

Structure of Metals

Material :- It is a matter from which something can be made.

Materials Science :- It is the application of science which deals with design and development of new products.

Engineering Material :- The material which is used to produce technical products is known as Engineering Materials.

Metallurgy :- It is a branch of science and technology which deals with properties of metals and their production and purification.

Mechanical Properties :-

1) Strength

2) Deformation

3) Hardness

4) Toughness

5) Stiffness

6) Brittleness

7) Creep

8) Fatigue

Atomic Bonding :- Two types : 1) Primary Bonding
2) Secondary Bonding

Ionic Bonding :- This bond is formed by donating valence electrons.

Ex:- NaCl.

To get stable configuration sodium donates one electron to chlorine. Thus bond is formed.

Conditions for Ionic bonding:-

- 1) It composes of both metals and non-metallic elements.
- 2) It is generally found in compounds.
- 3) It is the attraction b/w positive & negatively charged electrons.

Ex:- NaCl, MgO, Al₂O₃, CaF₂.

Covalent bonding:- This bond is formed by mutual sharing of valence electrons.

Conditions for Covalent bonding:-

- 1) It composes non-metals only.

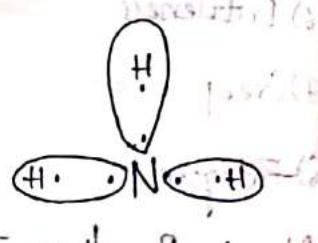
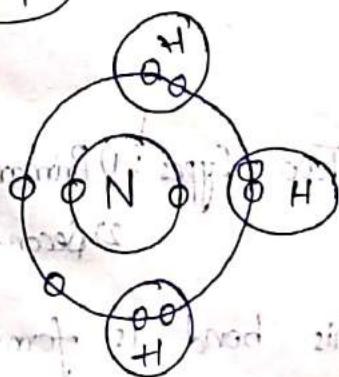
2)

Ex:- CH₄, NH₃, SiC, Diamond.

NH₃

N - 7 $1s^2$ $2s^2$ $2p^3$

H - 1 $1s^1$



Note:- In both cases electrons are bounded to atoms so it is having less conductivity.

Metallic Bonding:- As like Ionic and Covalent Bondings, in metallic bonding electrons are not bounded to atoms. In this valence electrons form electron sea which is negatively charged and remaining electrons form positive ion cores which are positively charged. So, the bond is formed by the attraction b/w positive ion cores and negative electrons.

Difference b/w Ionic, Covalent and Metallic Bondings:-

Ionic/Covalent vs Metallic

1) Bond energy:- High bond energy 1) Can't say. It depends upon metal. It is high for tungsten and low for mercury.

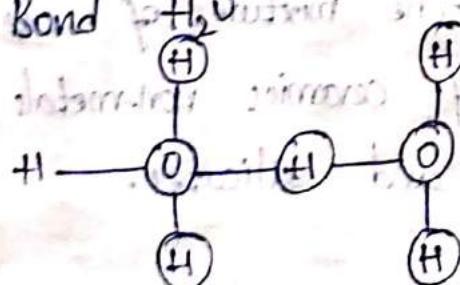
2) Bond strength:- High bond 2) Can't say. strength.

3) Conductivity:- Low. 3) High.

4) These are brittle. 4) These are ductile.

Secondary Bonding:- (or) Weak Bonding:- It is the bond b/w molecules.

Ex:- Hydrogen Bond



Classification of materials:-

- 1) Metals:
 - Pure metals
 - Alloys
- 2) Ceramics
- 3) Polymers:
 - Organic
 - Inorganic
- 4) Composites

Metal:- In metals atoms are arranged in order. That is why there are very strong compared to other materials.

Pure metal:- If a metal is having only a single element it

is called a pure metal.

Ex:- Aluminium, Copper, Magnesium, Nickel, Molybdenum, Silver, etc

Alloys:- It is the combination of two or more materials in which one must be a metal.

Note:- All metals are materials but all materials are not metals.

Ex:- Brass \rightarrow Copper + Zinc

Bronze \rightarrow Copper + Tin

Steel \rightarrow Iron + Carbon

Ceramics:- It is the mixture of one metal and other metal. In case of ceramics non-metals must be oxides, nitrides, carbides and silicates.

Ex:- Aluminium Oxide (Al_2O_3) . Magnesia (MgO), ZrO_2 (Zirconia).
Alumina

→ Sometimes it is formed b/w two non-metals also.

Ex:- SiC , Si_3N_4 , SiO_2 (Silica).

Polymers:- It is - the combination of number of monomers.

Organic Polymers:- If it is having elements like carbon, hydrogen, oxygen and nitrogen then it is called an organic polymer. If these are available in nature it is called organic polymer.

Inorganic Polymers:- Which are not available in nature are called as inorganic polymers.

Composites:- It is the combination of two (or) more materials.

Ex:- Concrete.

→ In case of alloys, we cannot find the elements with a naked eye.

