



Third Semester B.E./B.Tech. Degree Examination, June/July 2025

Material Science and Engineering

Time: 3 hrs.

Max. Marks: 100

- Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M: Marks, L: Bloom's level, C: Course outcomes.*

Module – 1			M	L	C
Q.1	a.	Explain classification of materials. Compare crystalline solids and non crystalline solids.	10	L2	CO1
	b.	Define (i) Crystal lattice (ii) Unit cell (iii) Planar atomic density (iv) Coordination number (v) Atomic packing factor.	10	L1	CO1
OR					
Q.2	a.	Derive atomic packing factor for simple cubic structure.	10	L2	CO1
	b.	Explain edge and screw dislocations.	10	L2	CO1
Module – 2					
Q.3	a.	State and explain HumeRothery rules.	10	L1	CO2
	b.	Explain Fick's laws of diffusion.	10	L2	CO2
OR					
Q.4	a.	Explain iron-carbon diagram with a sketch.	10	L2	CO2
	b.	Two metals A and B are used to form an alloy containing 75% A and 25% B. A melts at 650°C and B at 450°C. The solid solubility of metal A in B and of B in A are negligible. The metal pair forms an eutectic at 40% A and 60% B which solidifies at 300°C. Assume liquids and solidus lines are straight draw phase diagram for the alloy series.	10	L3	CO2
Module – 3					
Q.5	a.	Explain (i) Annealing (ii) Normalizing (iii) Hardening (iv) Tempering (v) Nitriding.	10	L1	CO3
	b.	Explain with sketch Jominy End Quench test.	10	L2	CO3
OR					
Q.6	a.	Explain with a neat sketch flame hardening.	10	L2	CO3
	b.	Explain with a graph T-T-T diagram.	10	L2	CO3
Module – 4					
Q.7	a.	With a neat sketch explain physical vapours deposition.	10	L2	CO4
	b.	Write advantages and disadvantages of surface coating.	10	L2	CO4
OR					
Q.8	a.	Explain different powder production techniques in mechanical methods.	10	L2	CO4
	b.	Explain the functions of lubricants and binders in powder metallurgy.	10	L2	CO4
Module – 5					
Q.9	a.	State properties, composition and uses of low, medium and high carbon steels.	10	L2	CO5
	b.	Explain with sketch hand-layup process.	10	L2	CO5
OR					
Q.10	a.	Briefly explain the selection criteria for selection of materials.	10	L2	CO5
	b.	With a sketch explain filament winding process.	10	L2	CO5

Q.1.a. Classification of materials

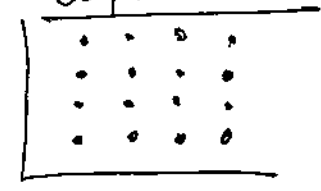
- Materials are broadly classified into:
1. Metals - Good Conductors of heat & electricity. (Eg:- Fe, Cu, Al)
 2. Polymers - Light weight, Poor Conductors, Corrosion-resistant (Eg:- Plastics, rubbers)
 3. Ceramics:- Hard, brittle, High-temperature resistant (Eg:- Aluminas, glass)
 4. Composites:- Combination of two more materials to get superior properties (Eg:- CFRP, MMC's)
 5. Semi Conductors:- Electrical conductivity b/w Conductors & insulators. (Eg:- Si, Ge)
 6. Biomaterials:- used in medical implants (Eg:- Ti alloys, Hydroxyapatite)

Crystalline vs Non-Crystalline Solids

Aspect
Atomic Arrangement
Structure diagrams
Melting point
Properties

Crystalline Solids
Long range, periodic order.
Eg:- Regular lattice with repeating pattern
Sharp & definite
Anisotropic
Crystalline

Non-Crystalline Solids (Amorphous)
Random, irregular arrangement.
Eg:- unequal points without order.
Gradual softening
isotropic.
(Non-crystalline)



① Q.1.a

(1.b.

i) Crystal Lattice -

A crystal lattice is a 3D periodic arrangement of atoms, ions or molecules in space showing the long-range order of a crystalline solid.

ii) unit cell -

A unit cell is the smallest repeating structural unit of a crystal lattice which when stacked in 3D, reproduces the entire lattice.

iii) Planar Atomic density (PAD).

It is the number of atoms per unit area whose centres lie in a specific crystallographic plane.

iv) Co-ordination Number (CN).

It is the number of nearest neighbour atoms surrounding a given atom in a crystal structure.

v) Atomic Packing factor (APF).

It is the fraction of total volume occupied by atoms in a unit cell.

Qa.

Definition

APF =

$\frac{\text{Volume occupied by atoms in unit cell}}{\text{Volume of the unit cell}}$

(2)

~~Qa~~

1) Atoms per unit cell (Counting rule) =
 SC has atoms only at 8 corners each.
 corner contribution $1/8$.

2) Geometry (Relation b/w a & r).
 in SC, nearest neighbours lie along
 the cube edge, atoms touch along
 the edge.
 $a = 2r$.

3) Volume:
 * Volume of atoms inside the
 cell.

$$V_{\text{atoms}} = N_{\text{cell}} \times \frac{4}{3} \pi r^3$$

$$= \frac{4}{3} \pi r^3 \times 1$$

$$= \frac{4}{3} \pi r^3$$

* Volume of the unit
 cell.

$$V_{\text{cell}} = a^3 = (2r)^3 = 8r^3$$

4) APF Calculation

$$\text{APF} = \frac{V_{\text{atoms}}}{V_{\text{cell}}} = \frac{\frac{4}{3} \pi r^3}{8r^3}$$

$$= \frac{\pi}{6} \approx 0.524$$

$$\text{APF} = 0.52$$

$$= 52.4\%$$

Q6. Edge dislocation

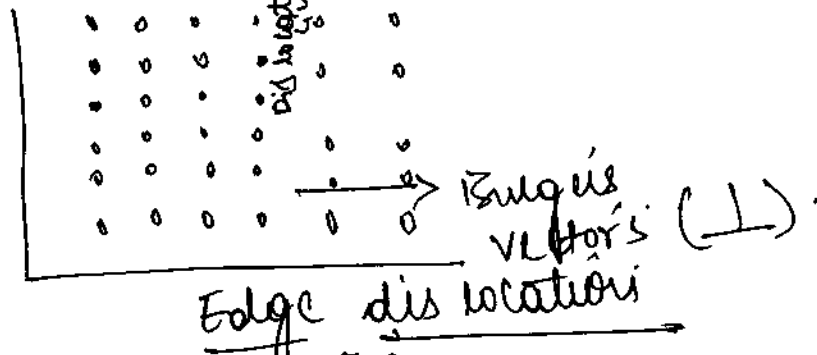
* Definition :- A line defect caused by the
 insertion of an extra half-plane of atoms
 into the crystal.

(3)

Line of dislocation: Along the edge of the inserted half-plane.

Burgers vector: \perp (Perpendicular) to dislocation line.

Stress field: Compressive stress above & tensile stress below the slip plane.



