLASSES MAGNETIC MATERIALS (CONTD.)

Class	Susceptibility χ	Example
Ferrimagnetic	large (unequal anti-parallel)	**ferrites** (MnZn, NiZn)

- Above **Curie temperature** ferromagnetic → paramagnetic (Fe 768 °C, Ni 358 °C, Co 1121 °C)
- **Soft magnetic** (low H_c, narrow loop, low loss): silicon steel (transformers), permalloy, **ferrites (high resistivity → HF cores, low eddy loss)**, amorphous metals
- **Hard magnetic** (high H_c, high $(BH)_{max}$): Alnico, **NdFeB** (strongest), SmCo, hard ferrites (barium/strontium)
- Superconductors: zero resistance below T_c, **Meissner effect**; type I (Pb, Hg) / type II (Nb–Ti, YBCO high-T_c 92 K) → MRI, maglev

INSULATORS DIELECTRIC MATERIALS

- **Dielectric constant ε_r, dielectric strength** (kV/mm breakdown), **loss tangent tan δ**, insulation resistance
- Polarisation mechanisms: **electronic** (all), **ionic**, **orientational (dipolar)**, space-charge (interfacial) — total decreases with frequency
- Clausius–Mossotti relation links ε_r and polarisability
- **Piezoelectric** (quartz, PZT), **ferroelectric** ($BaTiO_3$, spontaneous polarisation, hysteresis, very high ε_r), pyroelectric
- Breakdown: intrinsic, thermal, electrochemical, **discharge (partial discharge)**
- Insulating materials: mica, porcelain, glass, PVC, XLPE, transformer oil, SF_6 gas, paper; **insulation classes** Y (90 °C), A (105), E (120), B (130), F (155), H (180), C (> 180)

PLASTICS POLYMERS

Thermoplastics	Thermosets
linear/branched chains, re-meltable, recyclable	**cross-linked** 3-D network, set permanently
PE, PP, PVC, PS, PMMA (acrylic), nylon (PA), PET, PTFE (Teflon), ABS, PC	**Bakelite (phenol-formaldehyde)**, epoxy, polyester resin, urea- & melamine-formaldehyde, silicones
softer, tougher	harder, brittle, heat resistant
injection moulding, extrusion	compression / transfer moulding

INORGANIC NON-METALLIC CERAMICS

- Ionic/covalent bonding → **hard, brittle, high melting point, wear & corrosion resistant, insulating**, low thermal expansion, weak in tension
- Traditional: clay products, porcelain, refractories, cement, glass
- **Advanced**: alumina (Al_2O_3, insulators, substrates), zirconia (ZrO_2, toughened), **silicon carbide** (SiC, abrasives, heaters), **silicon nitride** (Si_3N_4, bearings, turbine parts), cubic boron nitride (CBN, cutting tools), titanates (capacitors)
- Glass: amorphous; tempered (surface compression), laminated; glass-ceramics
- Processing: powder pressing, slip casting, extrusion → drying → firing/sintering

PLASTICS POLYMERS (CONTD.)

- Polymerisation: **addition (chain)** (PE, PVC) vs **condensation (step)** (nylon, Bakelite — by-product water)
- Degree of polymerisation = molecular weight of polymer / mer weight
- **Glass transition temperature T_g**: glassy ↔ rubbery; crystallinity raises stiffness and density
- **Elastomers**: natural rubber (polyisoprene), **vulcanisation** with sulphur (cross-links), neoprene, SBR, silicone rubber
- Additives: fillers, plasticisers (flexibility, PVC), stabilisers, colourants, flame retardants
- Uses: PTFE (non-stick, low friction), PMMA (transparent), nylon (gears), PVC (pipes, cable insulation), PE (bags, bottles)

MODERN NANO & SMART MATERIALS

- **Nanomaterials**: at least one dimension **1–100 nm** → high surface-area-to-volume ratio, quantum effects
- 0-D (quantum dots, nanoparticles), 1-D (**carbon nanotubes**, nanowires), 2-D (**graphene**, thin films), 3-D (nanocomposites)
- Synthesis: **top-down** (ball milling, lithography) / **bottom-up** (sol–gel, CVD, self-assembly)
- Characterisation: **SEM, TEM, AFM, STM, XRD**
- CNT: very high strength (~100× steel), conductive; graphene: single carbon layer, strongest, best conductor

COMBINED MATERIALS COMPOSITES

- **Matrix** (binds, transfers load) + **reinforcement** (carries load): polymer (PMC), metal (MMC), ceramic (CMC) matrices
- Reinforcement forms: **fibre** (glass, carbon, aramid/Kevlar, boron), **particle** (concrete, cermets, WC–Co), **structural** (laminates, **sandwich panels** with honeycomb core)
- **Rule of mixtures** (longitudinal): $\mathbf{E_c = E_fV_f + E_mV_m}$; transverse: $1/E_c = V_f/E_f + V_m/E_m$
- Example: E_f = 70 GPa, E_m = 3 GPa, V_f = 0.6 → E_c = 42 + 1.2 = **43.2 GPa**
- High specific strength & stiffness (aircraft, sports goods, wind blades, automobiles); anisotropic
- Processes: hand lay-up, spray-up, filament winding, **pultrusion**, resin transfer moulding, autoclave curing, compression moulding
- Natural composites: wood, bone; RCC (steel in concrete)

MODERN NANO & SMART MATERIALS (CONTD.)

- Applications: drug delivery, catalysts, sensors, coatings, electronics, energy storage
- **Smart materials**: shape-memory alloys (**Nitinol** Ni–Ti), piezoelectrics, magnetostrictive (Terfenol-D), electro/magneto-rheological fluids, thermochromic
- Biomaterials (Ti alloys, hydroxyapatite), **functionally graded materials**

Q → A RAPID RECALL

Last main step of powder metallurgy	sintering
Typical P/M product with porosity	self-lubricating bearings
Hardness test with diamond cone	Rockwell C
Indenter angle in Vickers	136°
Test measuring toughness	Charpy / Izod impact
NDT for surface cracks in steel	magnetic particle
NDT giving permanent film record	radiography
Semiconductor for LEDs (direct gap)	GaAs
Material with negative susceptibility	diamagnetic
Core material for high-frequency transformers	ferrite
Strongest permanent magnet	NdFeB
Thermoset example	Bakelite
Process adding sulphur to rubber	vulcanisation
Rule for composite modulus	rule of mixtures
Size range of nanomaterials	1–100 nm
Shape-memory alloy	Nitinol (Ni–Ti)

TRAP EXAM TRAPS

- Thermoplastics soften on heating; thermosets char/decompose
- Ferrites are ferrimagnetic (not ferromagnetic) and are good for HF because of high resistivity
- Charpy and Izod values are not interchangeable
- Rule of mixtures (simple) applies along the fibre direction only
- BHN uses ball diameter D and impression diameter d — both in mm