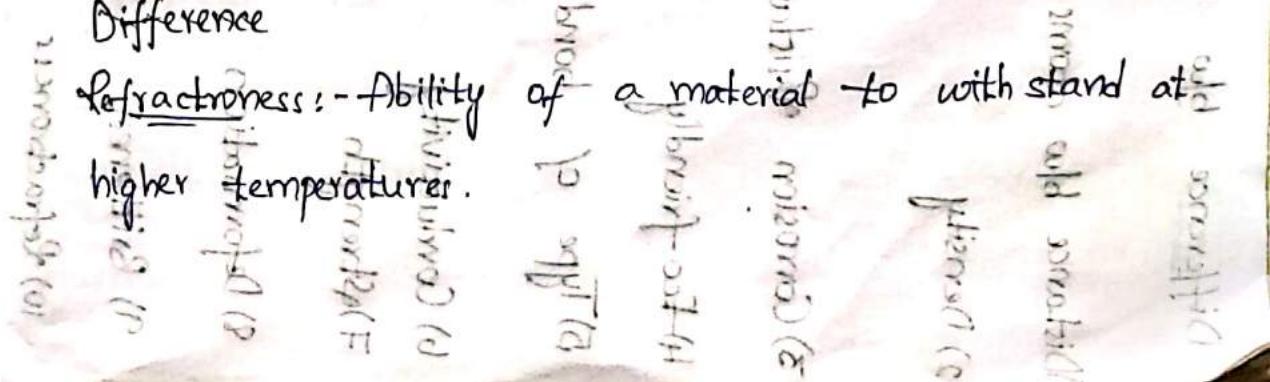
→ In case of composites, we can find elements with naked eye.

→ Alloy comes under a microscopic approach.

→ Composites comes under a macroscopic approach.

Difference

Refractoriness:- Ability of a material to withstand at higher temperatures.



<u>Difference</u>	<u>metals</u> , <u>ceramics</u> , <u>polymers</u> and <u>composites</u> :-
Distance b/w atoms	<u>Ceramics</u> Very less High
2) Density	Less High but compared to metals it is less

<u>metals</u>	<u>Ceramics</u>	<u>Polymers</u>	<u>Composites</u>
Distance b/w atoms	Very less High	High Very less	High Very low
2) Density	Less High but compared to metals it is less	Less Yes	No
3) Corrosion Resistance	Less Yes	Both ionic and covalent bonding	It is a weak bonding
4) Eco-friendly	High (silver, copper)	Less	Less
5) Type of bond	High	High but compared to metals it is slightly less	Very less because of the presence of carbides, nitrides
6) Conductivity	High	Less	High
7) Strength	High	Less	High
8) Deformation	Difficult	Difficult	Easy
9) Brittleness	Very high	Very high	Less

Mechanical Properties:-

- 1) Strength
- 2) Hardness
- 3) Brittleness
- 4) Deformation
- 5) Toughness
- 6) Fracture-toughness
- 7) Creep
- 8) Fatigue
- 9) Resilience
- 10) Proof Resilience
- 11) Stiffness

Strength:- Ability of a material to withstand loads without failure. Measured by Universal Testing Machine(UTM).

i) Tensile strength

ii) Compressive strength

iii) Shear strength (Apply load in transverse direction)

iv) Torsional strength

Hardness:- Ability of a material to withstand deformation, indentation (or) penetration, scratches.

→ Always strength is proportional to hardness.

Hardness measuring equipments:-

1) Rockwell hardness tests

2) Brinell hardness tests

3) Vicker's hardness tests

Brittleness:- It is a failure of material without any deformation in some cases with small deformation under application of.

Ex:- Brittleness - Wood, Glass without any deformation.

Cast iron with small deformations.

→ Strength is also proportional to Brittleness.

Deformation:- Change in shape without loss of material.

Ductility:- Ability of a material to deform under tensile load.

Ex:- Conducting wires.

Malleability:- Ability of a material to deform under compressive loads.

Ex:- Sheet Metal. Hardness is inversely proportional to deformation.

Toughness:- Ability of a material to absorb energy upto failure.

→ Deformation is proportional to Toughness.

Fracture toughness:- It is the ability of a material to absorb energy at the time of fracture (or) failure.

→ Izod (or) Charpy is used to measure fracture toughness.

Creep:- A slow and progressive deformation of a body at constant temperature.

Fatigue:- It is failure of the material due to repeated and reversal loads.

Resilience:- It is ability of a material to absorb energy without any change in shape.

Proof Resilience:- The ability of a material to absorb energy without any change in shape per unit volume.

$$\text{Proof resilience} = \text{Resilience}/\text{unit volume}$$

Stiffness:- Ability of a material to resist deformation.

Space Lattice:-

Atomic arrangement:-

1) Periodic arrangement (Equally spaced & arranged side-by-side).
2) Repetative (Alternative atoms must be same).

Crystal Structure:- It is of both periodic and repetitive arrangements.

Non-crystalline structure:- (or) Amorphous: It is neither periodic nor repetitive.

Quasi crystal structure:- It is having only periodic arrangement of atoms but not repetitive.

