

MATERIAL SCIENCE AND ENGINEERING

3RD SEMESTER MECHANICAL ENGINEERING



LECTURE NOTE

By

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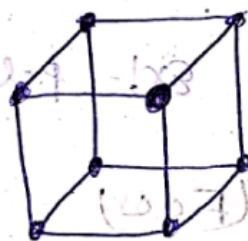
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Crystal Structures and Bonds :-

* unit cell :-

→ A crystal lattice may be imagined to be made up of a very large number of small units known as unit cells.



Crystal Lattice :-

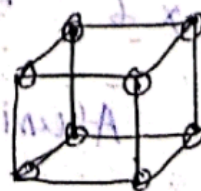
→ In a crystalline solid, it constitutes a number of units arranged in a regular pattern. The arrangement of an infinite chain of points is known as space lattice.

Types of cubic crystal

1. Simple cubic
2. Face centered cubic (FCC)
3. Body centered cubic (BCC)
4. Hexagonal close packed (HCP)

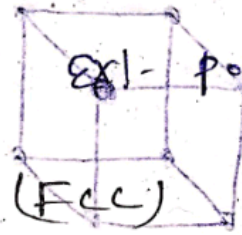
Simple cubic unit cell

1 atom
Coordination No. = 6



→ A corner atom of a simple cubic crystal is equally shared by 8 numbers of unit cell. Thus a corner atom contributes $\frac{1}{8}$ atom to each unit cell.

→ There are 8 corner's in a cube no of atoms in one simple cubic unit cell $8 \times \frac{1}{8} = 1$ atom.



* Face centered cubic (FCC)

→ In 1 unit cell of FCC there are 8 no of corner atom and 6 no of atoms in 6 faces of the cube.

→ Each corner atom equally shared by 8 no of unit cell. Thus each corner atom contributes $\frac{1}{8}$ atom to each unit cell.

→ Each face atom contributes $\frac{1}{2}$ atom to each unit cell. Thus no of atoms in one FCC unit cell $8 \times \frac{1}{8} + 6 \times \frac{1}{2}$

$$8 \times \frac{1}{8} + \frac{1}{2} \times 6 = 1 + 3 = 4$$



→ Example - Aluminium, Copper, Gold, Silver
Coordination Number ~ 12

* Body centered cubic :- BCC

→ A body-centered cubic (BCC) structure is a crystal structure where atoms are positioned at the corners of a cube and one atom is in the center of the cube.

Coordination Number = 8

Corner atoms = $8 \times \frac{1}{8} + 1 = 1 + 1 = 2$

Examples :- Chromium, iron, tungsten etc.

* Hexagonal close-packed (HCP)

→ There are 12 atoms are present in corners that contribute $\frac{1}{6}$ or 2 atoms present in the faces. 3 atoms are present in the body center.

total number of atoms at the corner = $12 \times \frac{1}{6} = 2$

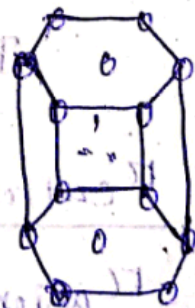
total number of atoms in the Face center = $2 \times \frac{1}{2} = 1$

3 atoms present the body center = $2 + 1 + 3 = 6$

Coordination no = 12

total atoms = $2 + 1 + 3 = 6$

Ex 1 - Cobalt, zinc, etc.



* Coordination number :- 10^{-10} m

→ Coordination number is defined as the no. of nearest neighbours with which a given species is in contact

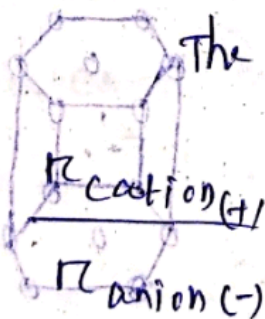
* Radius Ratio $\left\{ \begin{array}{l} \text{Cation} = (+) \\ \text{Anion} = (-) \end{array} \right.$

→ For ionic solid the ratio of radius of the cation (r^+) to the radius of the anion (r^-).

Radius ratio r^+/r^-	Coordination no.	Structure	Example
$1 - 0.732$	8	cubic	CsCl
$0.732 - 0.414$	6	Octahedral	NaCl
$0.414 - 0.225$	4	Tetrahedral	ZnS
$0.225 - 0.155$	3	Triangular	Boron oxide (B_2O_3)

Q In MgO crystal the radius of anion crystal is 140 pm (10^{-12} m) and cation 65 pm . Find out the Coordination no. of its cation.

→ Given, The radius of the cation (+) = 65 pm



The radius

of the anion (-) = 140 pm

$$\frac{R_{\text{Mg}^{2+}}}{R_{\text{O}^{2-}}} = \frac{65}{140} = 0.464$$

∴ From table w.r.t 0.464 radius ratio of Coordination no. = 6

Q In ZnS Compound the ionic ratio of Zn is $0.74 \text{ \AA}$
 $S = 1.84 \text{ \AA}$ Find out its coordination number.

$$R_{Zn^{2+}} = 0.74 \text{ \AA}$$

$$R_{S^{2-}} = 1.84 \text{ \AA}$$

Radius ratio =

$$\frac{R_{Zn^{2+}}}{R_{S^{2-}}} = \frac{0.74}{1.84}$$

$$= 0.402 \text{ \AA}$$

∴ From table w.r.t $0.402 \text{ \AA}$ radius ratio

Coordination no. is ~~2~~ 4.

Q CsCl Coordination no.

$$R_{Cs^{+}} = 1.69 \text{ \AA}$$

$$R_{Cl^{-}} = 1.81 \text{ \AA}$$

$$\frac{R_{Cs^{+}}}{R_{Cl^{-}}} = \frac{1.69}{1.81}$$

$$= 0.933$$

Radius & Coordination

Q NaCl Coordination no.

$$R_{Na^{+}} = 0.95 \text{ \AA}$$

$$R_{Cl^{-}} = 1.81 \text{ \AA}$$

$$\frac{R_{Na^{+}}}{R_{Cl^{-}}} = \frac{0.95}{1.81}$$

$$= 0.524$$

Rewind

Solid state

Crystalline solid

Amorphous solid

* Characteristics of solid

- (i) Definite shape
- (ii) Compressibility
- (iii) Definite volume
- (iv) Slow diffusion
- (v) Crystalline state
- (vi) Rigidity

* Difference between crystalline solid & amorphous solid.

Crystalline solids

- (i) Long range orderly arrangement of constituents.
- (ii) Definite shape
- (iii) They are true solids.
- (iv) Definite value of heat of fusion.

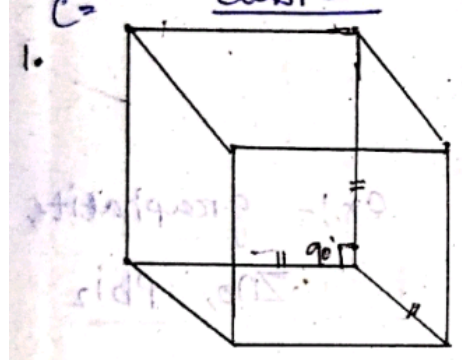
Amorphous solid

- (i) Short range random arrangement of constituent.
- (ii) Irregular shape.
- (iii) They are considered as pseudo solids or super cooled liquids.
- (iv) Heat of fusion does not have definite value.

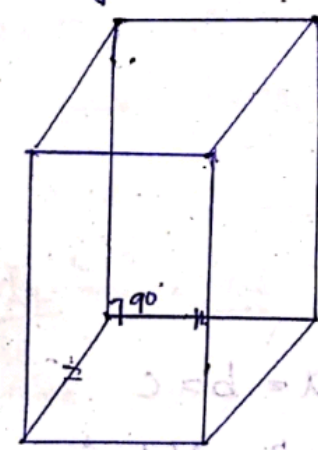
(v) They have sharp melting points. (vi) Gradually soften over a range of temperature and so can be moulded.

(vi) Ex1- NaCl, Diamond.

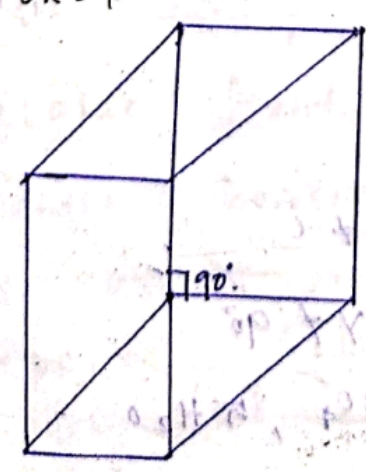
crystal system
cubic



2. Tetragonal



3. Orthorhombic



CTOM
Axial
Distance

$$a = b = c$$

$$a = b \neq c$$

$$a \neq b \neq c$$

Axial
Angles

$$\alpha = \beta = \gamma = 90^\circ$$

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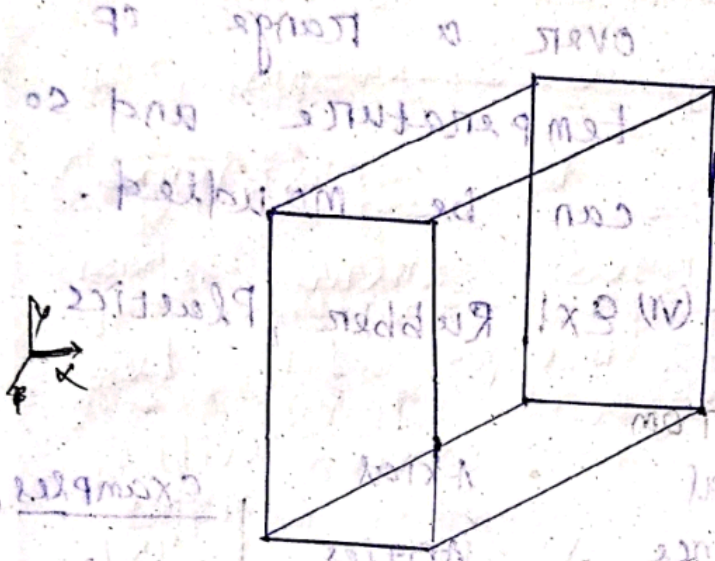
Examples

NaCl,
KCl, H
ZnS, Ag,
Cu

White tin,
 SnO_2 , TiO_2

Rhombic
sulfur,
 KNO_3 , BaSO_4

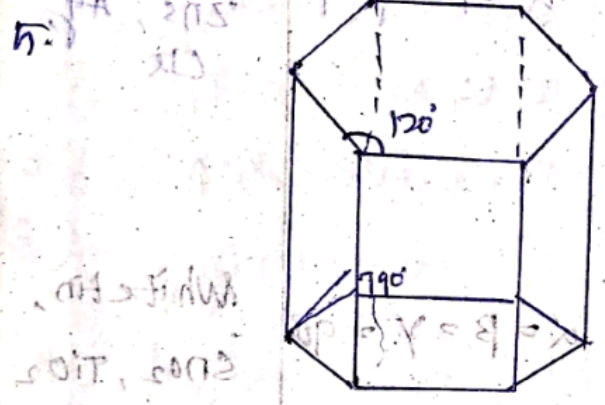
4 M = Monoclinic (232) $\begin{matrix} 1 & 2 & 3 \\ C & T & O & M & H & R & T \end{matrix}$



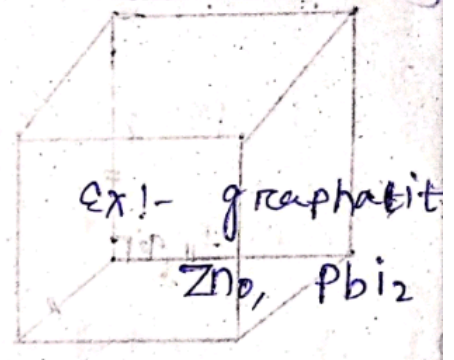
$a \neq b \neq c$ $\alpha = \gamma = 90^\circ$
 $\beta \neq 90^\circ$

Example = monoclinic sulf
 Na_2SO_4 , PbCrO_4

H = Hexagonal

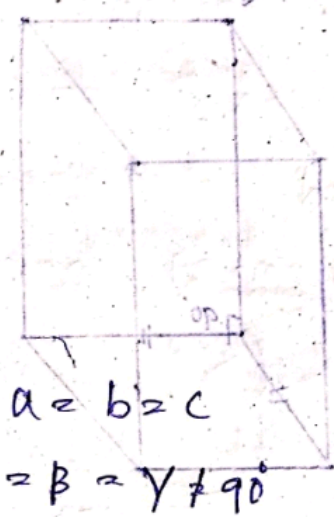
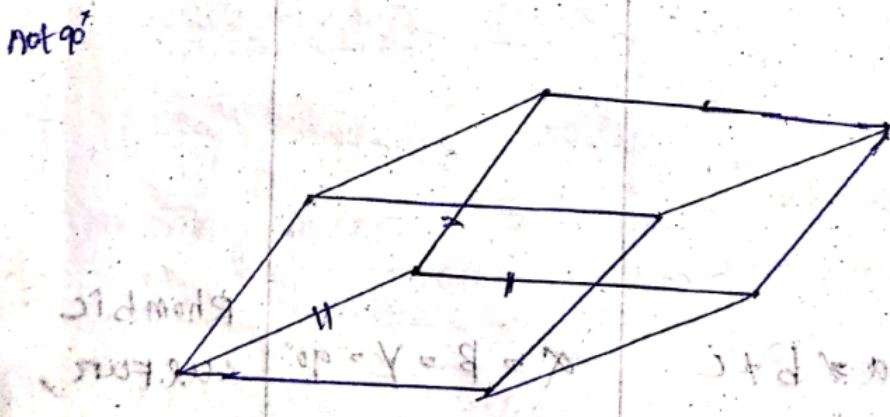


$a = b \neq c$
 $\alpha = \beta = 90^\circ$
 $\gamma = 120^\circ$



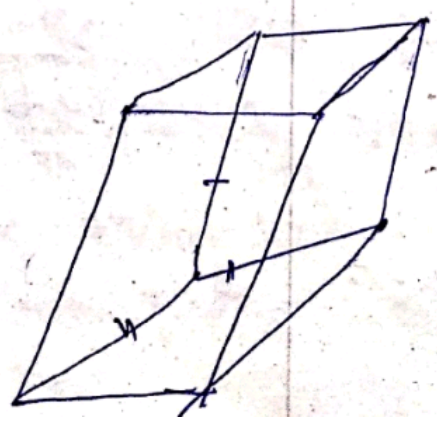
Ex! - graphite
 ZnO , PbI_2

G = Rhombohedral



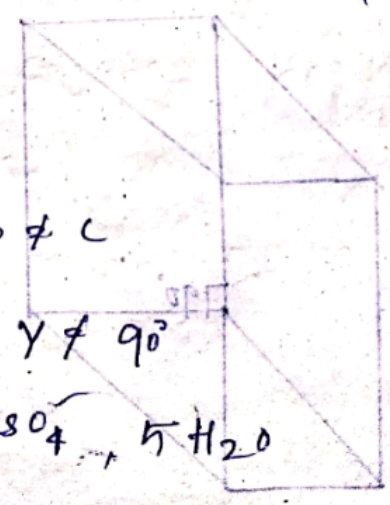
$a = b = c$
 $\alpha = \beta = \gamma \neq 90^\circ$
 Ex! - calcite, HgS

T = Triclinic



$a \neq b \neq c$
 $\alpha \neq \beta \neq \gamma \neq 90^\circ$

Ex! - $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$



BONDS IN SOLIDS:-

Types of bonding

Primary bond (strong)

- Ionic bond
- covalent bond
- metallic bond
- mix bonding

Secondary Bond

- van der Waals bond
- Hydrogen bond

Ionic bond

→ The chemical bond which is formed by the transfer of one or more valance electron from one atom to other is called ionic bond.

Ex:- NaCl

Covalent bond

DIPLOE BOND:-

occurs between polar molecules that have permanent dipole due to unequal sharing of electron.

These are formed by sharing of electron between two atoms. They have low boiling and melting points.

Metallic bond

Metallic bonding is a type of chemical bonding that arises from due to electrostatic force of attraction between valance electrons and positively charged metal ions or by sharing of free electrons between several positively charged metal ions.

* Mix bonding (polar covalent bond)

→ mix bonding is a type of bonding that have characteristics of both ionic & covalent bonds, where electrons are shared but not equally, resulting in a partial positive charge on one atom and a partial negative charge on the other.

* Vander Waals bond is 2 types

(i) Dispersion bond

(ii) Dipole bond

* Vander Waals bond is a weak secondary bond that occurs due to the attraction between molecules or atoms arising from dipole.

(i) Dispersion bond

A dispersion bond also known as London dispersion force is a weak inter-molecular force that exists between all atoms and molecules.

Ex- Nobel gas

* Hydrogen bond

→ Hydrogen bonding is a type of attractive forces that occurs when a hydrogen atom is covalently bonded to a highly electronegative atom like oxygen (O), Nitrogen (N) or Fluorine (F) and this hydrogen is attracted to another nearby electronegative atom with a lone pair of electrons.

→ ~~Ext. In water (H_2O) hydrogen atom~~

Ionic bond

Covalent bond

(i) These are formed by complete transfer of one or more electrons from one atom to another.

(i) These are formed by sharing of free electrons between two atoms.

(ii) These compounds are solids and generally good conductors of electricity.

(ii) These compounds may be solid, liquid or gases.

(iii) Weak van der Waals force of attraction exists in covalent bonds.

(iii) Strong electrostatic force of attraction exists in ionic compounds.

(iv) They have low boiling and melting points.

(iv) They have high boiling and melting points.