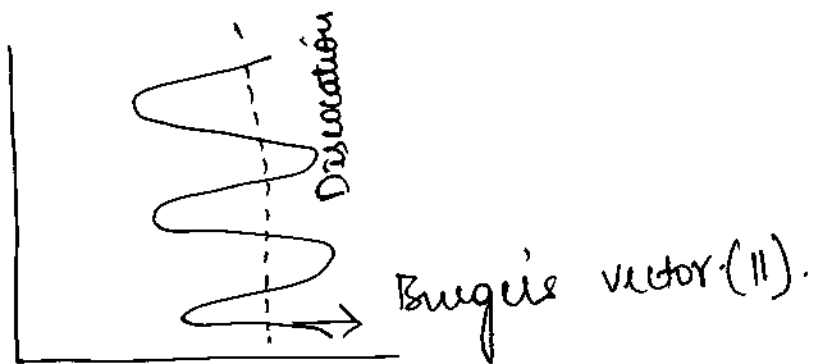
Screw dislocation

Definition: A line defect produced by shearing the crystal so that atoms are displaced in a spiral manner around the dislocation line.

Line of dislocation: Along the axis of the line.

Burgers vector: \parallel (Parallel) to dislocation line.

Stress field: Pure shear stress around the dislocation line.



Amir

3a. Hume-Rothery rules for solid solubility.
The rule, the conditions under which one metal can dissolve in another to form a substitutional solid solution.

1) Atomic size factor.

- * The difference in atomic radii of solute & solvent should be $< 15\%$.
- * Larger mismatch leads to lattice distortion, reducing solubility.

2) Crystal structure.

- * Solute & solvent metals must have the same crystal structure (FCC, BCC, HCP).

3) Valency.

- * Metals of same valency dissolve more readily.
- * A metal of higher valency dissolves a lower valency metal more readily than vice versa.

4) Electro negativity.

- * Solute & solvent should have similar electro negativity.
- * Large difference leads to intermetallic compound formation instead of solid solution.

3b.

Fick's law's of diffusion.

Diffusion is the movement of atoms/ions/molecules from high concentration to low concentration region due to thermal motion.

1) FICK'S first law (Steady-state diffusion).
 * it applies when the concentration gradient does not change with time (Steady state).

* Law $J = -D \frac{dc}{dx}$

J - Diffusion flux
 D - Diffusion coefficient (m^2/s)
 $\frac{dc}{dx}$ - Concentration gradient

(-) diffusion occurs down the concentration gradient.

Ex: - Gas diffusion through a thin metal sheet.

2) FICK'S Second law (Non-steady-state diffusion).

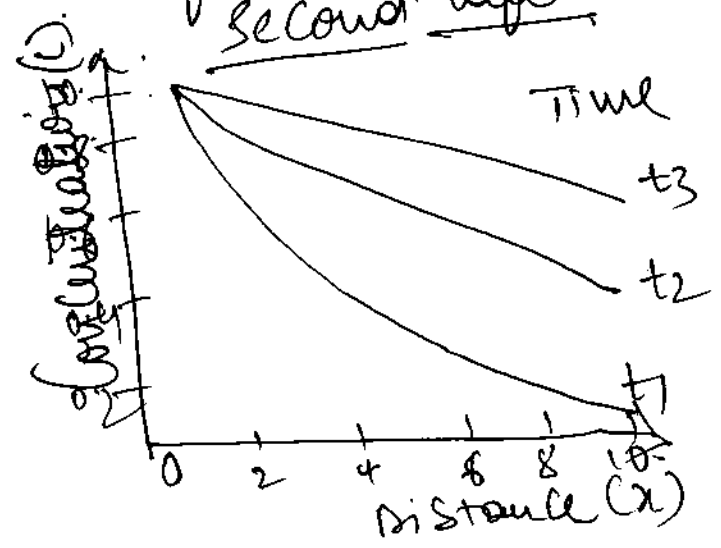
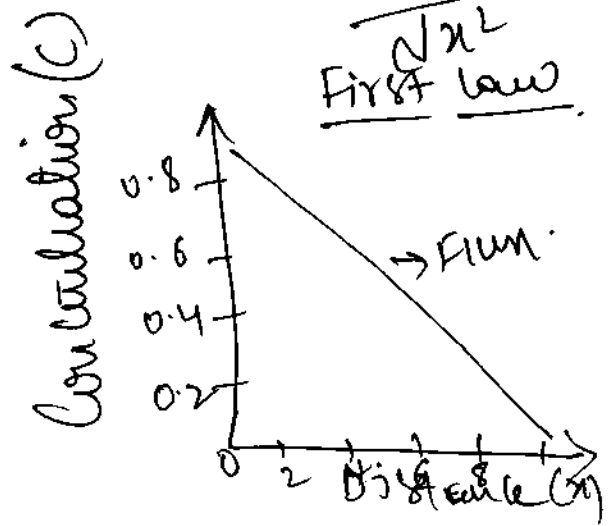
* it applies when the concentration gradient changes with time.

Law: $\frac{dc}{dt} = D \frac{d^2c}{dx^2}$

$\frac{dc}{dt}$ = rate of change of concentration with time.
 D - Diffusion coefficient.

$\frac{d^2c}{dx^2}$ - Curvature of concentration profile.
Second law

~~Graphs~~



Q.4a. The iron-carbon diagram shows the phases formed in Fe-C alloys as temperature & carbon content vary. It is most important phase diagram for steels & cast iron.

1. Composition range:

- * up to 6.67% C
- * Engg. steels contains up to ~0.01% C. beyond this → Cast iron.

2. Phases:

Phases	Composition / Nature	Description
Ferrite (α -Fe)	upto 0.022% C	Soft, ductile BCC structure.
^u Austenite (γ -Fe)	upto 2.14% C	FCC, Non-magnetic high solubility for 'C'.
Cementite (Fe_3C)	6.67% C	Hard & Brittle Iron Carbide.
Pearlite	~0.8% C (eutectoid)	Alternate layers of ferrite + cementite.
Ledeburite	~4.3% C (eutectic)	Austenite + Cementite mixture