Space Lattice:- The periodic arrangement of atoms in a crystalline solid can be described by network of points is called a space lattice.

Definition:- It is a 3 dimensional array of points in which each point must have identical surroundings.

Unit cell:- The smallest part in space lattice is called a unit cell. a, b, c are called lattice parameters. α, β, γ are the angles b/w them.

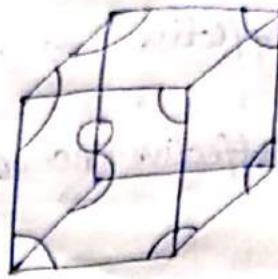
Types of unit cell:- Based on lattice parameters and lattice angles we have seven unit cells:

Name	Lattice Parameters	Lattice angles
1) Cubic	$a=b=c$	$\alpha = \beta = \gamma = 90^\circ$
2) Tetragonal	$a=b \neq c$	$\alpha = \beta = \gamma = 90^\circ$
3) Orthorhombic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ \neq \beta \neq 90^\circ$
4) Monoclinic	$a \neq b \neq c$	$\alpha = \beta \neq 90^\circ \neq \gamma$
5) Rhombohedral	$a=b=c$	$\alpha \neq \beta \neq \gamma$
6) Triclinic	$a \neq b \neq c$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$
7) Hexagonal	$a=b \neq c$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$

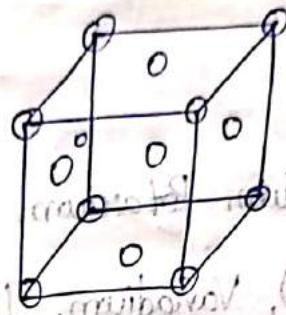
Crystal structure of metals:-

- 1) Simple cubic
 - 2) Body Centered Cubic
 - 3) Face Centred Cubic
 - 4) Hexagonal close Pack (H.C.P)
- i) Position of atoms
 - ii) Effective number of atoms
 - iii) Atomic Packing factor
 - iv) Co-ordination number
 - v) Examples

Position of atoms:-
Body Centered Cubic:-

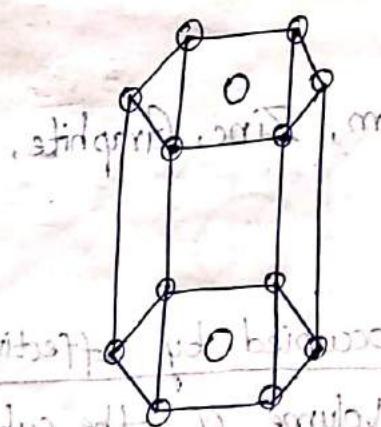


Face centered Cubic:-



Total 6 faces

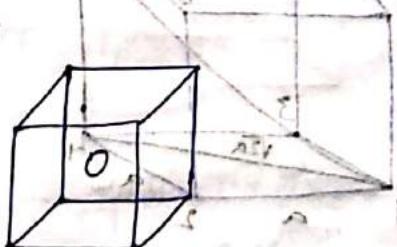
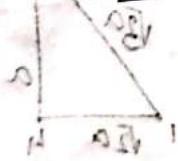
Hexagonal Closed Pack:-



Total 8 faces

Alternative faces have atoms. They are near to centre hence can't be shared.

Simple Cubic:-



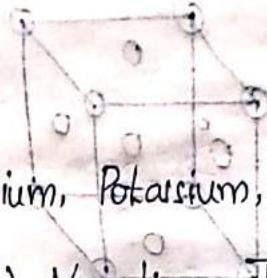
Effective number of atoms:-

For BCC, effective no. of atoms = $8 \times \frac{1}{8} + 1 = 2$.

For FCC, effective no. of atoms = $8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$.

For HCP, effective no. of atoms = $6 \times \frac{1}{6} \times 2 + 2 \times \frac{1}{2} = 6$.

Examples:-



B.C.C:- Ferrous, Chromium, Potassium, Lithium, Molybdenum, Sodium, Nayobium(Nb), Vanadium, Tungsten, Tantalum(Te).

F.C.C:- Ferrous, Aluminium, Silver, Gold, Copper, Nickel, Platinum and Lead.

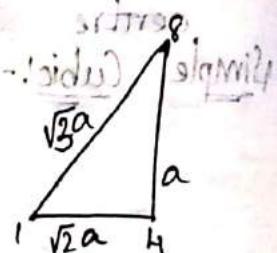
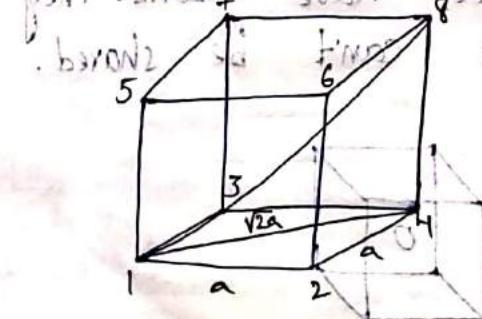
HCP:- Cadmium, Beryllium, Zinc, Graphite.