PHASE DIAGRAMS, FERROUS AND ITS ALLOYS

* Isomorphs

→ The substances which are having similar or identical crystalline or crystal structure, also having similar chemical formula, similar physical properties is known as isomorphs.

* Eutectic

→ When Eutectic reaction a liquid phase transforms into two solid phase at a specific temperature.

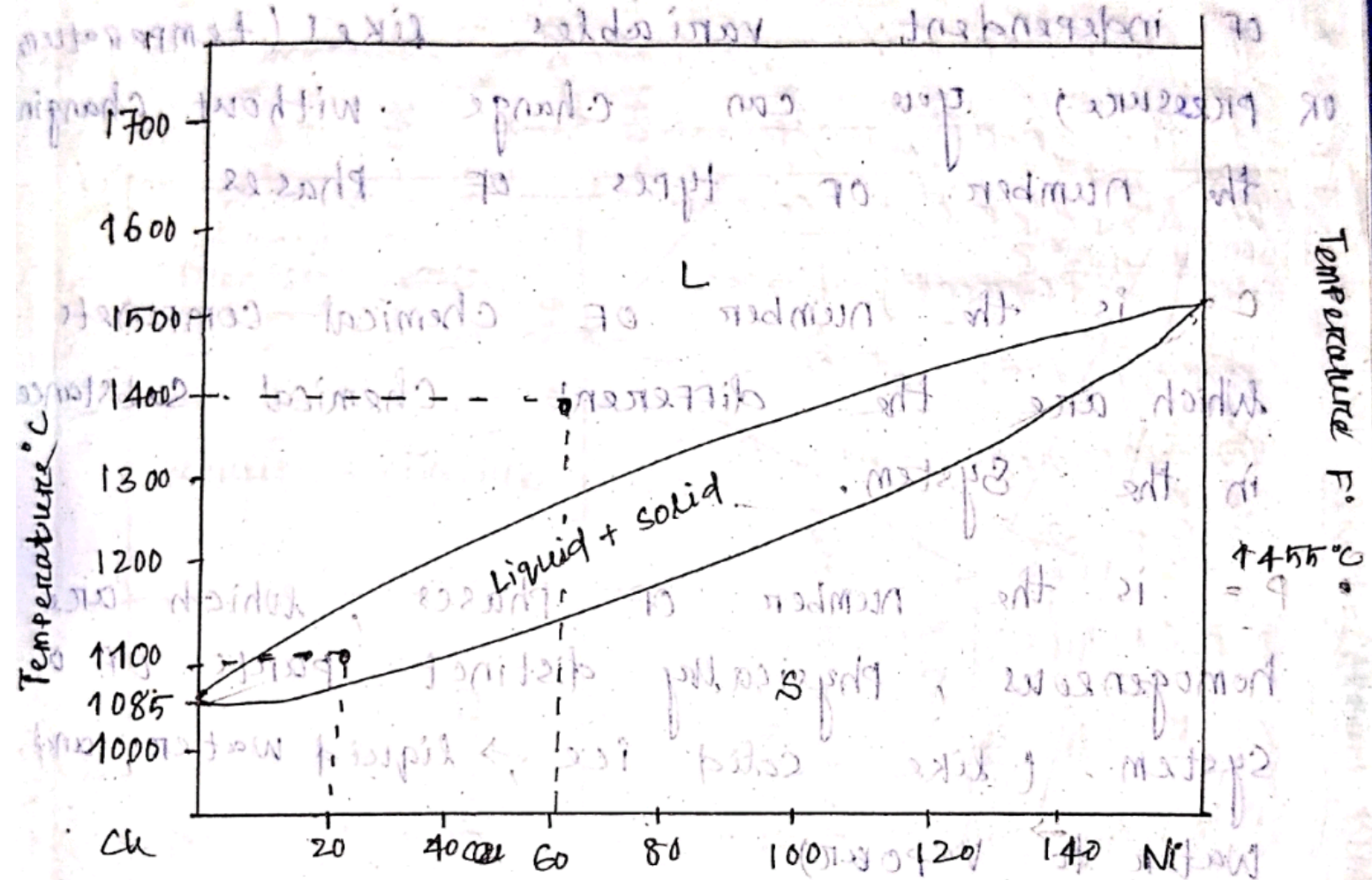
* Eutectoid

→ The Eutectoid reaction a ~~single~~ solid phase transforms into two other solid phases at a specific temperature.

* Phase diagram

→ It is a graphical representation of various phases of a substance as a function of temperature & composition.

Copper, Nickel alloy diagram



20 gram in 1100°C L+S

60 gram in 1400°C only Liquid

* Gibbs Phase rule

→ The Gibbs phase rule ~~state~~ ^{states} that $F + P = C - 2$.
that gives the number of degrees of freedom
independent variables like temperature,
pressure, and composition in a system at
Equilibrium.

Where F = degrees of freedom

C = Number of components

P = Number of phases

F is the degrees of freedom of independent variables like (temperature, OR pressure) you can change without changing the number of types of phases.

C is the number of chemical components which are the different chemical substances in the system.

P is the number of phases, which are homogeneous, physically distinct parts of a system (like solid ice $\rightarrow$ liquid water and water $\rightarrow$ vapour).

ORES OF IRON

$\rightarrow$ Hematite

$\rightarrow$ Magnetite

$\rightarrow$ Limonite

$\rightarrow$ Siderite

* Ferrite, ~~Austenite~~ Austenite, Cementite, Pearlite,

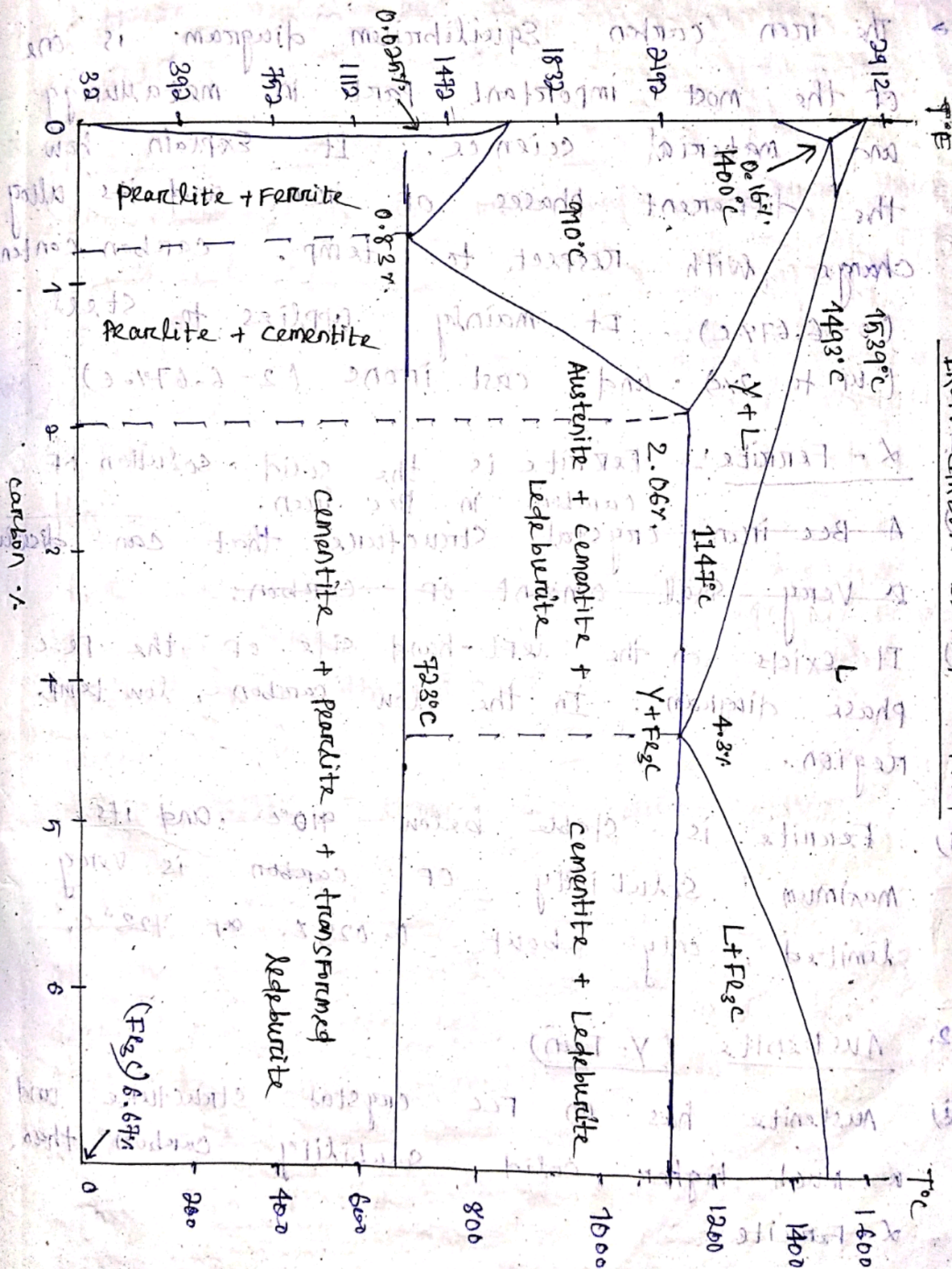
B and martensite are phases and

A microstructures found in iron-carbon alloys

L formed by different cooling ~~system~~ rates

F and carbon content.

IRON-CARBON BINARY DIAGRAM



* Iron - Carbon Phase / Equilibrium Diagram

→ The iron carbon Equilibrium diagram is one of the most important part in metallurgy and material science. It explain how the different phases of iron and its alloy change with respect to temp. carbon content (0-6.67% C). It mainly applies to steel (up to 2% C) and cast irons (2-6.67% C)

1. α - Ferrite! Ferrite is the solid solution of carbon in BCC iron.
(i) ~~A BCC iron crystal structure that can dissolve a very small amount of carbon.~~
(ii) It exists on the left-hand side of the Fe-C phase diagram. In the low carbon, low temp. region.
(iii) Ferrite is stable below 910°C and its maximum solubility of carbon is very limited, only about 0.025% at 722°C .

2. Austenite (γ - Iron)

- (i) Austenite has an FCC crystal structure and a much higher solid solubility of carbon than α - Ferrite.

(ii) Austenite appears in the central of the diagram between 910°C and 1400°C with ~~carb~~ carbon solubility up to 2.6% at 1147°C .

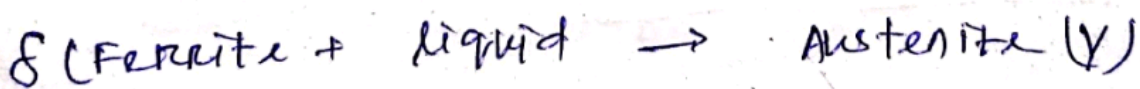
3. Cementite (Fe_3C)

(i) The cementite is an intermetallic compound which is denoted by Fe_3C . It has orthorhombic crystal structure.

(ii) It has 6.67% carbon and extremely hard and brittle.

Peritectic Reaction

(i) Pure iron melts at 1539°C . At about 0.16% C the high temperature form of iron, δ -Ferrite reacts with the liquid phase to form austenite (γ)



Eutectic Reaction

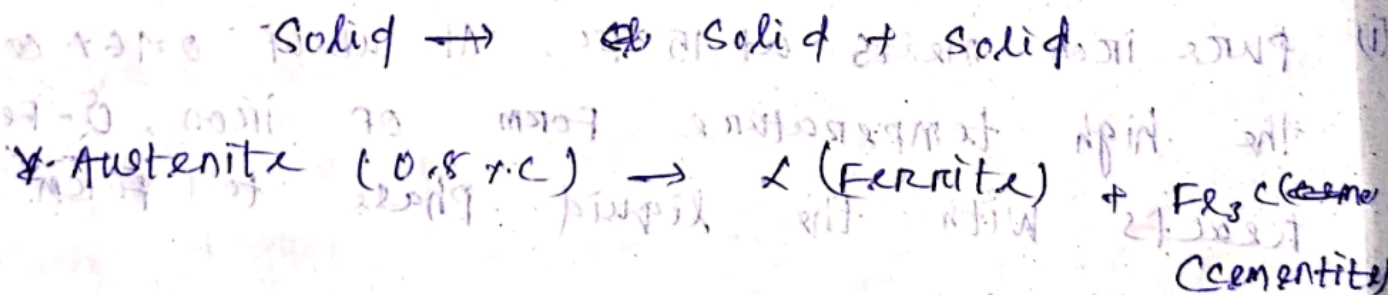
At the eutectic composition of 4.3% carbon, liquid iron solidifies into a mixture of austenite and cementite, which is called ledeburite.

This is a liquid $\rightarrow$ solid + solid reaction.
 $\text{Liquid } (4.3\% \text{ C}) \rightarrow \gamma (\text{Austenite}) + \text{Fe}_3\text{C} (\text{Cementite})$

→ on cooling through eutectic temperature, liquid decomposes into austenite and cementite. This mixture is known as ledeburite.

Eutectoid Reaction

- (i) At the eutectoid composition, austenite decomposes into a lamellar mixture of ferrite and cementite called pearlite. The reaction which occurs at 723°C .
- (ii) This is the eutectoid reaction a solid phase transforms into two other solid phases at a specific temperature.



• Iron and Carbon Steels

• Iron

→ Iron is a chemical element with symbol Fe and atomic number 26.

→ In its pure form, it is soft, ductile.

Carbon steels

→ Carbon steel is an alloy of iron and carbon with carbon content up to about 2%.

→ The addition of carbon increases strength and hardness.

Flow Sheet For Production of Iron and Steel

Iron ore + coke + limestone

Blast Furnace

Molten pig iron

oxygen

~~Furnace~~
Furnace

Electric Arc

Refined liquid steel

Secondary refining

casting

Hot cold Rolling & Shaping

Finished steel products

* ORES OF IRON

1. Hematite (Fe_2O_3)
2. Magnetite (Fe_3O_4)
3. Limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$)
4. Siderite (FeCO_3)

* Pig iron

→ Pig iron is known as worst iron. It is form of crude and brittle obtained directly from the blast furnace during the smelting of iron ore using coke and limestone.

• Classification of pig iron

• Basic pig iron

- This type is low in phosphorus and sulfur.
- It is primarily used in for steel making in basic oxygen ~~for~~ furnaces and electric arc furnace.

• Foundary pig iron

(i) Foundary pig iron ~~contains~~ also known as haematite pig iron.

or It is used in foundries for producing various types of castings, particularly gray iron castings.

• Nodular pig iron

(i) Nodular pig iron, also called ductile iron or grey grade pig iron is a high purity grade of pig iron used to produce ductile iron castings.

• Malleable pig iron

(ii) Malleable pig iron is a specialized grade with a low silicon content, which is used to produce malleable cast iron.

• Cast iron

→ Cast iron is an iron-carbon alloy containing 2-4% carbon along with small amounts of silicon, manganese, sulfur and phosphorus.

→ Its high carbon content so cast iron is hard, brittle, and non-malleable, good wear resistance and high compressive strength.

Composition

Carbon - 2-4%

Silicon - 1-3%

Manganese - 0.25-1%

Sulfur - up to 0.15%

Phosphorus - up to 1%

Classification of cast iron

(i) Gray cast iron

→ The micro structure of unalloyed gray cast iron contains graphite flakes in a matrix of mixture of ferrite and pearlite.

→ It has excellent compressive strength and vibration damping.

Application: internal combustion engine cylinders, blocks and heads, fly wheels.

(ii) White cast iron

→ The micro structure of unalloyed white cast iron contains large amount of Fe₃C and pearlite.
↓
cementite

→ It contains carbon in the form of carbides.

→ It is hard, brittle & high tensile strength and low compressive strength.

(iii) Nodular cast iron

→ Nodular cast iron also known as ductile iron or spherical graphite iron.

- Nodular cast iron ~~contains~~ ~~the~~ graphite is in the form of spheres or nodules instead of flakes.
- They are widely used in crankshafts, piston and cylinder heads, drive pulleys, bearings, etc.

(iv) malleable cast iron

- The microstructure of unalloyed malleable cast iron contains spheroidal carbon in a matrix of ferrite.
- Malleable cast iron is an important engineering material because of its high tensile strength (700 MPa max) and better elongation (11-15%).

Property :- High compressive strength, good wear resistance, vibration damping, corrosion resistance, Brittleness, good castability.

Uses!

- It is used as bed of different machine.
- It is used in pipes, automotive industry part such as cylinder heads, cylinder blocks and gearbox.

* WROUGHT IRON

→ Wrought iron is a very pure, soft, and malleable form of iron with very low carbon content (less than 0.08%) and fibrous slag inclusions.

Properties

• Low carbon content!

→ Wrought iron typically contains less than 0.08% carbon making it closer to pure iron than steel or cast iron.

• Malleability and ductility

→ Wrought iron is highly malleable (can be hammered or rolled into sheets) and very ductile meaning it can be easily drawn into thin wires, without breaking and can be worked into various shapes.

• Corrosion resistance!

→ It has good corrosion resistance because largely due to the silicate slag inclusions that help create a protective layer.

Application & uses

• Decorative purpose!

→ Wrought iron commonly used in decorative elements such as railings, gates, balconies, grilles etc.

• Pipes & Fittings

→ Wrought iron's superior corrosion and fatigue resistance makes it suitable for making pipes.

• Machinery parts

→ Components like chains, crane hooks, and engine bolts are fabricated from wrought iron.

cast iron

(i) cast iron contains 2-4% carbon along with silicon, manganese, and some impurities.

(ii) cast iron is hard, brittle and non-malleable.

(iii) It has higher compressive strength.