Transformations

Reactions	Temp (°C)
Eutectoid	727°C
Eutectic	1147°C
Peritectic	1493°C

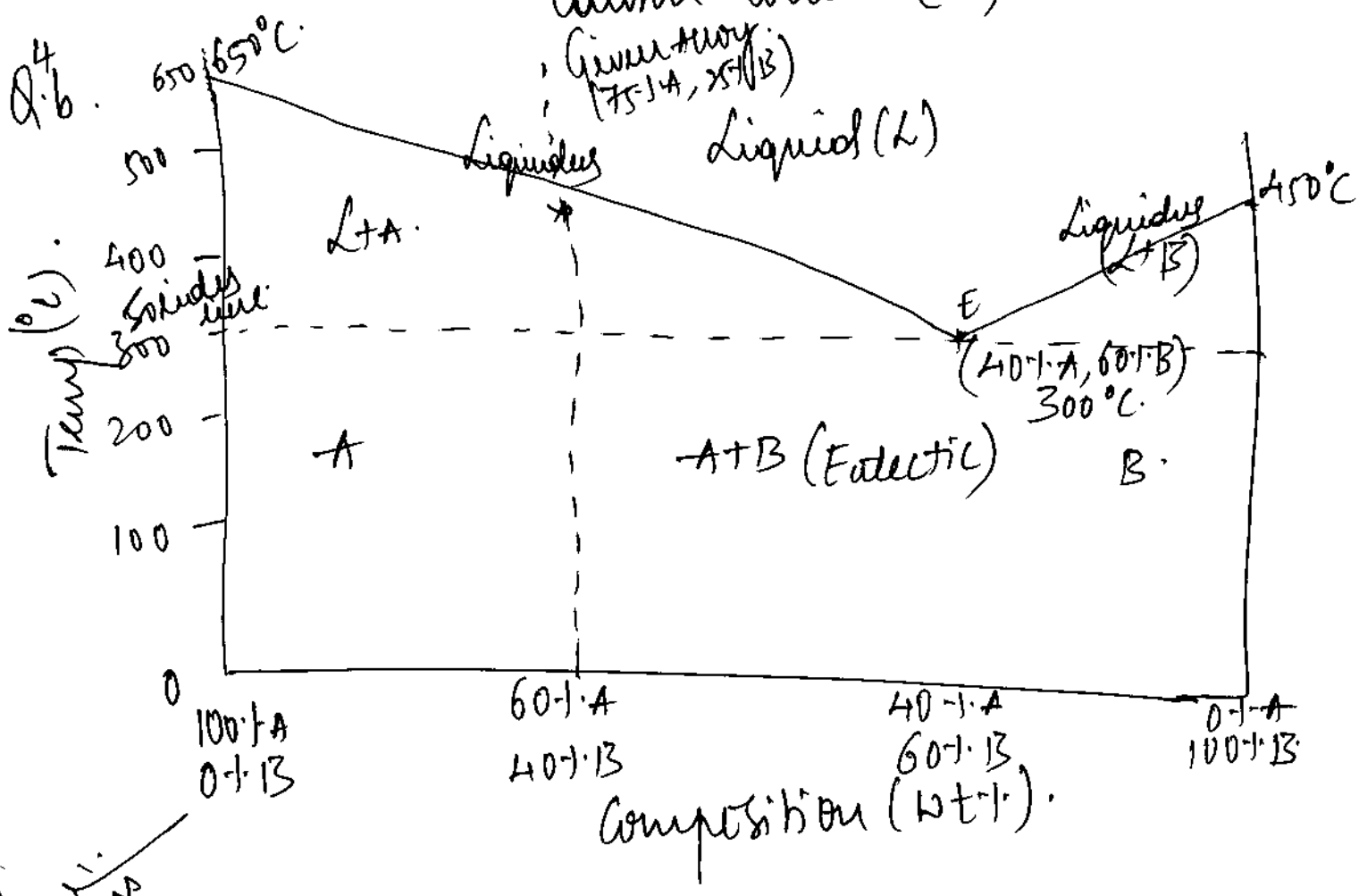
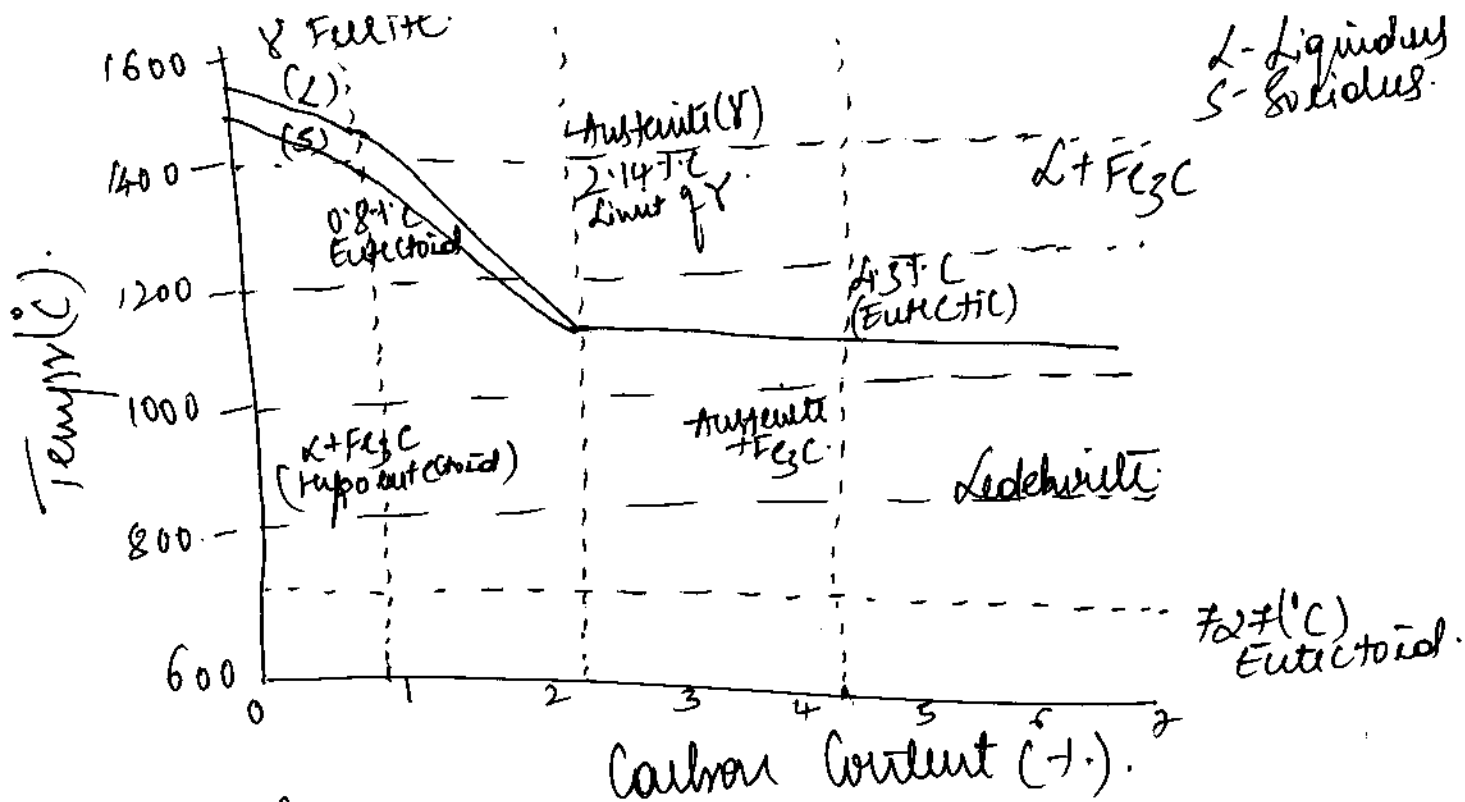
Types:

Reaction	Equation
Solid → Solid + Solid	$\delta (0.8\% C) \rightarrow \alpha (0.02\% C) + Fe_3C$
Liquid → Solid + Solid	$L (4.3\% C) \rightarrow \gamma + Fe_3C$
Liquid + Solid → Solid	$L + \delta \rightarrow \gamma$