Atomic Packing Factor:-

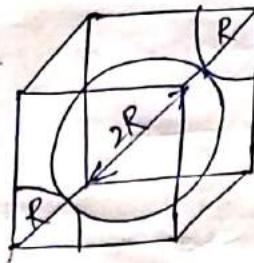
APF = Volume occupied by effective no. of atoms

Volume of the cube

at room temp. most solid state - silicon, Hf

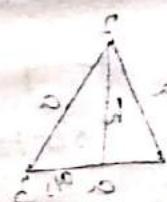


for BCC,



$$\Rightarrow HR = \sqrt{3}a \Rightarrow R = \frac{\sqrt{3}a}{4}$$

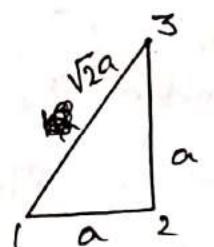
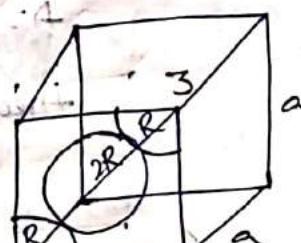
$$APF = \frac{2 \times \frac{4}{3}\pi R^3}{a^3}$$



$$= \frac{2 \times \frac{4}{3}\pi \times \frac{3\sqrt{3}}{16} \times a^3 \times \pi}{a^3} = \frac{2\pi^2 \times \frac{3\sqrt{3}}{16} \times a^3}{a^3} = \frac{3\sqrt{3}\pi^2}{16}$$

$$\therefore APF = \frac{\sqrt{3}\pi^2 a^2}{8} = 0.68$$

for FCC,



$$4R = \sqrt{2}a \Rightarrow R = \frac{\sqrt{2}a}{4}$$

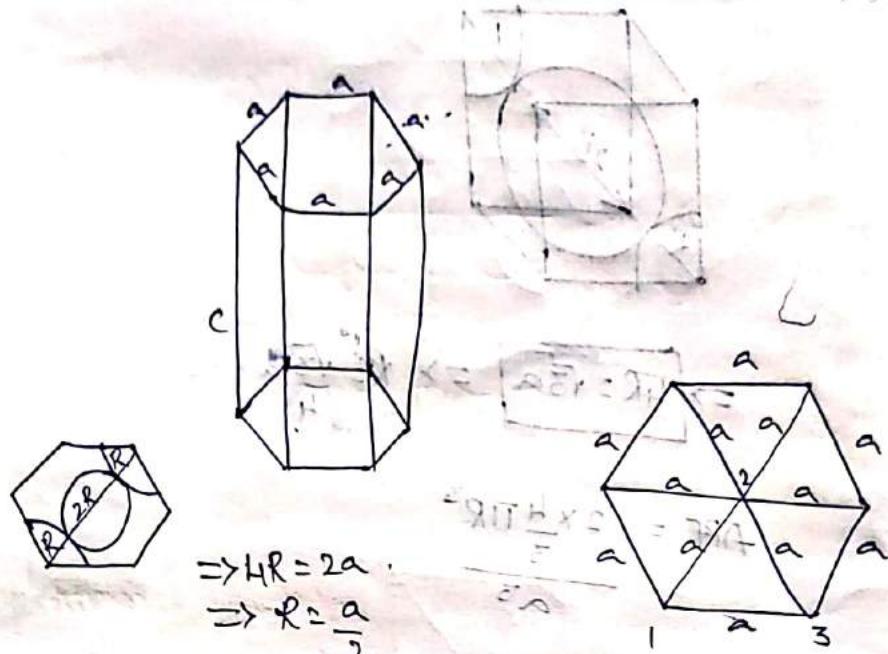


$$APF = \frac{2 \times \frac{4}{3}\pi R^3}{a^3}$$

$$= \frac{2 \times \frac{4}{3}\pi \times \frac{1}{4} \times \frac{2\sqrt{2}}{16} \times a^3}{a^3} = \frac{\sqrt{2}\pi^2}{16}$$

$$\therefore APF = \frac{\sqrt{2}\pi}{16} = 0.74$$

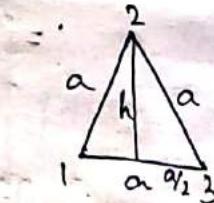
for HCP



$$\text{APF} = \frac{6 \times \frac{4}{3}\pi R^3}{3\sqrt{3}a^3 \times 1.63a}$$

$$= \frac{6 \times \frac{4}{3}\pi \times \frac{a^3}{8}}{\frac{3\sqrt{3}}{2} \times 1.63a^2}$$