(iv) Its melting point is 1200°C .

(v) cast iron is used in pipes, cookware, automotive parts.

wrought iron

(i) Wrought iron is a very pure, soft with less than 0.05% carbon and slag inclusions.

(ii) Wrought iron are malleable and ductile.

(iii) It has higher tensile strength.

(iv) Its melting point is 1500°C .

(v) wrought iron is used in decorative gates, railing, balconies.

MILD STEEL

- (i) It has low amount of carbon.
- (ii) mild steel is soft and ductile, which means it can be bent or shaped easily without breaking.
- (iii) Poor resistance to wear and abrasion because of its softness.
- (iv) It has low cost.
- (v) It has low tensile strength and cannot resist very high loads.
- (vi) It can easily be machined and welded.

Q. Discuss the purpose of alloying steel and write down the composition and application of HSS.

→ Purpose of alloying

→ The main purpose of alloying steel is to enhance characteristics like strength, toughness, hardness, wear resistance, corrosion resistance, and ability to perform under high temp.

HIGH CARBON STEEL

- (i) It has high amount of carbon.
- (ii) High carbon steel is very hard and brittle, the hardness increases the carbon content.
- (iii) Excellent wear resistance.
- (iv) It has high cost.
- (v) Has high tensile strength which means it can bear heavy loads and resist deformation.
- (vi) Difficult to machine and weld.

- Describe the composition, properties and uses of spring material?

Composition

Carbon - Primary element 0.50% to over 1% - provides hardness, and tensile strength.

Silicon - 0.15 - 2.00% for elasticity, helping springs recover their shape after deformation. improve yield strength.

Chromium - 0.30 - 1.20% Enhance corrosion resistance, wear resistance and improve strength.

Vanadium - 0.10% to 0.25%.

→ Improve strength and fatigue resistance in high stress.

→ A spring material is an elastic and resilient material, most commonly high-carbon spring steel, that can be deformed under stress but returns to its original shape when the force is removed.

Properties

High Elasticity

→ It is the ability of a material to return exactly to its original shape once the load is removed.

Fatigue Resistance

→ The ability ~~of~~ to a very large number of repeated loading and unloading cycles without breaking.

High tensile Strength

• Spring metals must possess high tensile strength so that they withstand high stress during operation.

Ductility and Toughness

→ The material should possess good ductility so that it can be easily drawn into wires or formed into shapes during manufacturing. Toughness helps the spring withstand sudden shocks and impacts without fracture.

Uses:-

- Automotive :- valve springs, clutch springs
- Industrial machinery :- Heavy load springs
- Aerospace :- Aircraft landing gear
- Musical instruments :- piano wires and guitar strings

• Magnetic steel

- Magnetic steel is a type of special steel which has the ability to attract and retain magnetism. It is mainly used for making permanent magnets and parts of electromagnetic devices. Main composition of magnetic steel are 0.4 - 1% carbon and 1 - 4% silicon & other impurities are Chromium, Nickel, Cobalt.

Properties

- High magnetic permeability
- High magnetic retentivity
- High coercive force
- Low Hysteresis loss
- good electrical resistivity
- good durability and wear resistance

Uses:-

- Electrical and electromagnetic applications.
- Automotive industry
- House hold appliances
- Construction and machinery

• Alloy Steel

- Alloy steel is a type of steel whose main composition is iron and carbon along with additional alloying elements such as Chromium, Vanadium, manganese, Nickel, molybdenum up to 5-10% by weight.
- It helps to increase like strength, mechanical properties, hardness, toughness, wear resistance, corrosion resistance.
- It has 2 types
 - (i) Low alloy steel
 - (ii) High alloy steel

• Silicon Steel:-

- Silicon steel is a type of iron-silicon alloy containing up to about 3.25% silicon. widely used in soft magnetic material in electrical application.
- The addition of silicon increases the resistivity, reduce core loss by lowering eddy current, reduce hysteresis loss.

• Stainless Steel

- When 11.5% or more Chromium is added to iron, a fine film of Chromium oxide forms spontaneously on the surface. It prevents oxidation, rust-~~inhabitation~~ inhibition, corrosion. As this steel cannot be stained easily, it is called stainless steel.
- The stainless steel basing on their microstructure can be grouped in to three metallurgical classes such as: Austenitic stainless steel, Ferritic stainless steel, Martensitic stainless steel.

• Austenitic Stainless Steel:-

Properties

- (i) They possess austenite structure at room temp.
- (ii) They possess the highest corrosion resistant of all the stainless steels.
- (iii) They are non magnetic.

Composition

Cr = 16 to 26%

Si = 1 to 2%

Mn = 2 to 10%

Ni = 3.5 to 22%

Uses:-

- Aircraft ~~and~~ industry (Engine parts)
- Chemical processing (heat exchangers)
- Food processing (kettle, tanks)
- Household items (cooking utensils)

• Ferrite Stainless Steel

Property

- They possess a micro structure which is primary ferrite.
- They are magnetic & have good ductility.
- They are more corrosion resistant than martensitic ~~stainless~~ steel.

Composition

Cr 11 to 27%.

Si = 1% ~~max~~

Mn = 1 to 1.5%

Uses:-

- Lining of petroleum industry.
- Heating element of furnaces.
- Screws & fittings.

• Martensitic Stainless Steel

Property

- They possess martensitic micro structure.
- They are magnetic in all condition & possess the best thermal conductivity of the stainless types.
- They have good toughness.
- They are easily hot worked.

Si - 1% Mn - 1% , Cr - 11.9% to 18%

Uses:-

- Pumps & valve parts
- Turbine buckets

→ EFFECT OF alloying Element:- IMP

(i) Chromium (Cr)

- Enhance Corrosion resistance by forming stable chromium oxides.
- It Joins with carbon, Form Chromium carbides which significantly increase the hardness, strength, and wear resistance of steel.

(ii) Manganese (Mn)

- Manganese acts as a powerful deoxidizing and desulphurizing agent, thereby removing harmful oxygen and sulfur impurities during Steel making.
- Manganese forms manganese carbides, which contribute to an increase in tensile strength, hardness, and wear resistance.
- Manganese also improves hardenability, helping steel to harden more deeply when quenched.

(iv) Nickel (Ni)

- Nickel is an austenite-forming element and is widely used to improve the toughness and ductility of steel.
- The main advantages of nickel are that it enhances toughness even at high temperatures.
- It increases toughness resistance to impacts.

(v) Vanadium (V)

- Vanadium is a strong carbide-forming element that forms very hard vanadium in the steel matrix.
- These carbides greatly increase the hardness, wear resistance and strength of steel.
- Promotes fine grain in steel.

(vi) Molybdenum

- Molybdenum increases hardenability and prevents softening in thick sections.
- It provides excellent high-temperature strength and creep resistance.

(vii) Tungsten

- Tungsten is a strong carbide-forming alloying element widely used in tool steels and high speed steels.

Non-Ferrous metals and its alloys

• Aluminium

- Light weight metal with low density, ~~about one-third~~ high tensile strength, corrosion resistant, excellent conductor of heat and electricity, malleable, ductile, non magnetic.

Uses:-

- Aeroplanes, auto motive parts, kitchen utensils, drink cans,

• Copper is - Reddish orange

- Excellent electrical and thermal conductivity, malleable, ductile and corrosion resistant.

Uses:-

- Electrical wires, cables, and components in electronics and motor. making alloy like brass and bronze.
- Heat exchangers and cooking utensils.

• Tin

- Malleable, ductile, corrosion resistant, and has a bright, silvery appearance.

Use

- mainly used as a protective coating for other metal such as tin cans, in soldering alloy.

◦ Lead

- Lead is a very soft, heavy and malleable metal with a high density.
- Lead is highly corrosion resistant and provides excellent shielding against harmful radiation.

Uses:-

- Lead is mainly used in lead-acid batteries for automobile and power storage applications.

◦ Zinc → Nut Bolt colour new

- Zinc is bluish-white metal with good corrosion resistant.

Uses:-

- It is primarily used to protect iron and steel, from rusting through a process called galvanization.
- Zinc is used to produce important alloys such as brass (copper + zinc) and various die-casting alloys for automotive and electrical components.

◦ magnesium

- very light weight metal, good stiffness, good shock resistance, and has good vibration damping.

Uses:-

- Structural materials in aerospace and automotive industry, alloying element in magnesium and aluminum alloys.

• Nickel

- Nickel is a hard tough and corrosion resistant metal. It maintains its strength even at high temperatures and has excellent resistance to oxidation.

• Uses

- Nickel is extensively used in the production of stainless steel and other high strength alloy.
- It is used for electroplating to improve corrosion resistance and surface appearance of metals.
- Nickel based super alloys are used in turbine blades, jet engines.

• ~~Brass~~

• Copper

- A soft, ductile, reddish orange metal with high electrical and thermal conductivity and good corrosion resistance.
- Its high conductivity makes it ideal for electrical wirings, cables and heat exchangers.

• Uses

- Electrical wiring, cookware, plumbing, liquid supply.
- Copper pipes are widely used for ~~substance~~ refrigeration lines.
- Used in coins, medals, and tokens either pure or in alloyed form.

• Brass

- Brass is an alloy of copper and zinc. usually golden yellow in appearance.
- Brass has excellent corrosion resistant.

Composition

- A common type with 70% copper and 30% zinc known for high ductility.
- A type of brass with a higher copper content around 85% and lower zinc.

Uses:-

- Electrical plugs, sockets, terminals.
- Musical instruments, &
- ~~Decorative articles~~ → gear bearings, valves.
- Decorative & Architectural.

• Bronze :- reddish brown

- Primary an alloy of copper and tin. Other elements like aluminium, manganese or silicon can be added or modify features.

~~Properties~~! - Uses!

- Bronze is used to manufacture bearings, worm wheels and gears.
- Its corrosion resistance makes it suitable for marine components such as ship propellers, valves, pump parts and underwater fittings.
- Bronze is used in coins & medals.

• Duralumin

Composition

- It primarily consist of aluminium (90-95%) copper (3.5-4.5%) with smaller amount of magnesium & manganese.

Properties

- After heat treatment ^(age hardening) it becomes significantly stronger.
- High tensile strength comparable to mild steel, light weight, low ~~melting~~ melting point.

Uses:-

- Also used for surgical instruments, cables, and fluorescent tube caps due to its strength and light weight.
- Duralumin is used in ~~air~~ aerospace, automobile.

• Hindalium

- An indian trade name for a corrosion-resistant aluminium alloy consisting of aluminium, magnesium, manganese, chromium and silicon.
- It is strong; hard, easy to clean, and resistant to scratches.
- It's main application is in manufacturing cooking utensils such as, pots, pans, and etc.

• magnesium :-

→ A light weight aluminium alloy with a small percentage of magnesium (5-10%) and aluminium (90-95%) and traces of elements such as silicon, manganese, copper and zinc.

→ Magnesium is used in the manufacturing of aircraft, and automobile parts, scientific instruments and metal mirrors.

• Nickel alloys

Inconel :-

→ A family of nickel-chromium based super alloys, it has ability to retain its strength and structural stability at extreme temp.

→ It has excellent resistance to corrosion, pitting and superior creep resistance and fatigue strength.

→ It is used in turbine blades, exhaust system, and combustion chamber & power generation gas turbines, nuclear reactors, chemical process equipment, etc. It is engine parts.

• Monel:-

- A nickel copper alloy with excellent corrosion resistant especially to sea water and acidic environment.
- It is used in marine hardware, chemical processing plant, valves, pumps. ~~and other composite etc~~

• Nichrome:-

- -It is an alloy of nickel (80%) and chromium (20%) & some composition include iron as well as. The high chromium content provides excellent oxidation resistance and electrical resistivity.
- These properties make it ideal for electrical heating elements in appliances like toaster, electrical ovens and hair dryers.

• Bearing alloys

- A bearing alloy is a used to reduce friction and wear between moving parts.

• Explain Physical vapour deposition (PVD) & Chemical Vapour deposition (CVD).

→ Physical vapour deposition is a vacuum deposition process in which materials are vapourized from a solid or liquid source and then condensed onto a substrate to form a thin film or coating. No chemical reactions occur during deposition, only physical processes are involved.

Basic principle:-

(i) Preparation of substrate:-

→ The workpiece surface is cleaned thoroughly to remove oxides, oil, moisture and contaminants.

(ii) Evaporation or sputtering of coating material

→ The coating material (metal, ceramic, alloy) is heated or bombarded so that it changes from solid to vapour phase.

(iii) Transport of vapour in vacuum:-

→ The vapour atoms move through a high vacuum chamber.

(iv) condensation and film formation:-

→ The vapour atoms deposit on the substrate surface and form a thin uniform, solid coating.

Common PVD techniques

(i) Thermal Evaporation:-

→ The coating material is heated in a high vacuum chamber until it evaporates, and the vapour condenses on the substrate surface.

EX! - Aluminium coating in optical lenses.

(ii) Sputtering:-

→ Atoms are physically ejected from the surface of a solid target when bombarded by energized ions (usually Ar ions) in a vacuum chamber.

ArC vapour deposition:-

→ Uses an electric arc to vaporize material from a cathode.

Applications:-

→ Tool industry - Hard coatings like TiN, TiC to improve wear resistance.

→ Electronics:- Thin metal film for semiconductors, integrated circuit.

→ Optics:- Anti-reflective or reflective coatings on lenses or mirrors.

→ Decorative:- Jewellery, watches, - automotive trims.

Advantages:-

- Produces very hard, wear resistant coatings.
- No chemical reactions - Environmentally clean.
- Can coat complex shape uniformly.
- Can be used for optical, decoration and functional coatings.

Limitation

- Require expensive vacuum equipment.
- Slow deposit rate compared to CVD.
- Requires ~~skilled~~ control.

Chemical vapour deposition!- (CVD)

→ Chemical vapour deposition is a process in which coating is formed by a chemical reaction of gaseous reactants on a heated substrate, producing a thin film coating and gaseous by products.

- It is widely used in semiconductors, optics, aerospace and tool coatings.

Basic principle:-

- Gas precursors (reactive gases) are introduced into a reaction chamber containing the substrate.

- (ii) Under control temperature and pressure, the gaseous react or decomposes on the substrate surface.
- (iii) This results in a solid ~~material~~ ^{layer} depositing on the substrate, forming a thin film.
- (iv) Unwanted by-products and excess gaseous are exhausted.

Advantages:-

- Producing very uniform coatings, even on complex shapes.
- High deposition rate.
- Excellent adhesion.