~~Classification~~

- * Hypereutectoid Steel: $> 0.8\% C$ (Ferrite + Pearlite)
- * Eutectoid Steel: $0.8\% C$ (100% Pearlite)
- * Hypoeutectoid Steel: $0.8 - 2.0\% C$ (Cementite + Pearlite)
- * Cast iron: $> 2.0\% C$ (Cementite + Graphite / Fe_3C)

⑦



~~Ans.~~

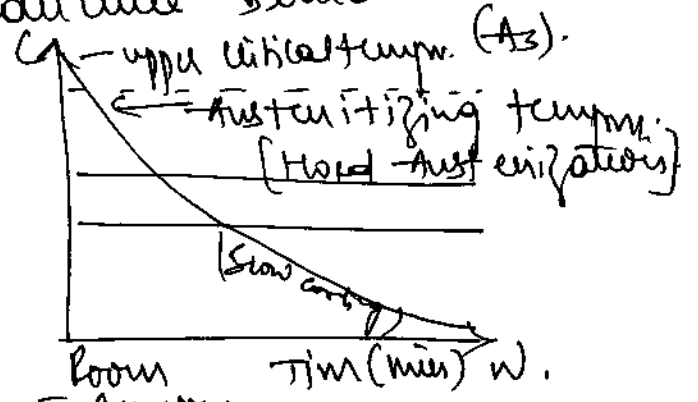
5a. i) Annealing.

* Purpose:- to soften steel, relieve internal stresses, improve ductility, refine grain structure, & enhance machinability.

Process:-

1. Heat steel above the critical temp.
2. Hold for a definite time,
3. Cool slowly in the furnace.

Result:- soft, ductile structure.



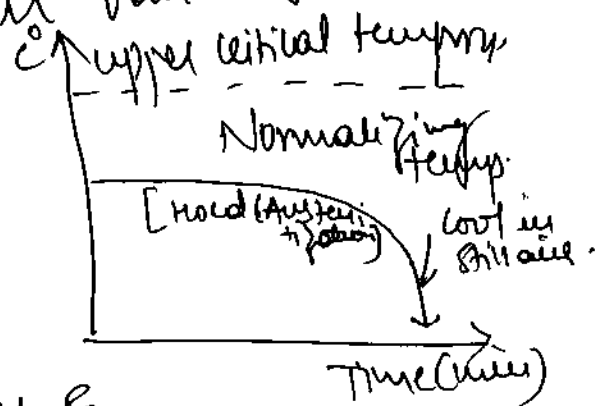
ii) Normalizing

* TO obtain uniform grain size & improve strength & toughness.

Process:-

1. Heat (30°C - 50°C above A₃).
2. Hold for suitable time.
3. Cool in still air.

Result:- Fine pearlite & refined grains - stronger than annealed steel.



iii) Hardening

* TO increase hardness & strength.

Process:-

1. Heat 30-50°C above upper critical temp.
2. Hold for uniform temp.
3. Rapidly quench in water, oil or

Formation of martensite → very hard but brittle.

iv) Tempering
* To reduce brittleness of hardened steel & improve toughness.

- Process
1. Reheat hardened steel below critical temp.
 2. Hold then cool in air.
- Controlled transformation of martensite to tempered martensite.

v) Nitriding

* To increase surface hardness, wear & corrosion resistance.

- Process
1. Heat steel (with Al, Cr, Mo) in ammonia gas (NH_3) to $500-550^\circ\text{C}$.
 2. N diffuses into surface forming hard nitrides.
- Very hard, wear-resistant surface without quenching.

5b. Jominy End Quench Test

1. The Jominy End Quench test is used to determine the hardenability of steel. i.e. the ability of steel to harden in depth under a given quenching condition.

2. Principle

When a std-size steel specimen is heated to the austenizing temp & quenched at one end only. The cooling rate decreases along the length of the specimen.

3) Apparatus

* Std specimen: 25 mm dia x 100 mm length.

~~Ques~~

(10)

* Quenching Setup: water jet impinging on the lower end of the vertically held heated specimen.

* Hardness: - Rockwell or Vickers to measure hardness along the length.

4. Procedure: -

1. Heat the specimen to austenizing temperature ($\sim 850-900^\circ\text{C}$) & hold.
2. Remove & quench one end with a steady jet of water.
3. After cooling, grind a flat surface along the specimen.
4. Measure hardness at regular intervals (Every 1.5 mm) from the quenched end.
5. Plot hardness vs distance from quenched end.

5. Observation & Result

* Hardness is highest near quenched end.

* Decreases gradually toward the opposite end (slowly cooling - pearlite).

* The hardness-distance curve indicates hardenability.

6. Applications

* Select steels for desired hardening depth.

* Compare hardenability of different alloys.

~~Ques~~

6a. Frame hardening

Frame hardening is a surface heat-treatment process in which the surface of steel is heated rapidly by a high-temp. (oxy-acetylene) and immediately quenched by water or air to form a hard martensitic layer on its surface, while the core remains tough & ductile.

Principle:-

- * The surface of medium or high-carbon steel is heated above its critical temperature using a frame torch.
- * The surface layer transforms to austenite on rapid quenching, the austenite converts to martensite producing a hard surface.
- * The core remains unaffected.

Equipment / Setup

- * oxy-acetylene frame torch for heating
- * water jet or spray system for quenching
- * Rotating or travelling mechanism to move the flame on large surface.