$$= 0.74.$$



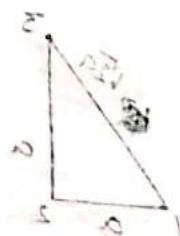
$$\Rightarrow [c = 1.63a]$$

$$A = \frac{1}{2} \times b \times h.$$

$$h^2 = a^2 - \frac{a^2}{4}$$

$$h = \frac{\sqrt{3}}{2}a.$$

$$A = \frac{\sqrt{3}}{4}a^2.$$

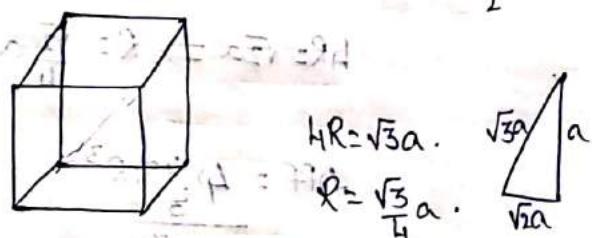


$$\text{Area of hexagon} = 6 \times \frac{\sqrt{3}}{4}a^2.$$

$$= \frac{3\sqrt{3}}{2}a^2.$$

$$\text{Volume} = A \times h = \frac{3\sqrt{3}}{2}a^2 \times c.$$

For simple cubic



$$\text{APF} = \frac{1 \times \frac{4}{3}\pi R^3}{a^3}$$

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

$$= \frac{\sqrt{3}\pi}{16} = 0.34.$$

Co-ordination number:- It is the number of neighbouring atoms for a particular atom. The atom must have a contact bet with all neighbouring atoms.

for BCC, coordination number is 8.

for FCC, coordination number is 12.

for HCP, coordination number is 12.

Defects in crystal structure:-

Defects in crystal structure :-
1) Point (0-D)
2) Line (1-D)

(1) Vacancy

(2) Interstitial

(3) Substitutional

(4) Schottkey defect

(5) Frenkel defect

1) Point (0-D)

2) Line (1-D)

3) Surface (2-D)

4) Volume (3-D)

Vacancy: The missing of atom from its position is known as Vacancy.

→ It is happening due to thermal contraction.

→ It is mostly found in metallic bondings.

Interstitial:- An atom is trapped between interstitial sites.

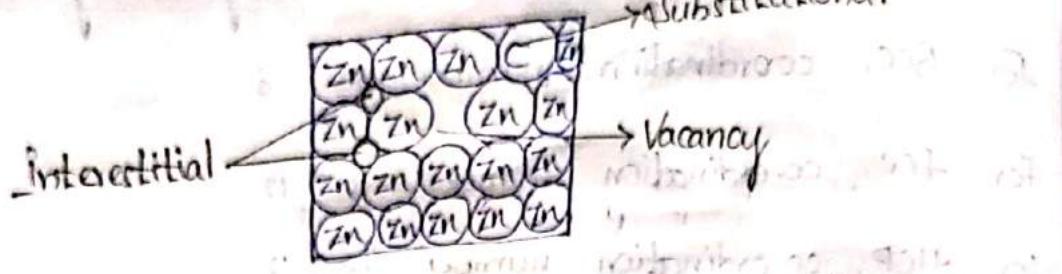
→ It may be of same atom or foreign atom.

→ Due to large diameter of atoms.

→ It is due to low atomic packing factor.

→ It is mostly found in metallic bondings.

Substitutional: It is formed by occupying atomic positions of parent atom.



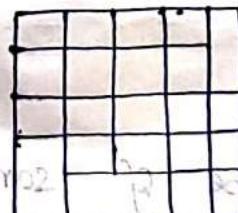
In above three cases there is a change in number of atoms so forces are not balanced. It is happening in metallic bondings.

→ increase of ionic and covalent due to vacancies of atoms, the charge is not neutral.

Schotkey defect: It is a cationic vacancy and anion vacancy. It is always occurred in pair.

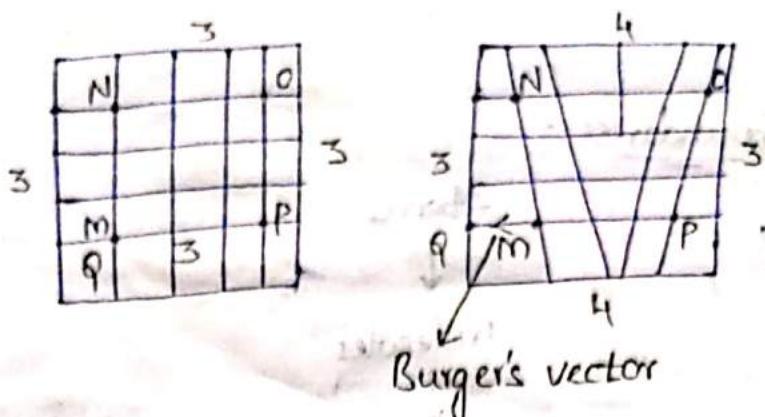
Frankel defect: It is a cation vacancy and cation interstitial.

Line defects: (or) Dislocations: The line imperfections are known as dislocations.



→ Dislocations concept is explained by Burgers' Vector

→ Burgers' vectors explain magnitude and directions of a dislocation.



→ Dislocations are of two types. They are:

1) Edge dislocation.

2) Screw dislocation.

Edge dislocation:- If dislocation is parallel to burger's vector it is called edge dislocation.

Screw dislocation:- If dislocation is perpendicular to burger's vector it is called screw dislocation.

Surface defects (or) plane defects:-

1) Surface defects.