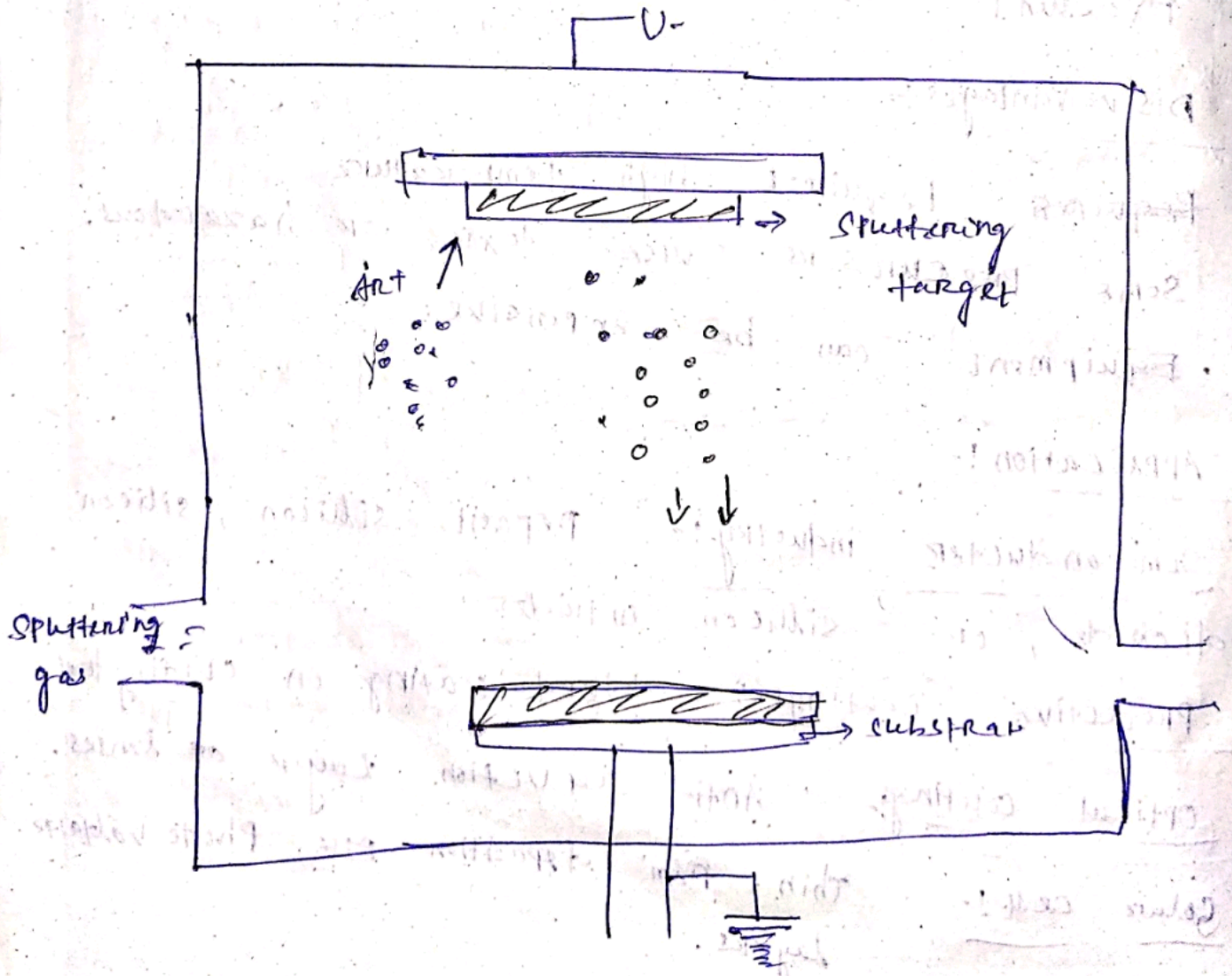
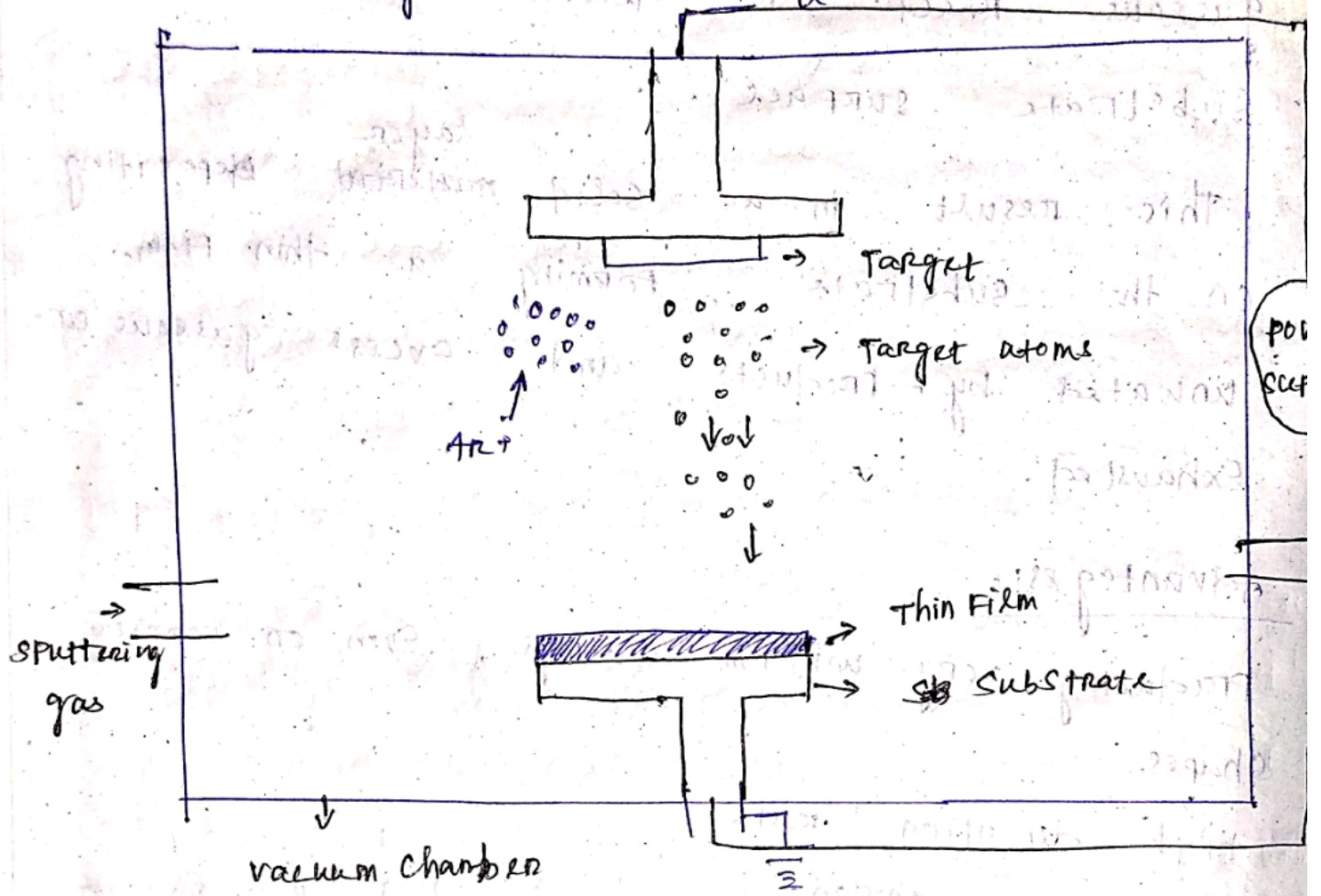
Disadvantages:-

- ~~Requires~~ Required high temperature.
- Some precursors are toxic or hazardous.
- Equipment can be expensive.

Application:-

- Semiconductor industry:- Deposit silicon, silicon dioxide, or silicon nitride.
- Protective coatings:- Hard coating on cutting tool.
- Optical coatings:- Anti-reflection layer on lenses.
- Solar cell:- Thin film deposition for photovoltaic layers.

Physical vapour deposition diagrams



• Electropolishing:-

- Electropolishing is an Electrochemical finishing process that removes a thin layer of material from a metal part.
- It provides shiny, smooth, brightens & ultra clean surface finish.

Photo Etching:

- A Photo Etching is a Chemical machining process that uses UV light, chemical, & photo resist to remove material from a selectively on the surfaces.
- Commonly applied in material such as Stainless Steel, Aluminium, titanium.
- Example of Conversion Coatings:
 - Phosphate Coating (Zinc) . Chromate zinc / Aluminium
 - black oxide (Steel) . ~~Ano~~ anodizing (Electro-chemical for aluminium)

• Hard Facing:-

- A process of depositing a wear resistant layer (like carbide, Cobalt) on the surface to improve hardness and durability.
- Application :- drill bits, pump parts,

• Briefly discuss liquid Penetration method. (NDT)

→ The liquid Penetrant test (LPT) is a non destructive (NDT) method used to detect surface breaking defects such as cracks, porosity, laps, ~~and~~ fracture, and lack of fusion in both ferrous and non-ferrous materials.

→ Liquid Penetrant testing (LPT) can be effectively used on non porous and non-metallic materials like glass, plastics, and ceramics.

Principle of operation :-

→ The fundamental operation of the liquid Penetrant test is with the help of capillary action.

→ When a liquid (penetrant) is applied to a clean surface, it naturally flows into the surface of breaking defects such as cracks, porosity, laps due to the capillary force.

→ After sufficient dwell time, the excess surface penetrant is removed and a developer is applied, which draws the trapped penetrant out of the defects, making them visible under normal or uv light.

(i) Surface cleaning:-

- The test surface is must be clean ^{thoroughly} to remove oil, greases, dirt, rust, or paint.
- A clean and dry surface is essential for accurate results.

(ii) Application of penetrant:-

- A liquid Penetrant (visible red dye or fluorescent dye) is applied evenly on the surface.

(iii) Dwell time:- Allow time for penetrant to enter defects (5 - 30 min)

(iv) Excess Penetrant removal:-

- The excess penetrant on the surface is ~~care~~ carefully removed using cloth, water or solvent without disturbing the penetrant inside defects.

(v) Application of developer:-

- A developer (dry powder or wet solvent or water base) is applied on the surface which helps pull the trapped penetrant to the surface and forms visible indication.

Inspection

The surface is inspected under white light (for visible dye) or ultraviolet light (for fluorescent dye). For defect indication.

Post cleaning:-

After inspection, the part is cleaned to remove all penetrant and developer.

Advantages:-

Simple, low cost, suitable for complex shapes.

Limitation

only detects surface defects, not internal defects.

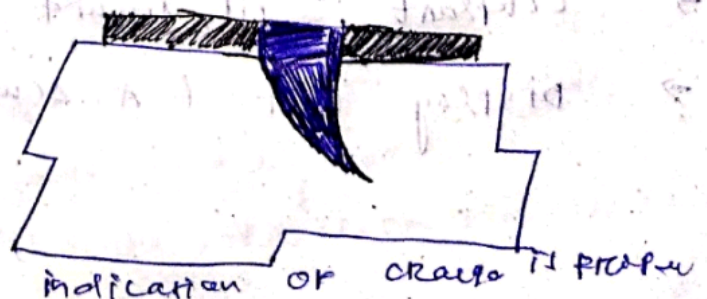
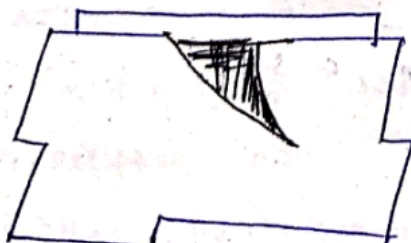
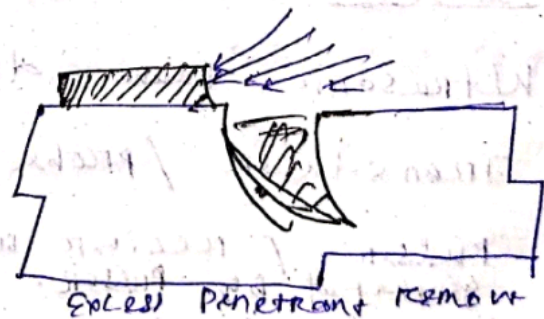
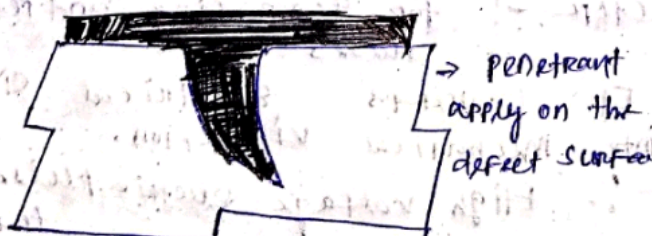
Surface must be clean and non-porous.

Application

Detection of crack in welded joints.

Used in aerospace components.

Applied in automotive industry.



• Briefly discuss ultrasonic inspection method?

⇒ Ultrasonic inspection is a non-destructive testing method that uses high frequency ultrasonic sound waves (typically 0.5 - 10 MHz) to detect internal flaws, voids, measure thickness and evaluate material properties.

Principle:-

Encounter - ~~continuity~~ discontinuity

- Ultrasonic waves are transmitted into the material through a transducer.
- When these waves encounter a discontinuity (crack, void, inclusion) part of the wave is reflected back.
- The reflected signals (echoes) are displayed on a screen, allowing detection and sizing of defects.

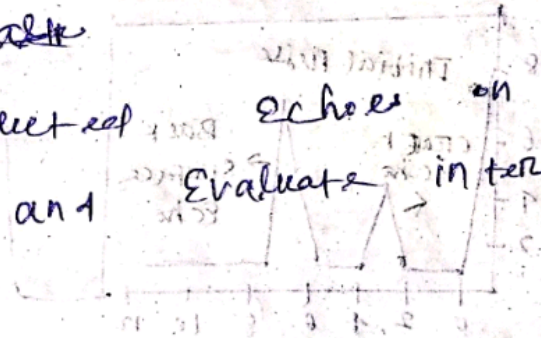
Equipment used:-

• Ultrasonic flaw detector ~~Receiver~~

- Ultrasonic flaw detector -! for generating and receiving pulses.
- Transducer / probe :- It converts electrical signals into mechanical vibration.
- Pulser / receiver unit :- High voltage electric pulse is generated by pulser. transmission
- Couplant :- oil, liquid to ~~apply~~ ensure proper sound.
- Display unit (A-scan, B-scan, C-scan)

Procedure:-

- Clean and Prep are the test surface
- Apply couplant to remove air gaps to ensure proper sound transmission.
- Place the transducer and transmit ultrasonic pulses into the material.
- Move or scan the probe across the surface
- ~~Reflected~~ ~~back~~ ~~the~~ ~~echo~~
- Interpret the reflected echoes on the screen to identify and evaluate internal flaws.



Advantages:-

- Detect deep internal defects with high accuracy.
- provides exact depth and size information of discontinuities.
- Safe method no harmful radiation.
- Gives immediate results.

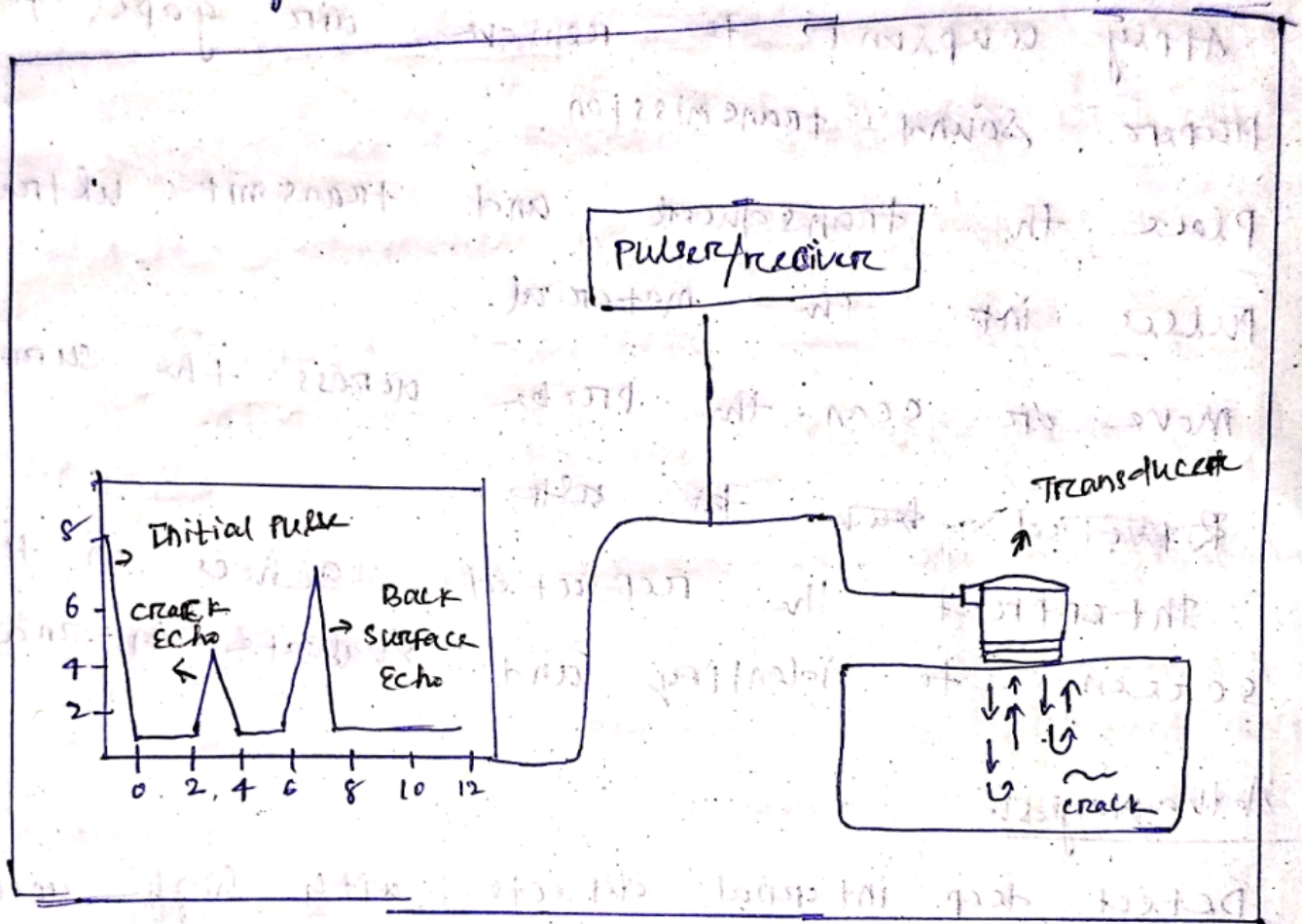
Disadvantages:-

- Require skilled and trained operators.
- Surface must be smooth and clean for coupling.
- Difficult to inspect complex shapes.

Application

- ~~inspection~~ of
- Detection of cracks, voids, inclusion in metal.
- Inspection of welds, castings, forgings.
- Thickness measurement of pipelines, pressure vessels, boilers.

→ Aerospace, automotive, power plants and manufacturing industry.



ULTRASONIC INSPECTION METHOD

- Explain notch sensitivity and effect of material performance?
- ~~Notch sensitivity~~ is a material property, that indicates
- Notch sensitivity is a measurement of how much a material's strength is reduced due to the presence of notches, grooves, holes, sharp corners or any geometry discontinuity, that causes stress concentration.

→ In other words, it describes how much a material's actual strength is affected by the stress concentration at a notch.

→ It is expressed as notch sensitivity factor (q)

$$q = \frac{\left(\frac{\sigma_f}{\sigma_t} - 1 \right)}{\left(\frac{\sigma_f}{\sigma_t} - 1 \right)}$$

$$q = (K_f - 1) / (K_t - 1)$$

Where K_f = fatigue stress concentration factor

K_t = theoretical stress concentration factor

Range:

$q = 0$ (material is not notch sensitive)

$q = 1$ (material is highly notch sensitive)

Effect of notch on material

Reduction in Fatigue Strength:-

→ Notch act as a stress raiser; accelerating crack initiation under cyclic loading.

• Crack initiation and propagation

→ Notches act as starting points for cracks.

with high notch sensitivity, cracks grow

quickly.

~~Material's~~ Examples:-

Example:-

+ High notch sensitivity :- cast iron, high strength steel

(-) Low notch sensitivity :- mild steel, aluminium, copper, (ductile material)

- Explain the working Brinell and Rockwell hardness test.

Brinell hardness

- A Brinell hardness test is based on the principle of measuring the resistance of a material to indentation.



Working principle:-

- The Brinell test measures hardness by pressing a hard spherical indenter into the surface of the material and measuring the size of the indentation.