Procedure

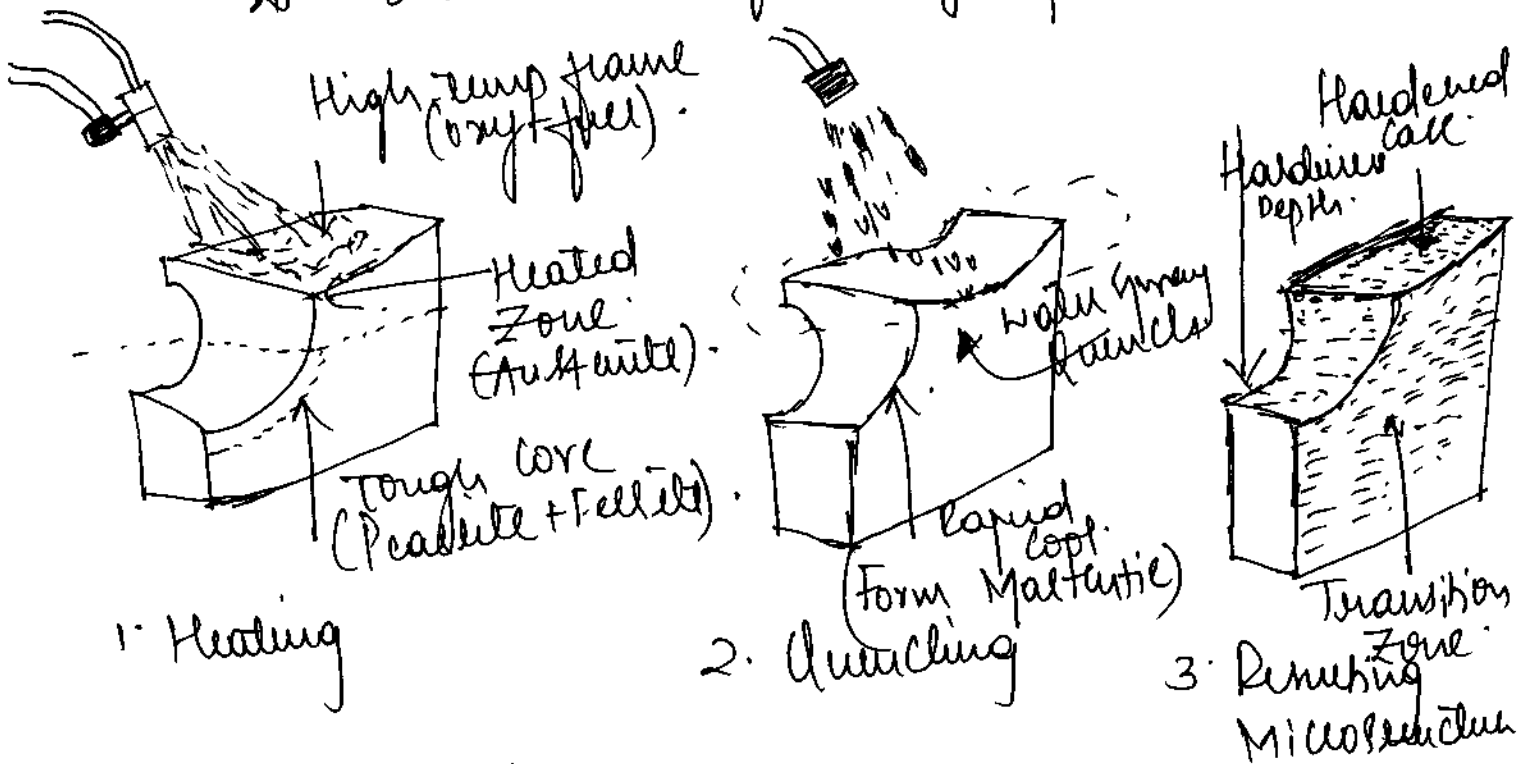
- 1) Clean the steel surface.
- 2) Heat the surface quickly with an oxy-acetylene flame to $850-900^{\circ}\text{C}$.
- 3) Maintain for a few seconds to allow uniform heating of the surface layer.
- 4) Immediately quench the heated area using the water spray.
- 5) Result - Formation of hard martensitic layer.

Application

- * Gear teeth * Camshafts * Crankshafts.
- * Machine guideways.

Advantages

- * Localized treatment * low distortion
- ** Economical for large parts.



6.b. T-T-T diagram

The TTT diagram shows the relationship b/w tempⁿ, time & transformation of austenite into other phases (Pearlite, bainite, martensite) under constant tempⁿ conditions.

Purpose

* used. to study & control the rate of transformation of austenite & to design heat treatments.

Description.

Axes.

x-axis: Logarithmic time (s).
y-axis: Tempⁿ (C).

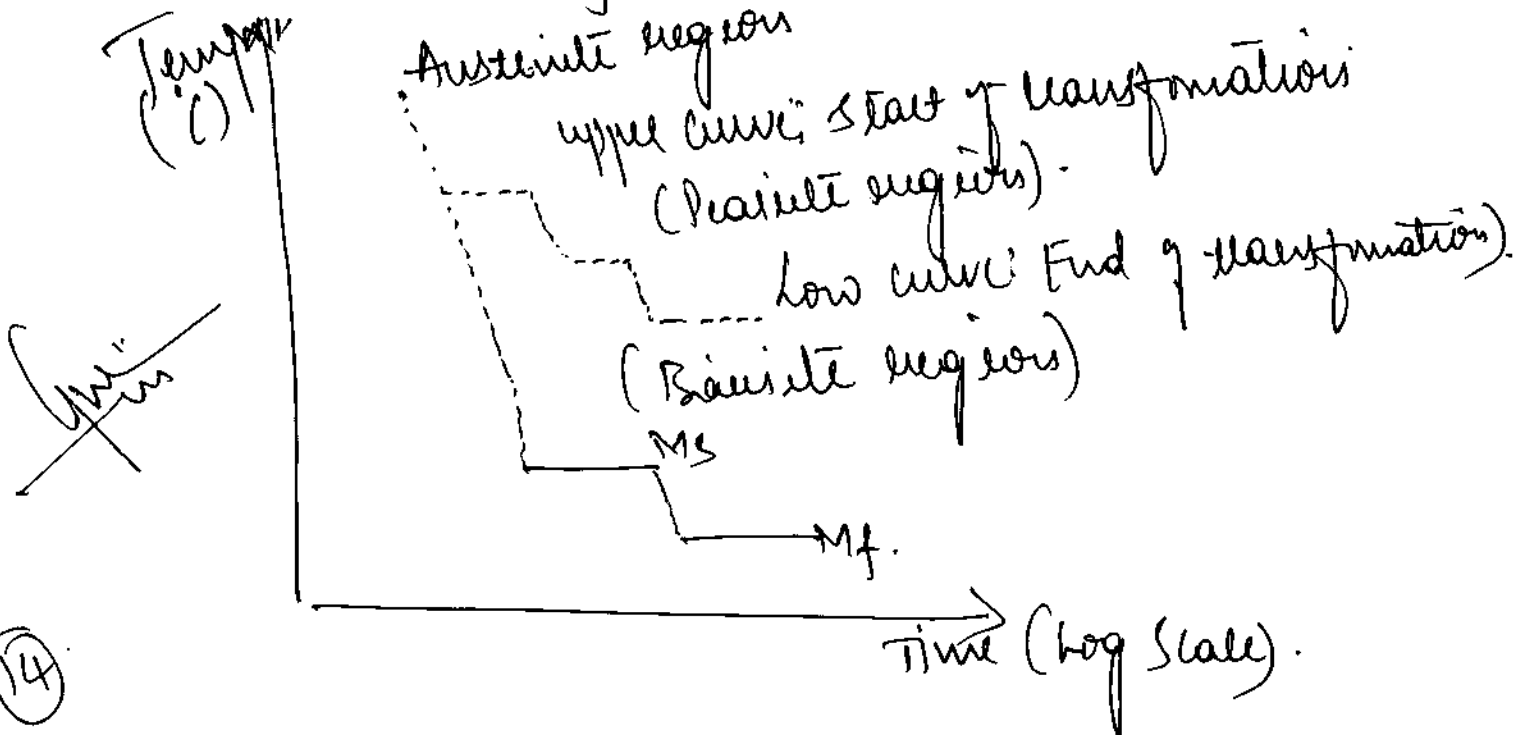
- * Cooling begins from the austenizing temp
- * Two C-shaped curves indicate start & finish of transformation.
- * The area b/w the curves shows formation of pearlite (at right) & bainite (at lower T).
- * Martensite forms below the Ms (start) & Mf (finish) lines by rapid quenching (non-diffusional).