2) Grain boundary.

3) Stacking faults.

Surface Defects:- 1) In FCC the surface atom is having bonding with 12 neighbouring atoms.

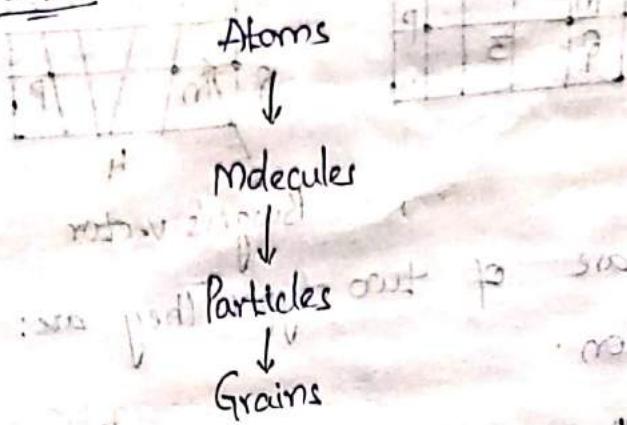
2) If the cell is broken there will be decrease in no. of neighbouring atoms.

3) Decrease in no. of neighbouring atoms causes high surface energy.

4) High surface energy causes change in crystal structure. That is why the substance is named as

defect

Grain boundaries:-



- In general atoms near to grain boundaries have less neighbours compared to atoms which are far away from the grain boundaries.
- Decrease in no. of neighbours cause change in crystal structure.

Types of grains:-

1-grain → Crystal.

More → Polycrystal.

→ Grain is also called as crystal.

Classification based on size of grains:-

1) Fine Grains → High strength material in hard & brittle

2) Medium Grains

3) Coarse Grains → low in strength & ductile

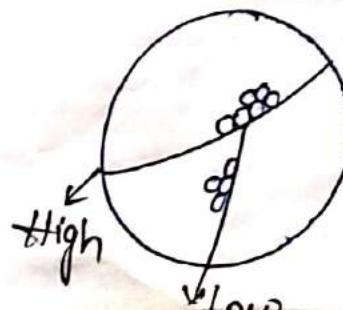
Large in size & soft & ductile

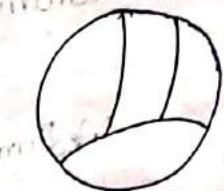
Small in size & hard & brittle

Property	Fine	Medium	Coarse
1) Density	High	Medium	Less
2) Atomic Packing Factor	High	Medium	Less
3) Distance b/w atoms	Less	Medium	High
4) No. of grain boundaries	High	Medium	Less
5) Strength	High	Medium	High Less
6) Hardness	High	Medium	Less
7) Brittleness	Less	Medium	High
8) Ductility	Less	Medium	High
9) Toughness	Less	Medium	High

Types of Grain boundaries:-

- 1) High angle grain boundary.
 - 2) Low angle grain boundary.
 - 3) Twin angle grain boundary.
- In case of high angle grain boundaries it has more neighbours.
- In case of low angle grain boundaries, it has less neighbours.





Twin boundaries

Stacking faults:- The stacking

- ABA -

- ABABABAABABAB

and shift

Stacking fault

→ Defect in stacking sequence is known as stacking

- fault

Volume Defects:- All casting defects are volume defects

Defects in Casting:-

1) Blow hole

2) Blister

3) Scar

4) Porosity

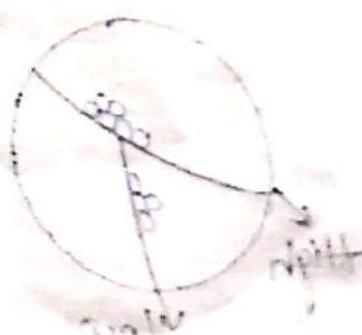
5) Shrinkage Cavity

6) Sand erosion

7) Cold shirt

8) Rat Tail

9) Shift



Grain size measurement :-

1) Comparision method.

2) Henry's Intercept method.

Comparision method (a) ASTM method :-

→ ASTM - American Society for Testing & Materials.

→ This method is used for measurement of equiaxed grains.

→ It is done at 100X.

→ It is done by a software (Material + Software).

$$N = 2^{n-1}$$

N - No. of grains/sq. inch.

n - ASTM number (the number starts from 1).

Suppose if n=3 then $N = 2^{3-1} = 2^2 = 4$ grains/sq. inch.

→ Area of 1 grain = $\frac{1}{4} (\text{inch})^2$

$$= \frac{1}{4} (25.4 \text{ mm})^2$$

$$= 161.29 \text{ mm}^2$$

→ In ASTM measurement each grain is assumed to be circular.

$$\frac{\pi}{4} d^2 = 161.29 \text{ mm}^2$$

$$d^2 = 205.36 \text{ mm}^2$$

$$d = 14.33 \text{ mm} \rightarrow 100X$$

For 1X $\Rightarrow d = 0.143 \text{ mm}$.