Procedure:-

- A hard steel or tungsten carbide ball indenter (usually 10 mm diameter) is pressed into the test surface.
- A known load (usually 500 - 3000 kgf) is applied for a standard time (usually 10 - 15 seconds).
- After removing the load, the diameter of indentation is measured using a microscope.

The Brinell hardness number (BHN) is calculated using the formula

$$BHN = \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})}$$

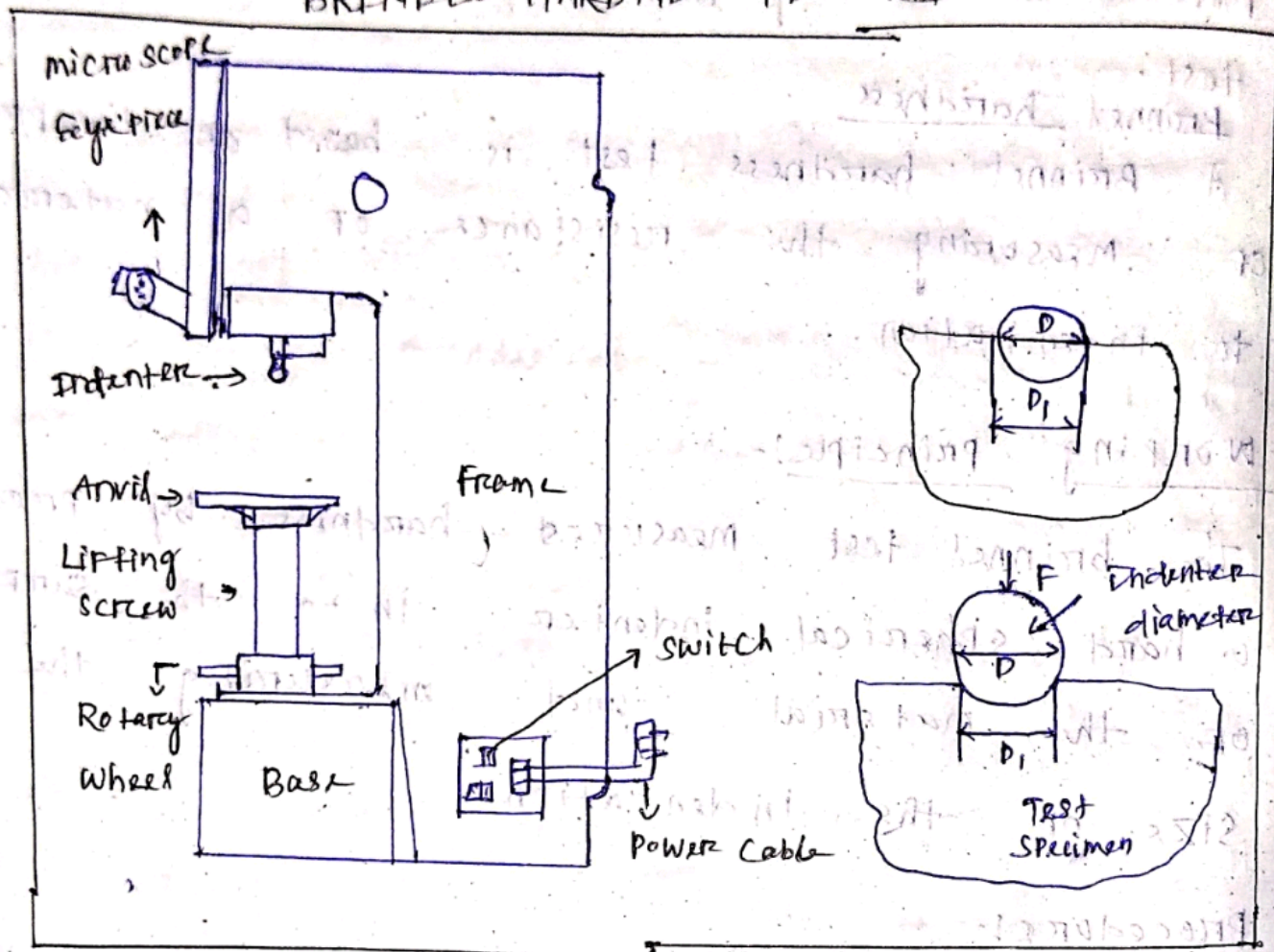
Where P = Applied load (kgf)

D = Dia of ball (mm)

d = dia of indentation

- A larger indentation means the material is soft a smaller indentation means the material is harder.

BREINELL HARDNESS TEST MACHINE DIAGRAM



• Rock well hardness test :-

→ The rock well hardness test is an indentation test that measures the hardness of a material by determining the depth of penetration by using a hard indenter a specific set of loads.

→ It is widely used because it gives a direct hardness number.

→ It requires no ~~microscopic~~ microscopic equipment & it is suitable for both soft and hard materials.

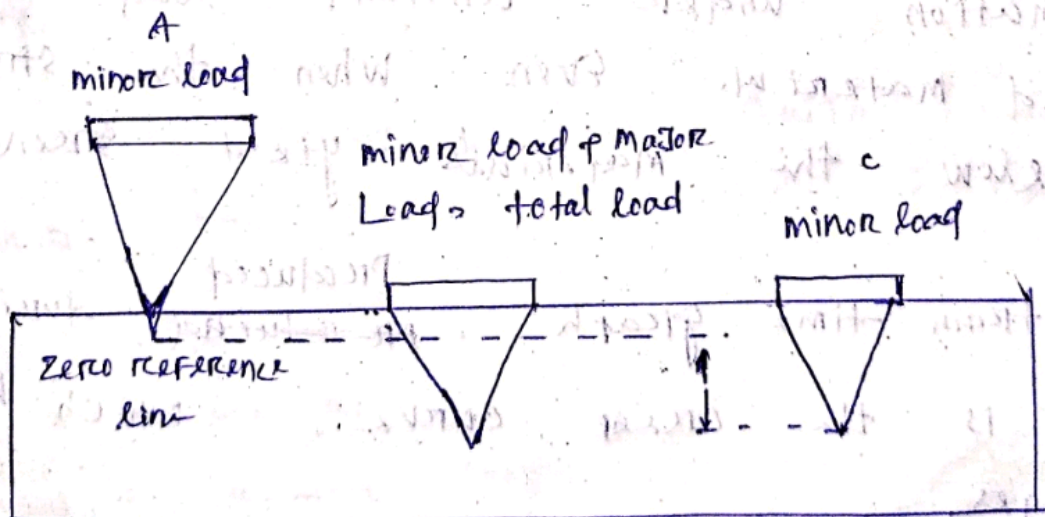
Procedure:-

- A minor load (usually 10 kgf) is applied first to seat the indenter, removing surface irregularities.
 - Then a major load (60, 100, 150 kgf depending on scale) is applied.
 - The load is ~~removed~~, but the minor load is kept, and ~~the load is removed~~ the depth of penetration ~~under the~~ ~~load~~ is measured.
 - The hardness value is automatically indicated on the Rockwell scale.
- ### Types of indenters:

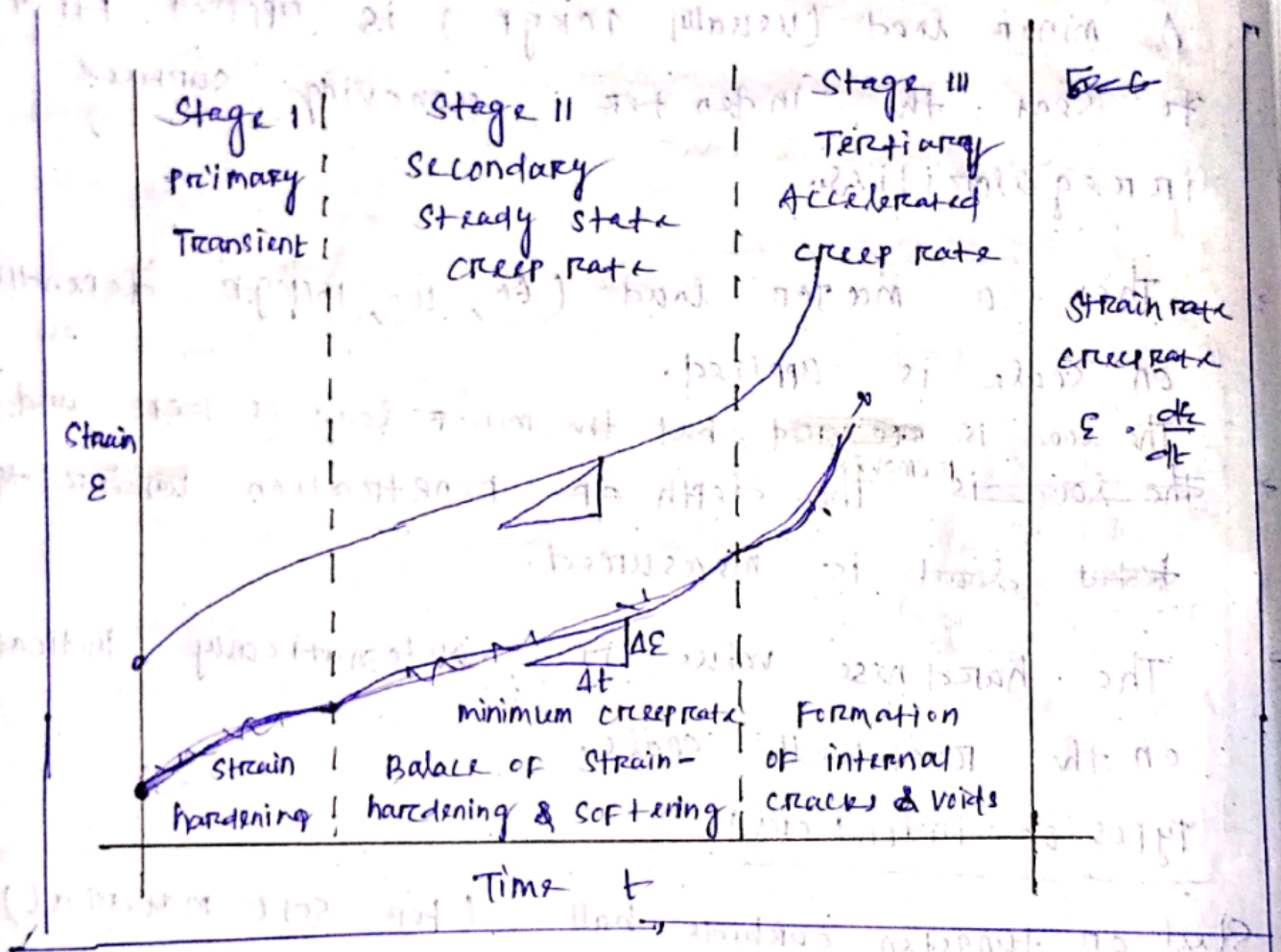
- Steel or tungsten carbide ball (For soft material)
- Conical diamond (For hard materials)

Diagram of R-H.T

~~A~~ ~~small~~



Draw and Explain the stage of creep curve.



b. Primary stage (stage I)

→ Creep is the slow and time dependent deformation under constant load of a solid material. Even when the stress is below the material's yield strength.

→ The strain-time graph produced during test is the creep curve, which has 3 stages,

1. Primary stage (stage-1)

- Also called transient creep.
- creep rate is high initially but decreases with time.

Reason

- The material experiences strain hardening - as it deforms, it becomes stronger and resists further deformation.
- Nature of curve creep rate decreases - curve bends downwards

2. Secondary stage (stage-2)

- Secondary creep also known as steady-state creep.
- The creep rate becomes constant, resulting in a straight line portion in the strain-time graph.

Reason

- A balance occurs between strain hardening and recovery process.

Characteristics

- Steady-state reason
- Longest duration stage
- Nature of curve constant slope → straight line region

Tertiary creep (Stage - III)

→ Tertiary creep is the final stage and is then failure of the material.

→ The creep rate increases rapidly until fracture.

Reason

→ As the material continuously deforms;

Significant microstructural damage

→ Formation of internal voids & micro cracks.

→ Necking in ductile material.

→ Reduction in cross-sectional area, leading to higher effective stress.

Nature of curve

→ Creep rate increases - curve bends upward.

4. Explain Fatigue and Endurance limit?

> Fatigue!

> Fatigue is the progressive and localized structural damage that occurs when a material is subjected to repeated or fluctuating stress (cyclic loading) over time. Even when the stress is below the material's yield strength.

> Characteristics of Fatigue!

> Occurs under cyclic or repeated loading.
> The failure is sudden, without significant plastic deformation.

> Cracks initiate at stress concentration areas.

> Stages of Fatigue Failure!

> Crack initiation, at stress concentration points.
> Crack propagation under cyclic stress. cracks slowly grows.
> Final Fracture - remaining cross-section fails suddenly.

> Endurance!

> The Endurance limit (Fatigue limit) is the maximum stress level a material can withstand for an infinite number of stress cycles without failure.

> It is the stress below which fatigue failure will not occur. Exists mainly for ferrous material (Steel, iron)

What is cleavage fracture? What factor influence

Cleavage fracture is a type of brittle fracture in which material breaks by crack propagation along specific crystallographic planes (called cleavage planes) without significant plastic deformation.

- The fracture surface appears bright, flat.
- cleavage fracture is common in BCC materials like Ferritic steels, at low temperature, high strain rate.

Factors influencing cleavage fracture:-

(i) Temperature:-

- Lower temperature reduce ductility and increase brittleness that causes cleavage fracture.

(ii) Strain rate:-

- High strain rate promotes cleavage fracture because there is less time for plastic deformation.

(iii) Impurities and inclusions:-

- Non-metallic inclusions (sulfides, oxides) act as stress concentration and initiate cleavage cracks.

(iv) Grain Size

- Finer grains increase toughness and reduce cleavage because cracks must change direction at grain boundaries.
- Larger grain promote easier crack propagation.

(v) Loading condition and geometry:-

- Notches, sharp edges, holes, and sudden change in cross-section produce stress concentration that promote cleavage.

CORROSION & Surface Engineering

• Corrosion

→ The process of deterioration or destruction and consequent loss of a solid metallic material through unwanted chemical, ~~or~~ electrochemical and biochemical attack by its environment at its surface is called corrosion.

• Types of Corrosion!

(i) Uniform Corrosion

→ This is the most common type, where the metal surface corrodes evenly due to chemical or electrochemical reaction with the environment.

Prevention

→ Apply protective coatings ^{like paint or grease to create a barrier.}, use corrosion resistant materials, and control environment exposure.

Example! The general rusting of steel gate, rust of iron, etc.

(ii) Galvanic Corrosion (bimetallic)

→ occurs when two dissimilar metals are electrically connected in an electrolyte. The more active metal acts as anode and corrodes faster.

Prevention

- Electrically insulate dissimilar metals, choose similar metals, use sacrificial anodes.

Ex:- Corrosion of steel bolts in contact with aluminium parts in marine environments.

(iii) Pitting Corrosion

- A localized form of corrosion that results in small holes, pits on the metal surface. Often caused by damage to protective oxide layer.

Prevent

- Selecting materials with high pitting resistance & specific grades of stainless steel.

Example:

- Localized rust, pit
- Stainless steel in chloride-containing environments.

~~Corrosion~~ (iv) Intergranular Corrosion

- A type of corrosion that occurs ~~along~~ the grain boundaries in metals, often due to impurities or heat treatment like welding.

Prevention

- Use low carbon alloy, perform proper heat treatments.

Examples:

- Cracking along the heat-affected zone of a welded stainless steel pipe.

• Stress Corrosion Cracking

→ Involves crack formation from a combination of tensile stress and corrosive environment, common in high-stress components.

Prevent

→ Reducing tensile stress through design or annealing, apply stress relief treatments.

Ex: cracking in pipeline steels.

~~Erosion~~ • NATURE OF CORROSION & ITS CAUSES

→ Corrosion is the gradual destruction or deterioration and consequent loss of a solid metallic material through unwanted chemical, electrochemical reactions with their environment, primarily involving oxygen, moisture, acids.

Nature of corrosion

→ Corrosion mostly occurs as a redox reaction where the metal oxidizes, losing electrons to the environment, and forms a compound like rust, iron oxide in case of iron.

→ It can occur as uniform surface corrosion

or localized forms such as pitting, cracks or stress corrosion, cracking which ~~weakens~~ the metal strength.

causes of corrosion

• moisture and humidity

→ moisture and oxygen

→ Water is a key component for most corrosion to occur. When a material is exposed to both moisture and oxygen, an electrochemical reaction can begin, leading to oxidation, and the formation of oxides.

Electrochemical reactions

- This is the most common cause, where an electrochemical cell ~~for~~ forms on the metal's surface.
- An anode (where oxidation occurs) and cathode (where reduction occurs) ~~from~~ form on metal.
- Electrons flow from the anode to the cathode through the metal, and ions move through an electrolyte.

Temperature!

- Higher temperature increases, the rate of chemical reactions, and diffusion, thus increasing corrosion rate.

Mechanical Stress!

- Area with stress, such as bends or cracks or ~~more~~ improve corrosion.

Factors affecting Corrosion

→ Surface Engineering

- Surface Engineering refers to the techniques and process used to modify the surface properties of materials to improve their performance, durability and appearance, without changing the bulk properties of the metal.
- These processes aim to enhance characteristics such as wear resistance, corrosion resistance, fatigue strength, friction, hardness.

Factors affecting Corrosion Limp 29.11.25

(i) Nature of metal

(a) Purity of metal

- Pure metal corrodes slower than impure metals. Impurities create local galvanic cells which increase corrosion rate.