Key features

- * upper nose ($\sim 550^\circ\text{C}$): Fastest transformation rate (minimum time).
- * Avoid nose region by rapid quenching to form martensite.
- * on slow cooling austenite \rightarrow pearlite
- * on rapid quenching, austenite \rightarrow martensite

Application

- * Design of heat treatment
- * Predicting microstructure & mech. Properties



7a. Physical vapour deposition (PVD) is a vacuum deposition method to produce thin films & coatings. It involves a material changing from condensed phase to a vapour phase and then back to a thin film. Condensed phase.

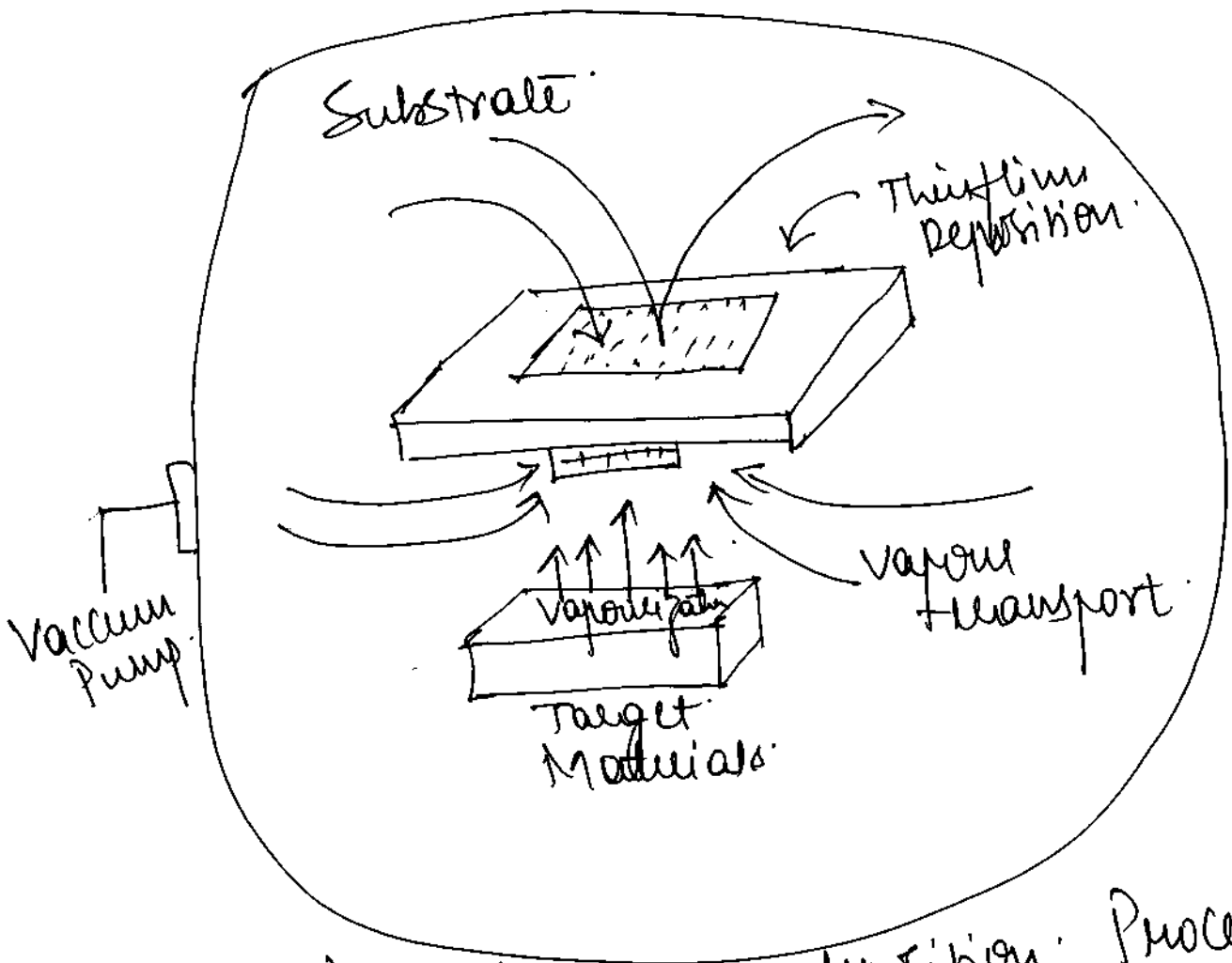
1. Vacuum Chamber:- The entire PVD process takes place in a high vacuum chamber. This is crucial to prevent contamination & to ensure that the evaporated material atoms can travel directly to the substrate without colliding with other gas molecules.

2. Target material:- A source material, also known as the "target" is placed inside the vacuum chamber.

3. Vaporization:- The target material is thus vaporized. There are several methods for this:
* Evaporation:- The target is heated, typically by electron beam or resistive heating, until it evaporates.
* Sputtering:- Ions are accelerated toward the target, knocking off atoms from its surface.

4. Transport:- The vaporized atoms travel through the vacuum.

5. Deposition:- The vaporized atoms then condense and adhere to a substrate, forming a thin film. This substrate is often heated to improve film adhesion & quality.



Physical Vapor Deposition Process

7b Surface coating involves applying a thin layer of material to the surface of a substance to enhance its properties.

Advantage:

1. Enhanced wear resistance: - Coatings can significantly increase the hardness & reduce the friction of a surface, making it more resistant to abrasion & erosion.

2. Corrosion Protection: - Many coatings act as a barrier, preventing corrosive elements from reaching the underlying material, thereby extending the lifespan of components.

3. Improved Aesthetics: - Coatings can provide a desired color, texture or reflectivity improving the visual appeal of a product.

4. BioCompatibility: in medical applications, biocompatible coatings are applied to implants to prevent adverse reaction with the human body & promote integration.
5. Reduced Friction: - Lubrication coatings can significantly reduce the coefficient of friction, leading to energy saving & reduces heat generation in moving parts.

Disadvantage

1. Cost: - The coating process, including equipment, materials, & skilled labors, can be expensive, specially for advanced coating techniques.
2. Adhesion Issues: - Poor adhesion b/w the coating & the substrate can lead to delamination when the coating peels off, compromising its effectiveness.
3. Stress & Cracking: - Difference in thermal expansion coefficients b/w the coating & the substrate can induce stress, leading to cracking or spalling of the coating, particularly under temp. fluctuations.

8a. Mechanical methods for powder production involve reducing the size of larger solid materials into fine particles.

1. Milling / Grinding:
 - * Principle: - This is the most common mechanical method. It involves applying compressive, impact, & shear forces to fracture the material.

Process:- materials is fed into mill where rotating elements or grinding media crush & abrade it into smaller particles.

Types

* Ball mill:- A rotating cylinder containing grinding media. As the mill rotates, the ball tumble & impact the material, reducing its size.

* Hammer mill:- utilize rapidly rotating hammers to impact & shatter the material against a stationary breaking plate or screen.

Result- Produces powders with a wide range of particle sizes, often irregular in shape.

2. Crushing:-

Principle- Primarily uses compressive forces to break down large lumps of material into smaller pieces. It often the preliminary step before milling.