(b) Physical State (Grain size microstructure)

- Fine grain and stress free metal corrodes slowly.
- If the metal has internal stress, cracks or dislocations, corrosion increases.

e. Position of Electrochemical Series:-

- metals high in electrochemical series (like magnesium, zinc) have more tendency to oxidize and corrode quickly.
- Noble metals like copper (Cu), silver, gold has greater resistance to corrosion.

f. Area Ratio Effect:-

- If a small anodic area is connected to a large cathodic area. The corrosion rate becomes very high.

(ii) Nature of Environment:-

a) Moisture and Humidity:-

- Corrosion increases in the presence of moisture. Higher humidity forms a thin electrolyte layer on the metal surfaces making corrosion easier.
- Higher humidity allows the formation of a continuous electrolyte layer on the metal surface thereby promoting electro-chemical reactions.

b. Temperature:-

- An increase in temperature speeds up the chemical reactions and increase the rate of corrosion.

c. pH of the Environment:-

- Acidic environments (low pH) promote rapid corrosion.
- While alkaline environment (high pH) often reduce it.

(i) Presence of Salt & Pollutants

→ Chlorides, Sulphates, and industrial gases (e.g., SO_2) make the environment more corrosive. Salt water increases conductivity and causes rapid rusting.

(ii) ~~Nature~~ of ~~Electrolyte~~

(iii) Electrochemical Factors!

a) galvanic coupling!

→ When two dissimilar metals are electrically connected in a conductive medium, the less noble (anodic metal) corrodes faster.

b) Presence of Oxide Film!

→ Some metals like aluminium, chromium form a stable, oxide layer that protects from corrosion.

(iv) Surface Conditions!

→ Smooth polished, and clean metal surfaces show lower corrosion rates because they do not retain moisture or dust.

→ Rough surfaces retain dust, water, and salts, causing localized corrosion.

Coatings:-

Applying a new continuous layer of metal surface to improve its properties & enhance its appearance.

~~It is not~~ ~~against~~

Examples:- Thermal spraying coatings, electroplating, physical vapour deposition, chemical vapour deposition, organic coatings.

Organic coatings:-

Organic coatings are paints, varnishes and polymers that act as a barrier to prevent moisture and oxygen contact with the metal.

Mechanical Finishing:-

Mechanical finishing is a surface treatment process in which the ~~surface~~ ~~character~~ material are improved by the application of mechanical forces such as polishing, buffing, grinding.

UNIT-III

Non-Ferrous Metals and their Alloys: Properties and Uses

Non-ferrous metals are those that do not contain iron in significant amounts. They are valued for properties such as corrosion resistance, low density, high thermal and electrical conductivity, and workability.

Non-ferrous metals

Aluminum (Al)

- **Properties:** A soft, ductile, and malleable, silvery-white metal with a very low density. It has excellent electrical and thermal conductivity and high corrosion resistance due to the formation of a self-protecting oxide layer.
- **Uses:**
 - **Packaging:** Foil, cans for food and beverages.
 - **Transportation:** Airplanes, cars, and marine vessels, due to its high strength-to-weight ratio.
 - **Construction:** Window frames, roofing, and cladding.
 - **Electrical:** Power transmission lines.

Copper (Cu)

- **Properties:** A ductile, reddish-orange metal with exceptionally high thermal and electrical conductivity, and good corrosion resistance.
- **Uses:**
 - **Electrical:** Wiring, cables, and motors.
 - **Plumbing:** Water pipes and fittings.
 - **Construction:** Roofing.
 - **Alloys:** The base metal for brass and bronze.

Tin (Sn)

- **Properties:** A silvery-white metal that is soft, malleable, and highly resistant to corrosion in water.
- **Uses:**
 - **Corrosion protection:** Coating steel to create "tin cans" for food packaging.
 - **Alloys:** A major component in bronze and solders.
 - **Electronics:** Soldering material.

Lead (Pb)

- **Properties:** A very soft and heavy metal with high density, low melting point, and excellent resistance to corrosion.
- **Uses:**
 - **Batteries:** Key component in car batteries.
 - **Radiation shielding:** Protective shielding for X-rays and nuclear materials.
 - **Solders:** Used in various solder compositions.
 - **Ammunition:** Primarily for bullets and shot.

Zinc (Zn)

- **Properties:** A bluish-white, brittle metal at room temperature that becomes malleable and ductile when heated. It has good corrosion resistance.
- **Uses:**
 - **Galvanization:** Primarily used to coat steel and iron to prevent rusting.
 - **Alloys:** A key component in brass.
 - **Batteries:** Used in dry-cell batteries.

Magnesium (Mg)

- **Properties:** An extremely light metal with a low density, high strength-to-weight ratio, and good castability.
- **Uses:**
 - **Alloys:** As an alloying element with aluminum to create lightweight, high-strength alloys for aerospace and automotive parts.
 - **Automotive:** Used in car components to reduce weight and increase fuel efficiency.
 - **Aerospace:** Used in aircraft parts for weight reduction.

Nickel (Ni)

- **Properties:** A silvery-white, lustrous, ductile, and corrosion-resistant metal that is also ferromagnetic.
- **Uses:**
 - **Alloys:** A major component in stainless steel and superalloys.
 - **Plating:** Applied as a protective and decorative coating.
 - **Batteries:** A component in rechargeable batteries.
 - **Aerospace:** Used in gas turbines and jet engine parts.

Non-ferrous alloys

Copper alloys

- **Brasses:**
 - **Composition:** Primarily copper and zinc, with some grades containing other elements like tin or lead.
 - **Properties:** Good strength and ductility, high corrosion resistance, and excellent machinability.
 - **Uses:** Musical instruments, plumbing fixtures, decorative items, and ammunition casings.
- **Bronzes:**
 - **Composition:** Primarily copper and tin, though modern bronzes can use aluminum, manganese, or silicon as the main alloying element.
 - **Properties:** Harder, more durable, and more resistant to saltwater corrosion than brass. Often has a low coefficient of friction.
 - **Uses:** Bearings, gears, marine propellers, sculptures, and electrical connectors.

Aluminum alloys

- **Duralumin:**

- **Composition:** Roughly 94% aluminum, 4% copper, 0.5% manganese, and 0.5% magnesium.
- **Properties:** Maximum tensile strength after heat treatment and age hardening, while remaining lightweight.
- **Uses:** Aircraft frames, rivets, and high-performance automotive parts.

- **Hindalium:**

- **Composition:** An alloy of aluminum and magnesium, sometimes with a small amount of chromium.
- **Properties:** Lightweight and corrosion-resistant, with good mechanical properties.
- **Uses:** Cookware, utensils, and general household items.

- **Magnelium:**

- **Composition:** An alloy of aluminum and 2% to 10% magnesium, sometimes with copper.
- **Properties:** High strength, lightweight, and good mechanical properties.
- **Uses:** Aircraft and automotive components.

Nickel alloys

- **Inconel:**

- **Composition:** A family of nickel-chromium-iron superalloys. For example, one common grade contains about 80% nickel, 14% chromium, and 6% iron.
- **Properties:** High-temperature strength, excellent corrosion resistance, and oxidation resistance.
- **Uses:** Aerospace engine components, gas turbines, and springs exposed to high temperatures.

- **Monel:**

- **Composition:** A nickel-copper alloy containing at least 63% nickel and 28% copper.
- **Properties:** Superior corrosion resistance, particularly in marine environments, and high strength.
- **Uses:** Marine hardware, pump fittings, propeller shafts, and chemical processing equipment.

- **Nichrome:**

- **Composition:** Varies, but a common version consists of 65% nickel, 15% chromium, and 20% iron.
- **Properties:** High heat and oxidation resistance.
- **Uses:** Electrical resistance wires and heating elements in furnaces and appliances.

Anti-friction/bearing alloys

Bearing bronzes

Bearing bronzes are designed to have a low coefficient of friction and high wear resistance for use in bushings and bearings. Common types include:

- **High-Leaded Tin Bronze (e.g., UNS C93200 / SAE 660):**
 - **Composition:** Typically contains copper, tin (e.g., 6–7%), and a significant amount of lead (e.g., 6–8%).
 - **Properties:** Excellent anti-friction properties, good machinability, and superior pressure resistance.
 - **Uses:** General-purpose bearings, bushings, and washers.
- **Phosphor Bronze:**
 - **Composition:** Copper and tin, with a small percentage of phosphorus added. A common Indian Standard (IS) grade specifies 87–90% copper, 9–10% tin, and 0.1–3% phosphorus.
 - **Properties:** High fatigue resistance, excellent wear qualities, and good elasticity.
 - **Uses:** Bearings, springs, and gears.
- **Aluminum Bronze:**
 - **Composition:** Copper and aluminum, often with iron and nickel.
 - **Properties:** High strength, toughness, and wear resistance, with excellent corrosion resistance.
 - **Uses:** Heavy-duty sleeve bearings and valve guides.
- **Gunmetal (Leaded Gunmetal):**
 - **Composition:** A bronze containing copper, tin, and zinc. A common composition is 88% copper, 10% tin, and 2% zinc.
 - **Properties:** Good castability and resistance to corrosion.
 - **Uses:** Bushings and bearings, especially in marine and steam applications.

Standard commercial grades as per BIS/ASME

- **BIS (Bureau of Indian Standards):** The BIS specifies material compositions and properties through various Indian Standards (IS). For example, IS 10569 (2005) covers aluminum bronze rods, bars, and sections, and IS 3091 (1999) covers aluminum bronze ingots and castings.
- **ASME (American Society of Mechanical Engineers):** The ASME references standards from other organizations, such as ASTM and SAE, for material specifications. For bearing bronzes, standard grades like UNS C93200 (SAE 660) are often specified and covered by ASTM standards such as ASTM B271 and B505.

Failure analysis: Introduction

Failure analysis is the systematic process of investigating why a product, component, or structure has failed. Its purpose is to determine the root cause of the failure and to prevent similar failures from happening again.

Key steps in failure analysis:

- **Gather background information:** Collect data about the component's design, manufacturing, material specifications, maintenance history, and service conditions.
- **Initial inspection:** Perform a preliminary visual and macroscopic examination of the failed part to document the extent and location of the damage.
- **Non-destructive testing (NDT):** Use methods that do not damage the component to find flaws(any mark).
- **Destructive testing (DT) and analysis:** Take samples from the failed component and conduct tests to determine mechanical properties and microstructural features.
- **Identify the failure mechanism:** Based on the gathered evidence, determine the physical phenomenon that caused the failure, such as fracture, fatigue, or corrosion.
- **Perform root cause analysis:** Trace the failure mechanism back to the fundamental cause, which could be a material defect, design flaw, manufacturing error, or misuse.
- **Provide recommendations:** Suggest corrective actions to prevent recurrence.

Fracture: Ductile fracture, brittle fracture, cleavage, and notch sensitivity-Fracture is the separation of a material into two or more pieces under an applied stress. The way a material fractures provides clues about its properties and the cause of failure.

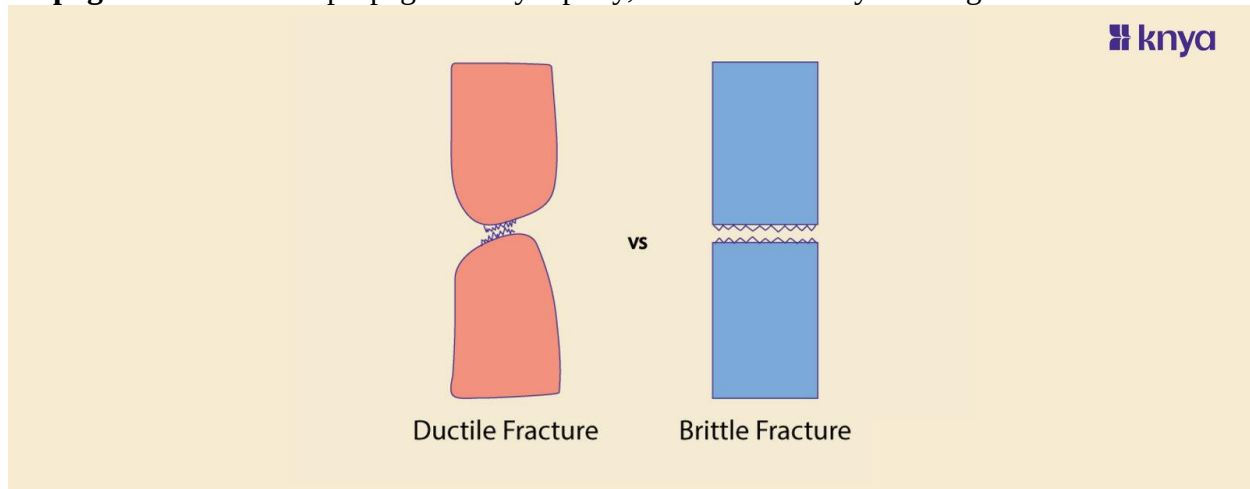
Ductile fracture

- **Deformation:** Exhibits significant plastic deformation (stretching or necking) before fracture.
- **Energy absorption:** Characterized by high energy absorption, which makes the failure more stable and predictable.
- **Appearance:** The fracture surface is rough and fibrous due to the formation and coalescence(merging of elements to form one mass or whole) of microvoids.
- **Propagation:** The crack propagates relatively slowly, often providing visible warning signs.

Brittle fracture

- **Deformation:** Occurs with little or no plastic deformation, leading to sudden, catastrophic failure.
- **Energy absorption:** Involves low energy absorption, making the material vulnerable to sudden failure under load.
- **Appearance:** The fracture surface is typically flat, shiny, and crystalline in appearance.

- **Propagation:** The crack propagates very rapidly, often without any warning.



Cleavage

Cleavage is a type of brittle fracture where a crack propagates along specific crystallographic planes (cleavage planes) in a crystalline material. It is a characteristic feature of brittle failure in certain metals and ceramics.

Notch sensitivity

Notch sensitivity is a measure of how much a material's fracture strength is reduced by the presence of a notch, crack, or other stress concentrator.

- **Mechanism:** Notches cause a concentration of stress at their tip, which can initiate a crack.
- **Highly sensitive materials:** Brittle materials like cast iron are very notch-sensitive, meaning a small notch can cause a significant drop in strength.
- **Low sensitivity materials:** Ductile materials like mild steel are less notch-sensitive because plastic deformation at the notch tip can relieve the stress concentration.

Fatigue-Fatigue is a failure mechanism that occurs in materials subjected to cyclic or fluctuating stresses. Fatigue damage is cumulative and can lead to failure at a stress level below the material's yield strength.

Endurance limit (or fatigue limit)

- **Definition:** The maximum stress amplitude below which a material can theoretically endure an infinite number of stress cycles without failing.
- **Applicability:** Only some materials, particularly ferrous and titanium alloys, exhibit a true endurance limit.

- **Significance:** It is a critical design parameter for components subjected to cyclic loading, such as rotating shafts, gears, and engine parts.

Characteristics of fatigue fracture

A typical fatigue fracture surface shows distinct zones:

1. **Crack initiation:** A crack usually starts at a stress concentration point, such as a sharp corner or a surface defect.
2. **Stable crack growth:** This region is characterized by smooth, concentric "beach marks" or "striations" that represent the step-by-step growth of the crack with each loading cycle.
3. **Sudden fracture:** Final, rapid failure occurs when the crack reaches a critical size and the remaining cross-section can no longer withstand the load.

Variables affecting fatigue life

- **Applied stress:** The magnitude of cyclic stress is the most important factor; higher stresses lead to a shorter fatigue life.
- **Stress concentration:** Features like notches, holes, and sudden changes in cross-section can create stress risers that act as crack initiation sites.
- **Surface quality:** A smooth, polished surface improves fatigue life by minimizing potential crack initiation points.
- **Material properties:** The microstructure, strength, and hardness of the material are significant factors.
- **Environmental factors:** Corrosive environments can dramatically reduce fatigue life through a process called corrosion fatigue.
- **Residual stresses:** Internal stresses from manufacturing can be either beneficial (compressive) or detrimental (tensile).

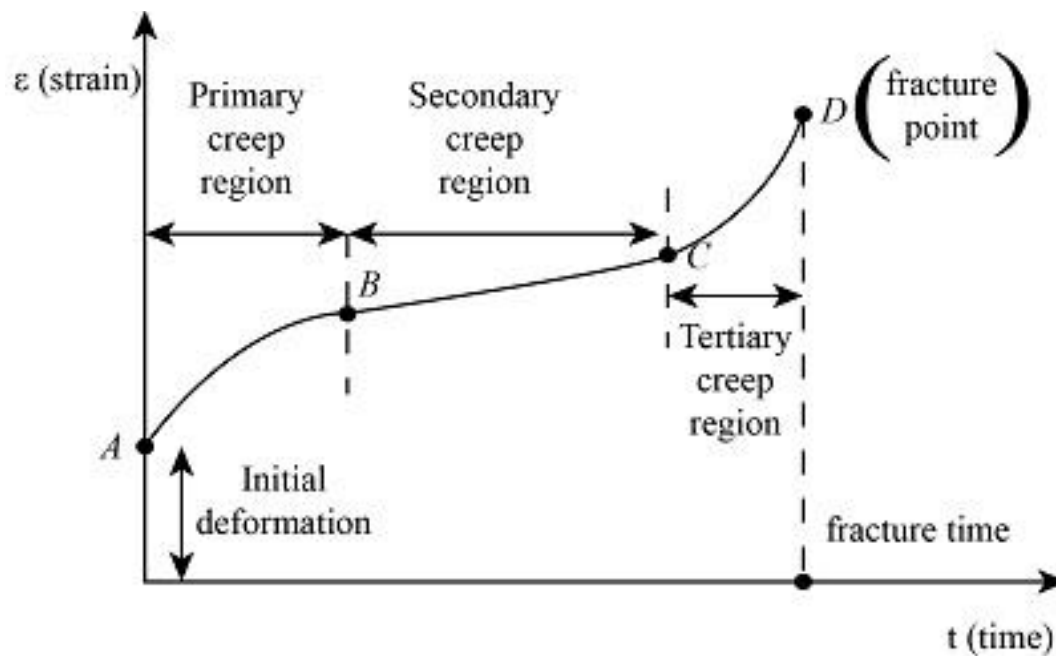
Creep

Creep is the time-dependent plastic deformation of a material under a constant load at elevated temperatures.