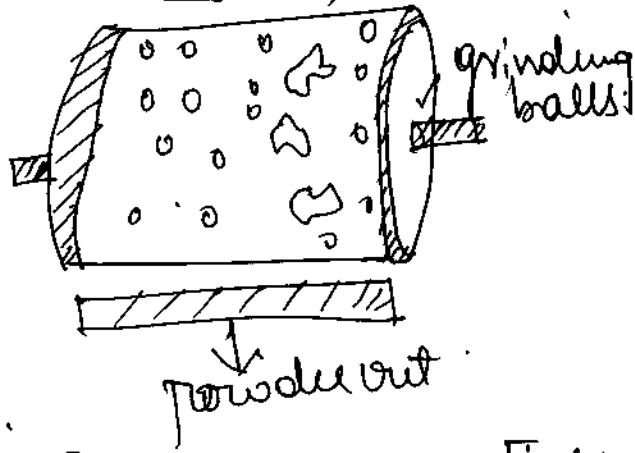
Process:- Material is fed b/w two surfaces that exert a powerful compressive forces causing the material to fracture.

Types:-

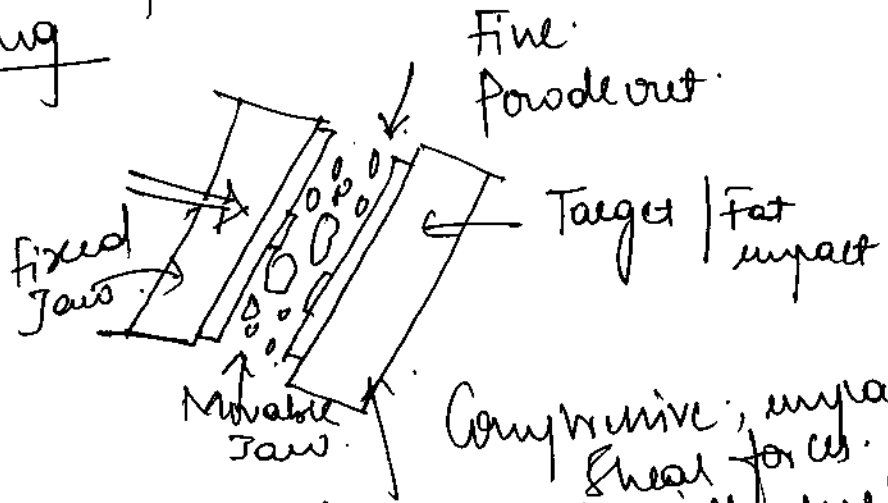
Jaw Crushers:- Have a fixed jaw & a movable jaw that reciprocates to crush material fed b/w them.

Roll Crushers:- Consists of one or more rotating rolls that draw materials b/w them & crush it.

1. Milling / Grinding → Ball mill



2. Crushing



8b. Lubricant & all additives mixed with metal powder to reduce friction b/w powder particles and die walls during compaction & ejection.

Function:

- * Reduce friction: - Decreases friction b/w powder & die wall → uniform density.
- * improve flowability: - Enhances the flow of powder during die filling.
- * Easy ejection: - Prevents sticking of compact to die → reduce tool wear.
- * Minimize compaction pressure: - Lower required pressing load.
- * Enhance surface finish: - Produces smoother surface of green compact.

Common Lubricants:

Stearic acid, Zinc Stearate, Graphite, Lithium Stearate

2. Binders

Binders are temporary additives used to hold the powder particles together to improve the green strength of the compact before sintering.

Function:

* Increases

A Assist

↳

x

Green strength: Prevent disintegration of compact during handling.

Shaping: Help in forming complex shapes without cracking.

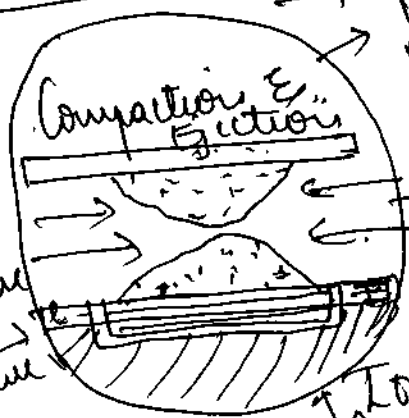
Uniform density: Aids in maintaining shape & uniform density in green compact.

Minimize dusting: Prevent segregation & powder loss.

Common Binders :-

Polyvinyl alcohol (PVA), Methyl Cellulose, wax.

Lubricant: Reduce friction

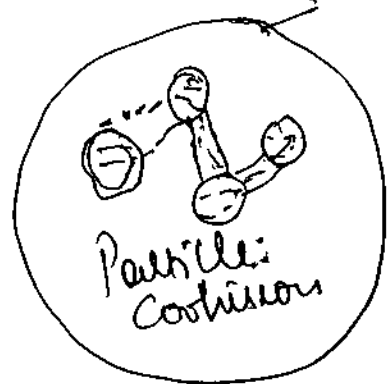


Uniform Density

Easy Ejection

↑ Tool life. Prevent galling

Binders: Provide green strength & shape retention



9a. Low Carbon Steel (Mild Steel).
Carbon Content: 0.05% - 0.25%

Properties

- * High ductility & Malleability: Can be easily formed, bent & stretched without breaking.
- * Low strength & hardness: - Relatively soft and weak compared to other steels.
- * Good weldability: - Easy to weld due to low Carbon Content, which minimizes hardening & cracking in the weld zone.
- * Moderate toughness: Can absorb impact energy reasonably well.
- * Good machinability: - Easy to cut & shape.

Microstructure: - Primarily Ferrite & Pearlite.

Uses:

- * Structural Components (Beams, plates, angles) in buildings & bridges.
- * Automotive body panels, pipes & tubes.
- * Wires, Nails, & General purpose.
- * Sheet metal products, such as appliances & cans.

Medium Carbon Steel:

Carbon Content: 0.25% - 0.50%

Properties:

- * Increased strength & hardness: - Stronger & harder than low Carbon Steel due to higher Carbon Content.
- * Decreased ductility & Malleability: - Less formable than low Carbon Steel.

- * Good toughness: offers a good balance of strength & toughness.
- * Moderate weldability - more difficult to weld than low carbon steel.

Microstructure: - Ferrite, Pearlite, & potentially some Martensite after heat treatment.

Uses:

- * Axles, gears, crankshaft & connecting rods in machinery & automotive applications.
- * Railway wheels & tracks.
- * Heavy-duty structural components.
- * Forgings & Agriculture equipment.

High Carbon Steel

Carbon Content: 0.60% - 1.50%

Properties

- * Very high strength & hardness; The hardness & strength of the carbon steels
- * Low ductility & malleability: very brittle & difficult to form.
- * Excellent wear resistance: - due to high hardness, it resist abrasion well.
- * Poor weldability: - very difficult to weld.

~~Q&A~~

Microstructure:

Primarily Pearlite with cementite formed after heat treatment, Martensite can be formed.

uses:

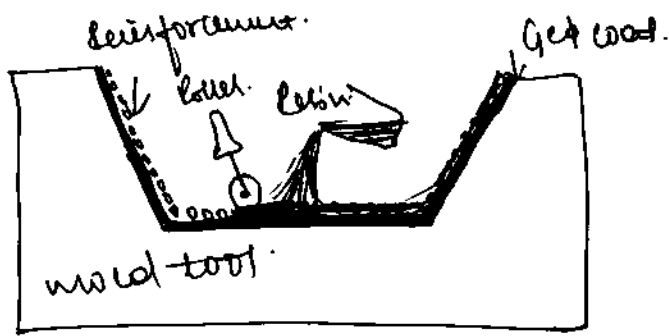
- * Cutting tools (knives, chisels, drills, saws).
- * Springs & die & molds.
- * Hammers & other impact tools,
- * wear resistant parts.