Creep curve-A creep curve is a graph of **strain (deformation) versus time** for a material subjected to a constant load and temperature, illustrating the three stages of creep: primary, secondary, and tertiary. Primary creep shows a decreasing strain rate, secondary creep has a constant strain rate, and tertiary creep involves an accelerating strain rate that leads to material rupture. This curve is essential for understanding material behavior under high-temperature, long-term stress conditions.

A plot of strain versus time for a material under constant stress and temperature typically shows three stages:

1. **Primary (transient) creep:** The creep rate decreases over time due to work hardening.
2. **Secondary (steady-state) creep:** The creep rate is constant as a balance is reached between work hardening and recovery. This stage is most important for engineering design.
3. **Tertiary (accelerated) creep:** The creep rate accelerates rapidly, leading to fracture. This stage is caused by microstructural changes, necking, and void formation.



Creep fracture

Creep fracture, or stress rupture, occurs when a material fails due to the accumulation of creep deformation.

- **Characteristics:** Creep fractures are often intergranular, forming along grain boundaries.
- **Appearance:** Failed components may show signs of bulging and thick-edged, low-ductility fractures.

Destructive testing

Destructive testing (DT) involves testing a specimen to the point of failure to determine its mechanical properties.

Tensile testing

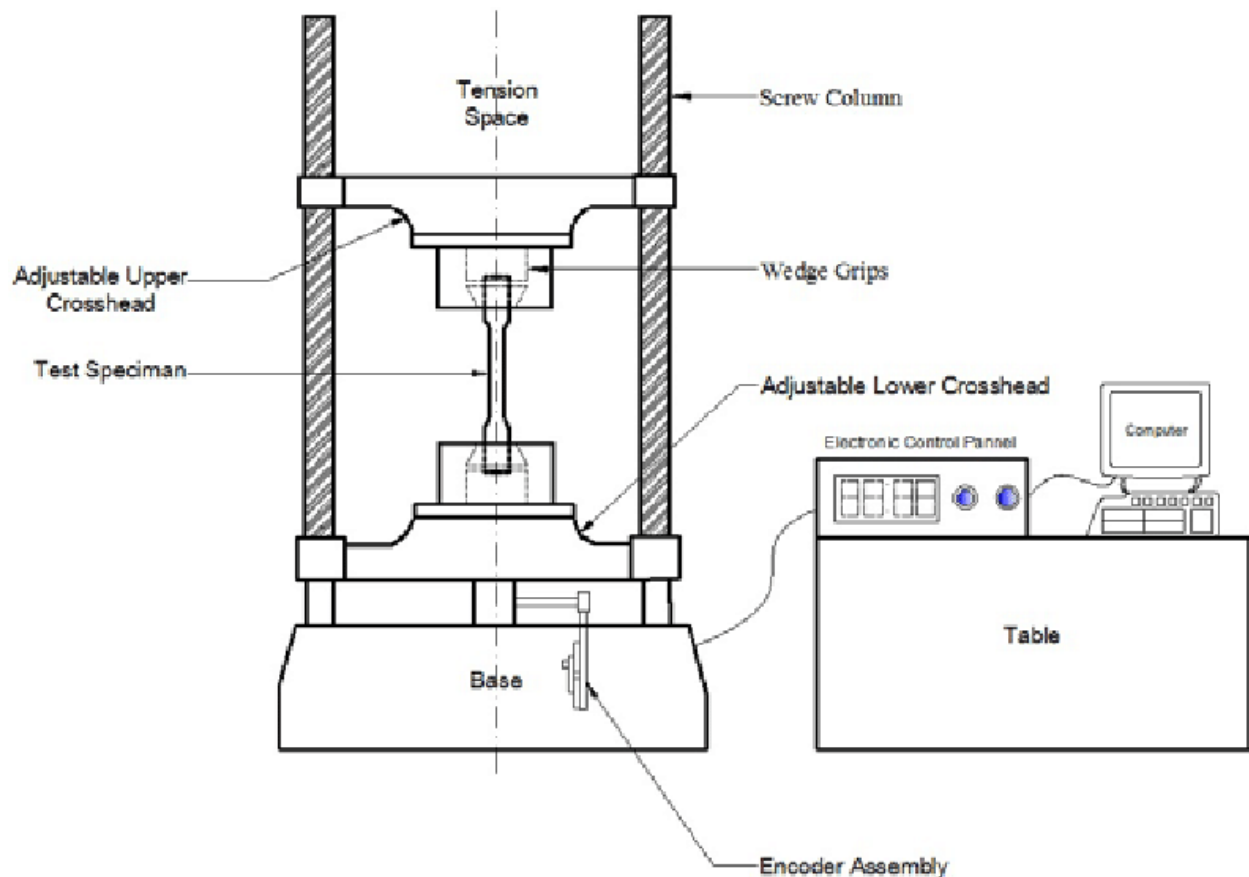
- **Purpose:** Measures a material's response to a tensile (pulling) force.

- **Process:** A standard "dogbone" shaped specimen is pulled until it fractures. The applied load and resulting elongation are measured.
- **Results:** Yield strength, ultimate tensile strength, elongation, and Young's modulus are determined from the stress-strain curve.

Tensile testing is a destructive mechanical test that measures a material's response to being pulled or stretched until it breaks. The test involves clamping a sample specimen and applying a controlled tension to it, recording the force and the resulting elongation. This process is used to determine key mechanical properties like ultimate tensile strength, yield strength, and ductility.

How it works

- A standardized material sample is held between two grips.
- A testing machine pulls the grips apart, applying a tensile (pulling) force to the specimen.
- The force applied and the specimen's change in length are continuously measured.
- The force is increased until the material fractures.
- The resulting data is often plotted on a stress-strain curve, which provides information about the material's mechanical properties.



What it measures

- **Yield strength**: The point at which the material begins to deform permanently.
- **Ultimate tensile strength**: The maximum stress the material can withstand before failure.
- **Ductility**: The material's ability to deform under tensile stress, which can be observed by how much it stretches before breaking.
- **Young's modulus**: A measure of stiffness or the material's resistance to elastic deformation.
- **Poisson's ratio**: The ratio of transverse strain to axial strain.

Applications

Tensile testing is used across many industries to evaluate materials such as metals, plastics, composites, and textiles.

- **Construction**: Ensuring the strength of structural components.
- **Automotive and aerospace**: Testing parts for safety and performance under stress.
- **Packaging**: Verifying the strength and durability of packaging materials.
- **Textiles**: Evaluating the strength of fabrics and threads.

Compression testing

- **Purpose**: Measures a material's behavior under a crushing load.
- **Process**: A specimen is placed between two platens and compressed.
- **Applications**: Used for brittle materials like concrete, foams, and ceramics, and to determine properties like compressive strength and yield strength.

Compression testing is a mechanical test that determines a material's response to crushing forces by measuring properties like strength, stiffness, and deformation. It is performed by applying a compressive load to a sample using a universal testing machine and analyzing the resulting stress and strain data. This process helps evaluate material integrity for a wide range of applications, from a product's design phase to quality control and engine diagnostics.

How it works

1. A standardized specimen is placed between the platens (flat plates) of a universal testing machine.
2. The machine applies a gradual, controlled compressive force to the specimen.
3. Sensors measure the force applied and the resulting deformation (strain) of the material.
4. This data is used to generate a stress-strain curve, which reveals key properties like elastic limit, yield point, and compressive strength.

Materials and applications

- **Materials**:
Used for testing various materials like concrete, composites, foam, plastics, and metals.
- **Components**:

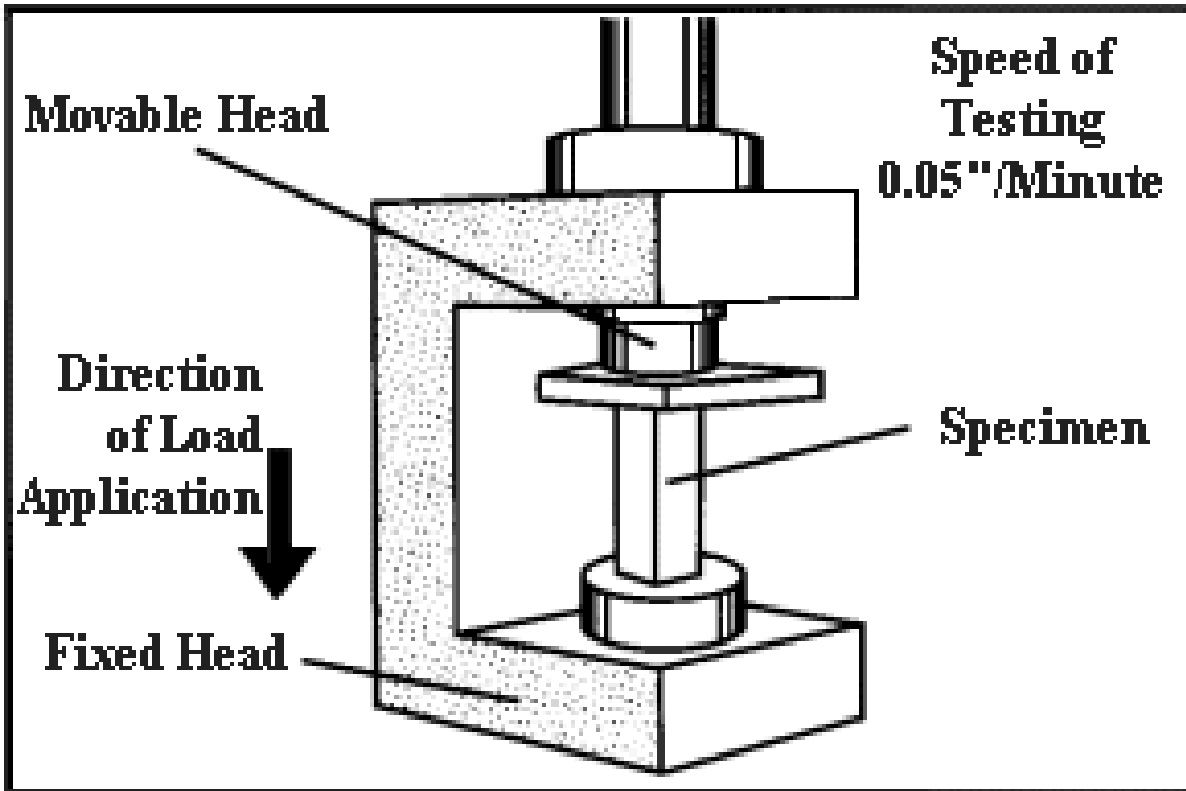
Also performed on finished products and components such as springs, medical devices, and packaging.

- **Engine diagnostics:**

A specific type of compression test is used to check the health of an internal combustion engine by measuring the pressure in each cylinder to detect issues with valves, rings, or gaskets.

Key properties determined

compressive strength, elastic limit, yield point or yield strength, modulus of elasticity, and ductile fracture limits.



Hardness testing

- **Purpose:** Measures a material's resistance to permanent indentation.
- Hardness testing evaluates a material's resistance to indentation, scratching, or wear by pressing an indenter into its surface and measuring the resulting mark. Common methods include the Rockwell, Brinell, and Vickers tests, which are widely used in quality control for materials like metals. It's a fast, low-damage method to assess material properties like strength and suitability for a specific application.
- **Brinell test:** A hard, large carbide ball is pressed into the surface with a specific load. The diameter of the resulting indentation is measured to calculate the Brinell Hardness Number (BHN).

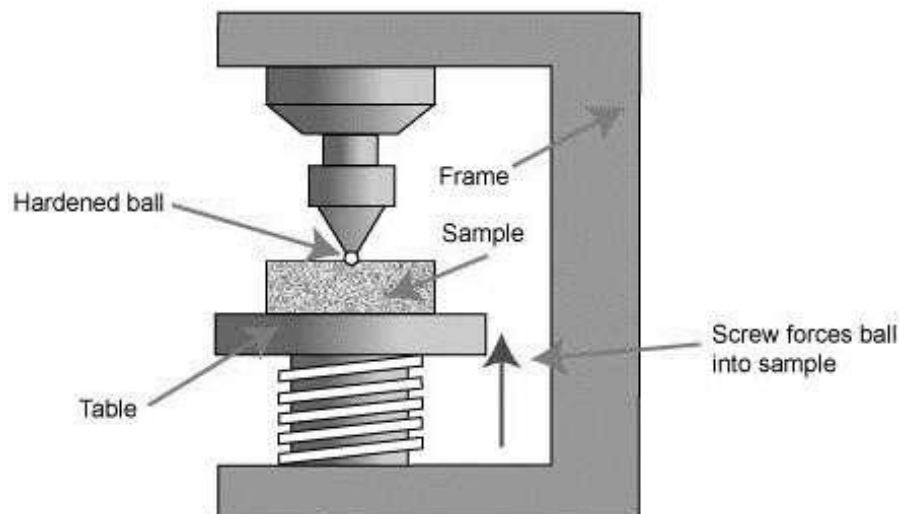
The Brinell hardness test measures a material's resistance to indentation by applying a specific force with a hardened steel or tungsten carbide ball. The depth of the resulting spherical indentation is measured, and the Brinell Hardness Number (BHN) is calculated from the applied load and the surface area of the indentation. This method is often used for materials with coarse grains or rough surfaces, such as castings and forgings.

How the test works

- **Indentation:** A spherical indenter (usually a hardened steel ball) is pressed into the material's surface with a known force for a specified dwell time.
- **Force and Ball:** The test parameters include the diameter of the ball (e.g., 10 mm) and the applied load (e.g., 3,000 kgf).
- **Measurement:** After the load is removed, the diameter of the circular indentation is measured, typically with a microscope, in at least two perpendicular directions.
- **Calculation:** The Brinell hardness number (BHN) is calculated using the formula:

Key characteristics

- **Deep, wide impression:** The Brinell method creates the deepest and widest indentation of common hardness tests, which helps to average out any irregularities in the material's structure.
- **Suitable for coarse materials:** It is ideal for testing materials that are too coarse or rough for other methods, like large castings and forgings.
- **Limited by material hardness:** The test is not suitable for very hard materials, as the ball indenter may deform, leading to inaccurate results.
- **Standard notation:** Results are often reported with the test conditions, such as "70 HB 10/500/30," which indicates a Brinell hardness of 70, using a 10 mm ball and a 500 kgf load held for 30 seconds.



- **Rockwell test:** Uses a minor and major load sequence to press a smaller indenter into the material. The depth of the indentation is measured and converted directly into a hardness number, making it quicker and easier than the Brinell test.
- The Rockwell hardness test is an indentation test that measures a material's resistance to permanent deformation. It works by applying a minor load to an indenter, then a major load, and finally removing the major load while keeping the minor load applied. The depth of the indentation after the major load is removed is used to determine the material's hardness value. Different scales, which use different loads and indenters, exist to test a variety of materials, such as steel, aluminum alloys, and polymers.

How the test is performed

1. **Apply minor load:** A preliminary force, or minor load, is applied to the indenter (either a ball or a diamond cone) to seat it on the material's surface. This sets a zero reference point.
2. **Apply major load:** An additional, larger force is applied for a specific duration to create a deeper indentation.
3. **Remove major load:** The major load is removed, but the initial minor load remains in place.
4. **Measure depth:** The change in the depth of the indentation under the minor load is measured. This depth is then converted into a Rockwell hardness number.

Key components

- **Indenter:** The object that is pushed into the material. It can be a conical diamond for hard materials or a steel ball of varying diameters for softer materials.
- **Loads:** There are two loads: a minor (preload) and a major (total test load).
- **Scales:** Different combinations of indenters and loads create different scales, denoted by a single letter (e.g., HRC for a hard steel, HRB for softer metals).
- **Hardness number:** A dimensionless number that is a function of the penetration depth from the major load application. A smaller indentation depth corresponds to a higher hardness number.
-



Bend test

- **Purpose:** Evaluates a material's ductility and ability to resist fracture under bending loads.
- **Process:** A specimen is bent to a specified angle over a mandrel. It is then visually inspected for cracks or fractures.

A bend test is a materials testing method that evaluates a material's ductility, flexibility, and strength by bending it to a specific angle to check for fractures or defects. It's a simple, often inexpensive, quality control test used for materials like metals and plastics, and it helps ensure a material can withstand bending forces without breaking. The test involves a specimen being supported at two points and force being applied at another point (typically the midpoint) until the desired bend is achieved.

What a bend test evaluates

- **Ductility:** The ability of a material to deform plastically without fracturing.
- **Strength:** A material's resistance to bending.
- **Soundness:** Reveals internal defects, such as cracks or voids, on the outer surface of the bend.