96. Hand lay-up process is the simplest & oldest method of composite fabrication used to produce fiber-reinforced polymers (FRP) components, particularly for low volume production.

Process Steps:

1. Mold Preparation
 - * The mold surface is cleaned & coated with a release agent. (eg:- wax) to prevent sticking.
2. Gel Coat Application
 - * A gel coat (resin layer) is applied on the mold surface to provide a smooth outer finish & surface protection.
3. Placement of reinforcement
 - * Reinforcing fibers or mat (eg:- Glass, Carbon, aramid) are placed over the gel coat.
4. Resin application
 - * Polymer resin (eg:- Epoxy) is applied manually using brushes or rollers to impregnate the fiber.
5. Rolling
 - * Rollers are used to remove air bubbles & ensure uniform resin distribution.
6. Curing
 - * The laminate is allowed to cure at room temp or under mild heat.
7. Demolding & Finishing
 - * After curing, the part is removed from the mold & finished to the required shape.

~~Q.11~~



Hand easy up.

10-a. Material selection is the process of choosing the most suitable for a specific engineering component or product based on functional, economic & environmental requirements.

Major Selection Criteria:

1. Mechanical Properties
 - * Strengths, hardness, toughness, stiffness, fatigue & wear resistance.
 - (Ex: Steel for shaft due to high strength).
2. Physical Properties
 - * Density, melting point, thermal & electrical conductivity.
 - (Ex: Copper for electrical wires).
3. Chemical Properties
 - * Corrosion, oxidation & chemical resistance.
 - (Ex: Stainless steel for corrosive environment)
4. Manufacturing Consideration
 - * Malleability, castability, weldability & formability.
 - (Ex: Al. for ease of forming)
5. Economic factors
 - * Cost of material, availability & service life.
6. Environmental & Sustainability factors
 - * Recyclability, energy consumption in processing, & environmental impact.

~~Ques~~

10.6 Filament winding is a composite fabrication process where continuous fibers, impregnated with resin, are wound under tension over a rotating mandrel in specific patterns to form hollow, high-strength composites.

Process Steps -

1. Mandrel Preparation:

* Mandrel (mold) is cleaned & coated with a release agent.

2. Fiber Impregnation

* Continuous fibers pass through a resin bath to get coated with resin.

3. Winding:

* The resin-coated fibers are wound onto the rotating mandrel at controlled angles (hoop & helical).

4. Curing:

* The wound structure is cured at room or elevated temperature to harden the resin.

5. Mandrel Removal:

* After curing, the mandrel is removed leaving the finished composite shell.

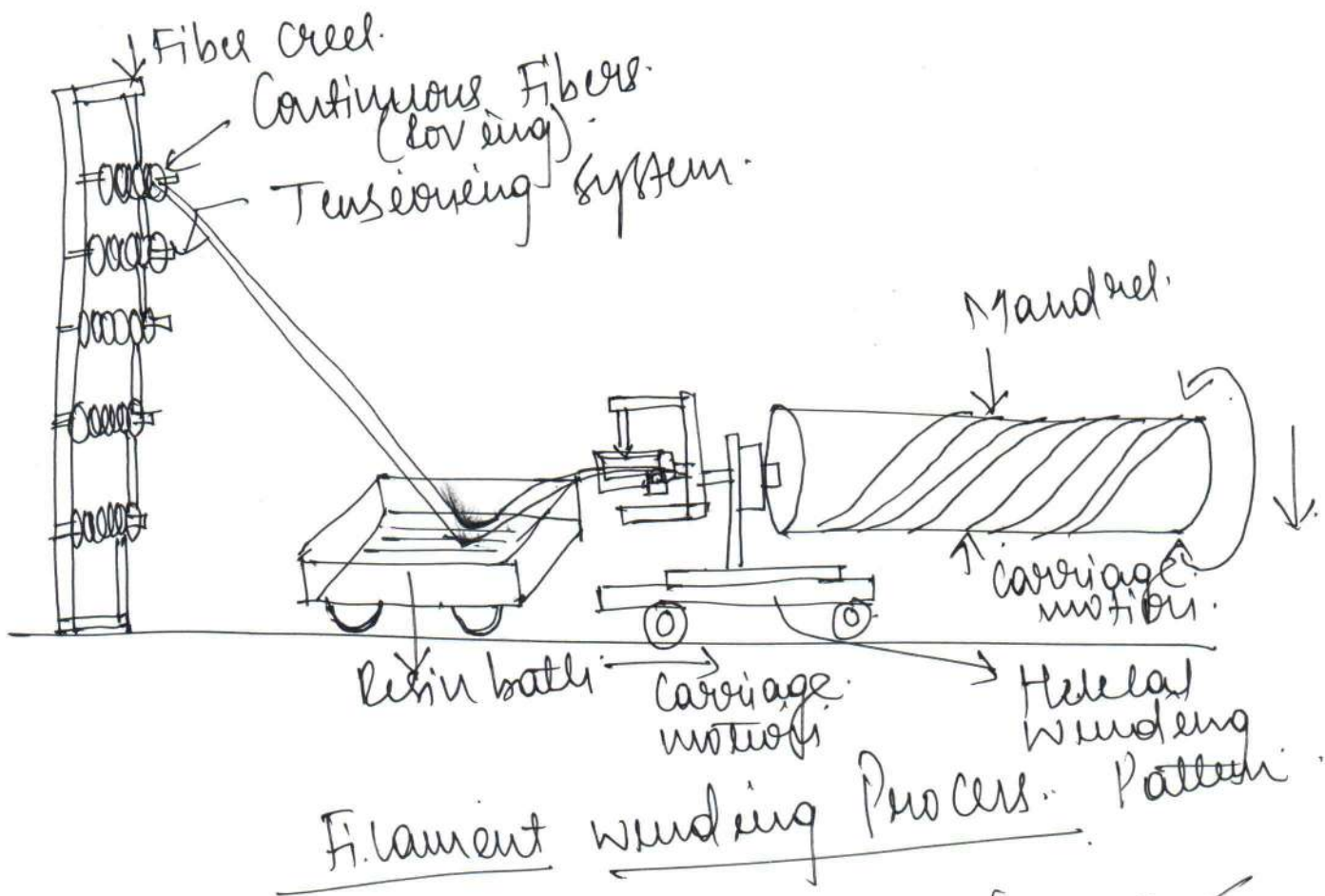
Application

* Pressure vessels * Gas cylinders
* Pipes & nozzles motor casing.

Advantages

* High strength-to-weight ratio
* Good fiber orientation control.

~~Composites~~



~~Guvi~~
 22/10/25

~~Guvi~~

~~SP2~~ 23/10/25

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