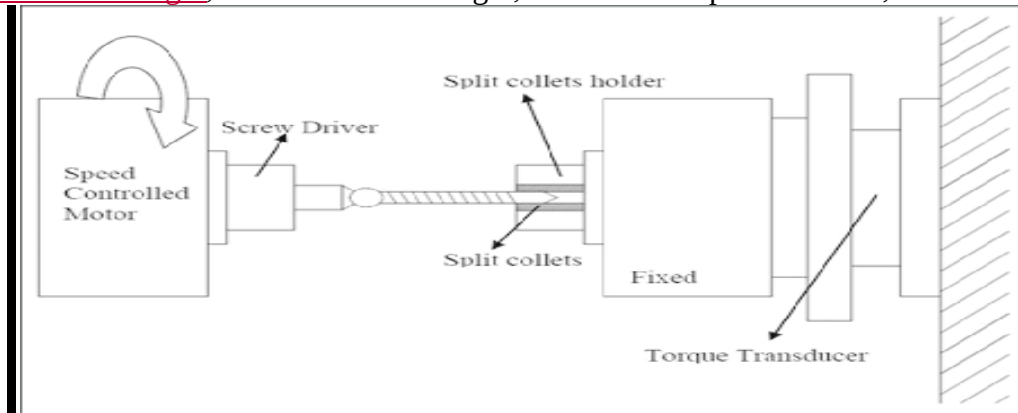
How it's performed

1. **Preparation:** A sample specimen is prepared, often cut to specific dimensions and edges are sometimes deburred or ground to prevent tearing.
2. **Setup:** The specimen is placed on two support anvils, which can be a fixed distance apart.
3. **Loading:** A force is gradually applied to the specimen at a specific point (like the center for a three-point test) or multiple points, causing it to bend.
4. **Inspection:** After the test, the bent specimen is inspected for any cracks or other deformities, especially on the outer surface of the bend.



Torsion test

- **Purpose:** Evaluates a material's behavior under twisting forces (torque).
- **Process:** A specimen is twisted, and the torque and angle of twist are measured.
- **Applications:** Used for shafts, wires, and fasteners to determine shear modulus and torsional strength.
- Torsion testing is a type of mechanical testing that evaluates the properties of materials or devices while under stress from angular displacement. Torsion testing can be split into two distinct categories: testing raw materials like metal wires or plastic tubing to determine properties such as shear strength and modulus, or functional testing of finished products subjected to torsion, such as screws, pharmaceutical bottles, and sheathed cables. The most common mechanical properties measured by torsion testing are modulus of elasticity in shear, yield shear strength, ultimate shear strength, modulus of rupture in shear, and ductility.



Fatigue test

- **Purpose:** Determines the fatigue life and endurance limit of a material under cyclic loading.
- **Process:** A specimen is subjected to repeated load cycles until failure. Tests are run at different stress levels to generate an S-N curve.

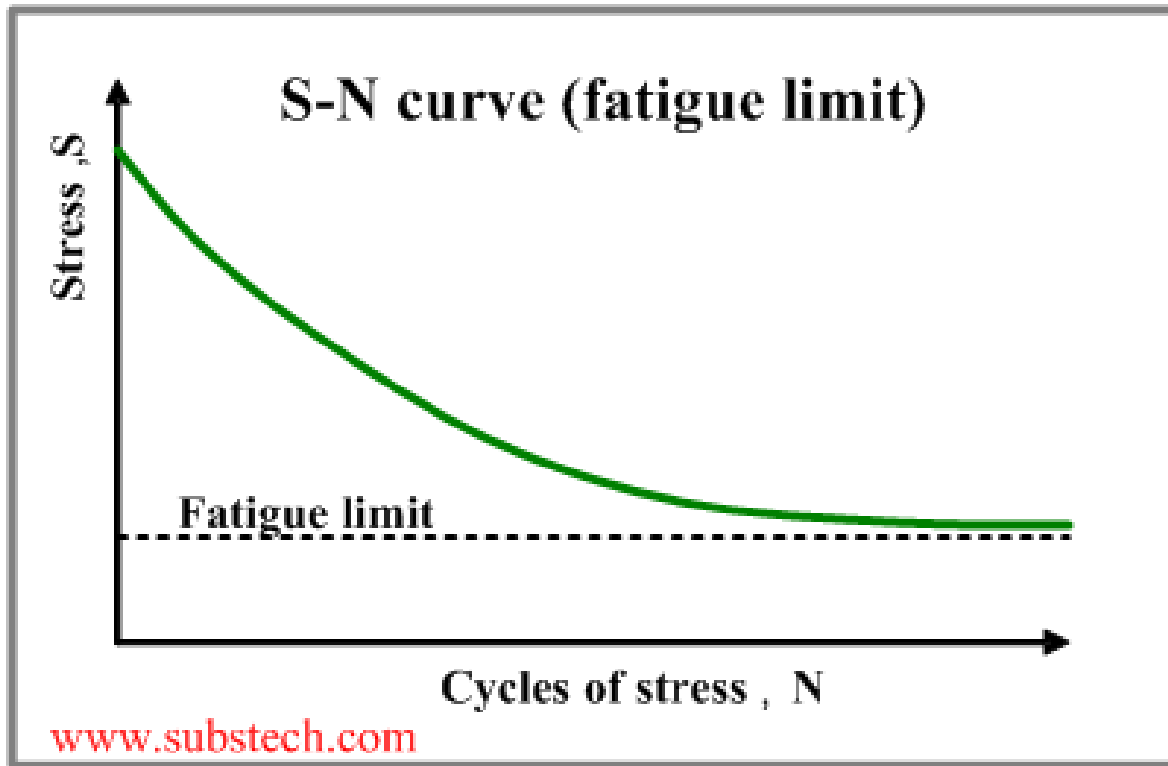
A fatigue test is a mechanical engineering procedure used to determine a material's ability to withstand repeated, cyclic loading (stresses from tension, compression, bending, etc.) over time. These tests are crucial for predicting a component's lifespan and ensuring its safety under real-world conditions, as fatigue can cause failure at loads below the material's ultimate strength. The results are often used to create [S-N curves](#), which plot stress versus the number of cycles to failure.

What a fatigue test does

- **Evaluates durability:**
It assesses how a material will hold up under repeated stress, which is common in many applications like aerospace, automotive, and structural engineering.
- **Predicts lifespan:**
It helps determine the number of stress cycles a component can endure before it fails, which is known as its fatigue life.
- **Identifies weaknesses:**
By applying various cyclic loads and measuring the results, engineers can identify critical locations and potential flaws in a design.
- **Informs design improvements:**
The data gathered allows engineers to optimize material choices and design components to be more resistant to fatigue failure.

How a fatigue test works

- **Applies cyclic loads:**
A specimen is subjected to a series of repeated stresses in a controlled manner. This can be in the form of tension, compression, bending, torsion, or a combination.
- **Measures cycles to failure:**
The test runs until the specimen fractures, and the number of stress cycles it endured is counted.
- **Uses sensors:**
Devices like strain gauges and load cells are used to accurately measure the forces and stresses on the test specimen.
- **Generates data:**
The results from multiple tests can be plotted on an S-N curve (stress vs. number of cycles to failure), which is a key tool for engineers to predict material behavior.



Creep test

- **Purpose:** Measures the time-dependent deformation of a material at elevated temperatures under a constant load.
- **Process:** A specimen is placed in a high-temperature chamber, subjected to a constant load, and its elongation is measured over time.

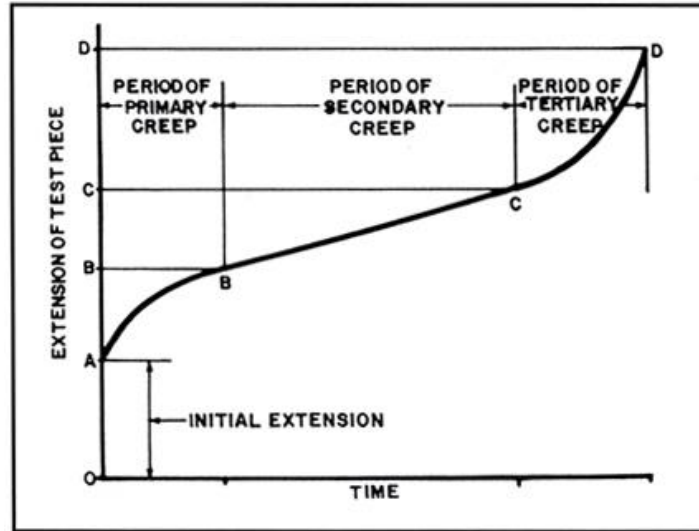
A creep test is a material science experiment that measures how much a material deforms over time when subjected to a constant stress or load at a constant temperature. This test is used to determine a material's long-term strength and stability, especially under high-temperature conditions found in applications like jet engines or pipelines. The results are often plotted as strain versus time and are used to predict the material's lifespan .

What is measured

- **Deformation:** The change in the material's shape or length is the primary measurement.
- **Strain:** This is the measure of deformation, often plotted on a graph against time.
- **Time:** The test runs for an extended period, sometimes thousands of hours.
- **Temperature:** The test is conducted at a specific, constant temperature, often elevated, to mimic real-world conditions.
- **Stress:** A constant load is applied to the specimen throughout the test.

How it works

1. A specimen of the material is prepared.
2. The specimen is placed in a testing machine and subjected to a constant elevated temperature.
3. A constant load is applied to the specimen.
4. The deformation of the specimen is measured and recorded at regular intervals over an extended period.
5. The results are plotted on a graph to show the rate of creep.



Non-destructive testing (NDT)-

NDT methods inspect materials or components for flaws without damaging them.

Visual inspection (VT)

- **Principle:** The most basic NDT method, involving the visual observation of a component's surface for defects such as cracks, corrosion, and misalignment.
- **Tools:** May use mirrors, borescopes, or magnifying glasses for hard-to-reach areas.

Magnetic particle inspection (MPI)

- **Principle:** Used on ferromagnetic materials. A magnetic field is applied, and fine magnetic particles are dusted onto the surface. Surface and near-surface cracks disrupt the magnetic field, causing the particles to gather and reveal the defect.
- **Detection:** Can use dry or wet particles, often fluorescent, for better visibility.

Liquid penetrant test (PT)

- **Principle:** A liquid dye (penetrant) is applied to the surface of a non-porous material and allowed to seep into surface-breaking flaws. Excess penetrant is removed, and a developer is applied, which draws the penetrant out of the flaws, making them visible.
- **Detection:** Can be used on a wide range of materials and is effective for detecting surface cracks and pores.

Ultrasonic inspection (UT)

- **Principle:** High-frequency sound waves are introduced into the material. Flaws, such as cracks or voids, cause reflections (echoes) that are detected and analyzed to determine the flaw's size and location.
- **Applications:** Used for detecting internal defects and measuring material thickness.

Radiography (RT)

- **Principle:** Uses X-rays or gamma rays to produce a film or digital image of the component. Internal features and defects, such as porosity, inclusions, and cracks, show up as variations in contrast on the image.
- **Applications:** Used for inspecting welds, castings, and complex components.

Corrosion and Surface Engineering

Nature and Causes of Corrosion

Corrosion is the gradual deterioration of materials, typically metals, due to chemical or electrochemical reactions with their environment, converting a refined metal into a more chemically stable form such as an oxide, hydroxide, or sulfide. The primary causes include exposure to air (oxygen), moisture (water), acids, salts, pollutants, and contact with dissimilar metals.

Electrochemical Reactions

Most corrosion is an electrochemical process involving an **anode** (where oxidation/metal dissolution occurs) and a **cathode** (where reduction/electron acceptance occurs), connected by a metallic path and an electrolyte.

Electrolytes

An electrolyte is a conductive medium (e.g., water with dissolved salts, acids, or bases) that facilitates the transport of ions between the anodic and cathodic regions. The presence of electrolytes (like salt in water) significantly increases the rate of corrosion by enhancing the conductivity of the medium.

Factors Affecting Corrosion

1.Environment:

High humidity, temperature, and the presence of corrosive gases or salts (especially near the sea) accelerate corrosion.

2.Material Properties:

Reactivity: More reactive metals (lower electrode potential) corrode faster.

Purity: Impurities in a metal can set up local electrochemical cells, increasing corrosion.

Passivity: Some metals (e.g., stainless steel, aluminum) form a stable, protective oxide film that prevents further corrosion.

3.Physical Conditions:

Stress/Strain: Areas of higher stress or strain (cuts, bends) are more susceptible to corrosion.

Temperature: Higher temperatures generally increase the rate of corrosion.

pH: Acidic environments (low pH) are generally more corrosive than neutral or basic ones.

Types of Corrosion

Corrosion can be classified by its appearance or mechanism:

- **Uniform:** Even attack over the entire surface.
- **Galvanic:** Occurs when two dissimilar metals are in electrical contact in an electrolyte; the more active metal corrodes preferentially.
- **Crevice:** Localized corrosion in confined spaces where fluid access is limited.
- **Pitting:** Localized corrosion that creates small holes or pits.
- **Intergranular:** Occurs along the grain boundaries of the metal.
- **Stress Corrosion Cracking:** Caused by the combined action of a corrosive environment and mechanical stress.

Corrosion Control

- **Material Selection:** Choosing corrosion-resistant materials (e.g., noble metals, specific alloys like stainless steel or titanium) appropriate for the service environment.
- **Environment Control:** Removing corrosive elements from the environment (e.g., deaeration of water, using dehumidifiers, adding corrosion inhibitors to the medium).
- **Design:** Avoiding sharp corners, crevices, and situations that trap moisture or create galvanic couples between dissimilar metals.
- **Protective Coatings:** Applying barriers or more active coatings (see below).
- **Cathodic Protection:** Supplying a protective electrical current, often using a sacrificial anode (more active metal like zinc or aluminum) that corrodes instead of the protected structure (e.g., pipelines, ships).

Surface Engineering Processes

Surface engineering modifies the properties of the surface phase to reduce degradation from wear, corrosion, and fatigue.

- **Coatings and Surface Treatments:**
 - **Cleaning and Mechanical Finishing:** Processes like sandblasting, bead blasting, polishing, and acid pickling are used to prepare the surface by removing oxides, rust, oils, and other contaminants before coating or treatment.
 - **Organic Coatings:** Paints, lacquers, and polymer-based coatings provide a barrier to slow the diffusion of water and oxygen to the metal surface.
 - **Electroplating and Special Metallic Plating:** An electrochemical process where a layer of a desired metal (e.g., nickel, chromium, zinc, gold) is deposited onto a substrate using an electric current to enhance corrosion resistance, wear resistance, or appearance. Electroless plating is a related process that does not use an external electric current.
 - **Electropolishing and Photo-etching:**
 - **Electropolishing:** The reverse of electroplating, using an electrochemical process to remove a thin, controlled layer of metal, especially from stainless steel. It selectively

removes microscopic peaks and burrs, resulting in a smooth, bright, ultra-clean, and highly passivated surface.

- **Photo-etching (or chemical etching):** A highly accurate process using chemical methods (often combined with photolithography) to remove material to create intricate designs or patterns, especially for electronic components.
- **Conversion Coatings:** Formed by a chemical or electrochemical reaction that transforms the metal's surface into a protective layer that enhances corrosion resistance and paint adhesion:
 - **Oxide Coatings (Anodizing):** An electrolytic process that forms a protective oxide film, commonly on aluminum and magnesium alloys.
 - **Phosphate Coatings:** A chemical process creating a crystalline phosphate layer, widely used in the automotive industry for rust proofing and as a base for paints.
 - **Chromate Coatings (Passivation):** Forms a thin, protective chromate film on metals like aluminum, zinc, and cadmium, significantly boosting corrosion resistance.
- **Thin Film Coatings:** Applied through vapor deposition techniques:
 - **PVD (Physical Vapor Deposition):** Processes like sputtering or evaporation deposit a thin film in a vacuum, improving strength and durability.
 - **CVD (Chemical Vapor Deposition):** A process where a volatile precursor reacts or decomposes on the substrate surface to produce a uniform film.
- **Hard-facing, Thermal Spraying and High-Energy Processes:**
 - **Hard-facing:** Applying a hard, wear-resistant material to a surface by welding or spraying to reduce wear and abrasion.
 - **Thermal Spraying:** A group of processes (e.g., High-Velocity Oxygen Fuel (HVOF), plasma spray) that melt or semi-melt materials (metals, ceramics) and spray them onto a substrate to form a thick, protective coating.
 - **High-Energy Processes:** Techniques like laser cladding or electron beam treatments for surface modification.

Process/Material Selection

Selection depends on the required performance (corrosion resistance, wear resistance, aesthetics), the substrate material, cost, and environmental considerations.

Pollution Norms for Treating Effluents

Effluents from surface engineering and metal finishing processes (especially electroplating, pickling, and chromate conversion) are hazardous and contain heavy metals (Cr, Ni, Zn, Cu), acids (sulfuric, phosphoric, hydrochloric), cyanides, and other toxic chemicals.

- **Standards:** Effluent treatment must comply with national and local environmental regulations. In India, the Central Pollution Control Board (CPCB) sets the standards.
- **Key Norms:**
 - **Neutralization:** Acidic and alkaline effluents must be mixed and neutralized to a specific pH range (typically 6.5 to 8.5).

- **Heavy Metal Removal:** Various methods (chemical precipitation, ion exchange, membrane filtration) are used to remove heavy metals to below prescribed limits (e.g., for Cr, Ni, Zn, Cu). Hexavalent chromium must be reduced to trivalent chromium before precipitation.
- **Cyanide Treatment:** Cyanide-containing effluents require specific oxidation treatments (e.g., alkaline chlorination) to break down the cyanide.
- **Suspended Solids Removal:** Coagulation, flocculation, and sedimentation/filtration processes remove solid particles.
- **Monitoring:** Continuous monitoring of key parameters (pH, heavy metal concentrations, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS)) is mandatory, with regular reporting to regulatory bodies. Adherence to these norms is essential for environmental stewardship and legal compliance.