1. Find the grain size in diameter for ASTM number 9 at 100x.

$$\text{Sol. } n = 9.$$

$$N = 2^{n-1} = 2^8 = 256 \text{ grains/inch}^2$$

$$\text{Area} = \frac{1}{256} (25.4)$$

$$\frac{\pi}{4} d^2 = 2.52 \text{ mm}^2$$

$$d^2 = 3.20 \text{ mm}^2$$

$$d = 1.78 \text{ mm}$$

Teney's Intercept Method :- This method is only for non-equiaxed grains. It is done at 100x. → It is done manually and sometime it is done by software also (Material + Software).



$$\text{Total length} = l_1 + l_2 + \dots + l_9.$$

$$= 1.1 + 1.6 + 1.9 + 2.1 + 2.0 + 1.9 + 1.5 + 1.0$$

$$= 14.9.$$

$$\text{Intersecting Lines} = 15$$

$$\text{Grain size} = \frac{\text{Total length}}{\text{Intersecting points}}$$

$$= \frac{14.9}{15} = 0.99 \text{ cm.}$$

Phase:- A phase is nothing but chemically homogeneous and physically distinct and mechanically separable.

Homogeneous:- It is of same composition throughout the substance.

Ex:- Pure water, sugar or salt water, Brass (90% Cu + 10% Zn).

Non-Homogeneous:

Ex:- Water + Oil, impure water.

Distinct:- Looking different

Ex:- Water + Oil, Concrete.

Separable:

Ex:- Water + Oil, Milk + water - Separable by Swan.

Component:

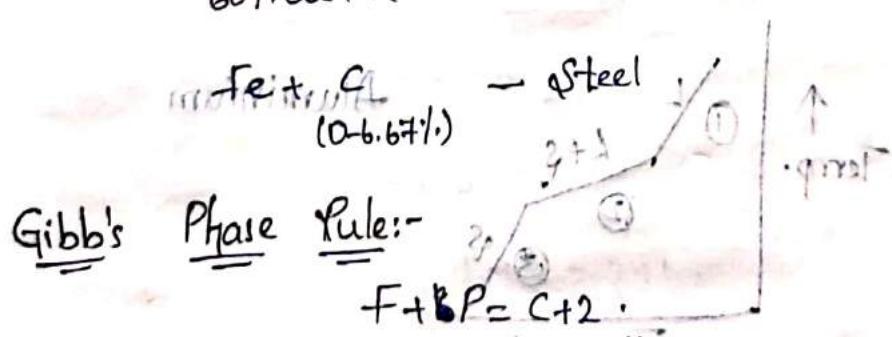
Variables:

1) Thermodynamic Variable.

2) Composition Variable.

70% Cu + 30% Zn.

60% Cu + 40% Zn - Dutch metal.



P - No. of phases.

C - No. of components.

2 - No. of Variables (Pressure, Temperature).

$$F + P = C + I \quad (\text{Assuming pressure}$$

1 - Temperature is variable.

f - Degrees of freedom.

Degrees of Freedom: Number of variables which can be changed to maintain the system in equilibrium.

Equilibrium:

1) No change in phase.

Ex: - Water at 30°C & 90°C .

2) No change in position. (Static equilibrium).

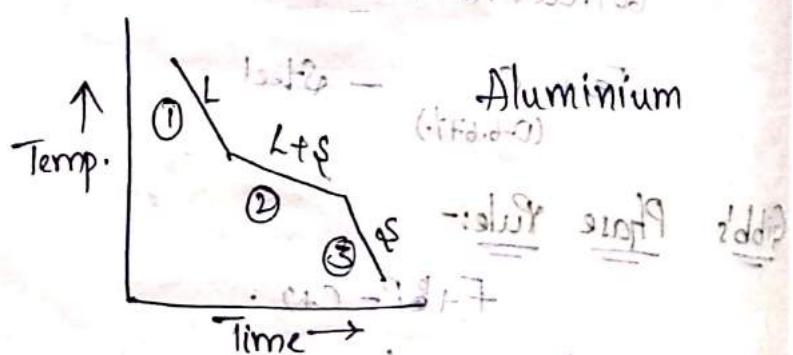
3) Moving with same speed (or) velocity (Dynamic equilibrium).

→ A body in space has 6 DOF.

→ Man has 3 DOF.

Cooling curves of pure metals & alloys:

Cooling curves for pure metals:



$$\textcircled{1} \rightarrow F + P = C + I$$

$$F + I = I + I$$

$$F = 2 - 1 = 1$$

$$\textcircled{1} \Rightarrow F + P = C + I$$

$$F + 2 = 1 + 1$$

$$F = 0$$

$$\textcircled{2} \Rightarrow F + P = C + I$$

$$F + 1 = 1 + 1$$

$$F = 1$$

Cooling

Curves for alloys :-

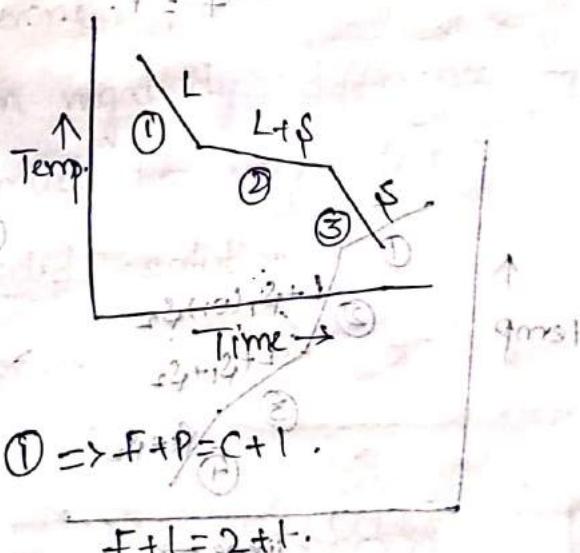
Alloy \rightarrow Normal

Alloy \rightarrow Utectic (Nice melting)

Alloy \rightarrow Off-utectic

Normal alloy :-

Brass \rightarrow Cu + Zn



$$\textcircled{1} \Rightarrow F + P = C + I$$

$$F + 1 = 2 + 1$$

$$\textcircled{2} \Rightarrow F + P = C + I$$

$$F + 2 = 2 + 1$$

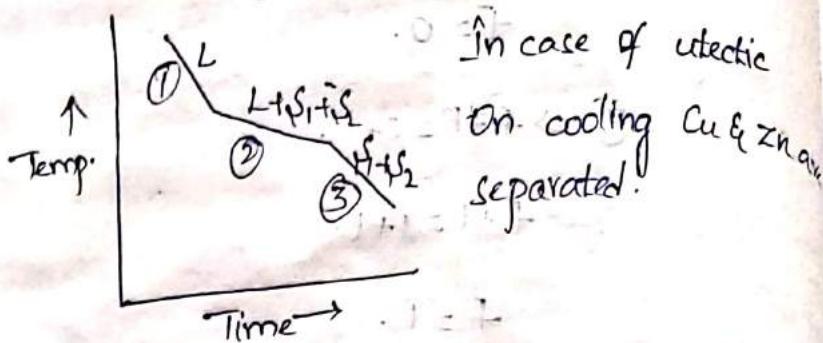
$$\textcircled{3} \Rightarrow F + P = C + I$$

$$F + 1 = 2 + 1$$

$$F = 2$$

Ulectic alloy:-

Brass \rightarrow Cu + Zn.



$$\textcircled{1} \Rightarrow f+P = C+I \quad \textcircled{1} \Rightarrow f+P = C+I$$

$$f+I = 2+1 \quad \therefore f+P = C+I \quad f+3 = 2+1.$$

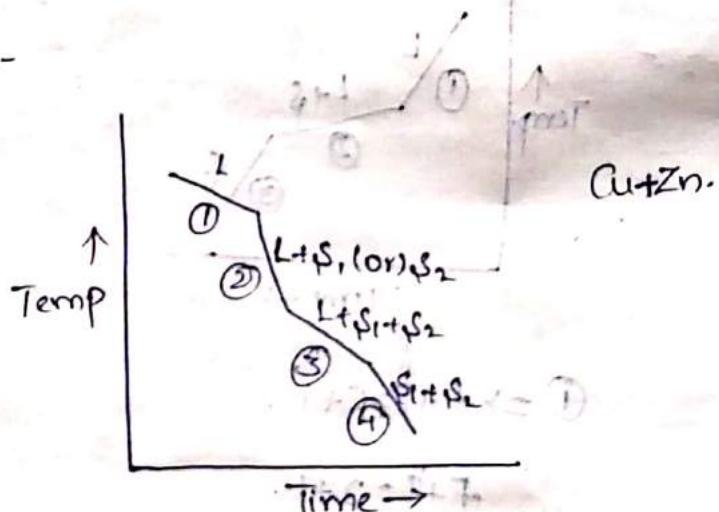
$$f = 2 \quad \text{f} = 0 \quad f = 1.$$

$$\textcircled{3} \Rightarrow f+P = C+I :$$

$$f+2 = 2+1. \quad \therefore \text{f} = 0 \quad \text{f} = 1.$$

$$f = 1.$$

Off - Ulectic:-



$$\textcircled{1} \Rightarrow f+P = C+I. \quad \textcircled{2} \Rightarrow f+P = C+I.$$

$$f+1 = 2+1. \quad f+2 = 2+1.$$

$$f = 2. \quad f = 1.$$

$$\textcircled{3} \Rightarrow f+P = C+I. \quad \textcircled{4} \Rightarrow f+P = C+I.$$

$$f+3 = 2+1. \quad f+2 = 2+1.$$

$$f = 0. \quad f = 1.$$

Solid solution:- It is an alloy formed when atoms of solute are uniformly dissolved in atoms of solid.

Ex:- Sugar + Water, Water + Salt, Brass, Bronze, etc.

Hume-Rothery's Rules of solid solubility (H-R Rules):-

1) Atomic size factor:- The size difference b/w solute and solvent must be less than 15%.

2) Crystal structure:- The structures of solute and solvent must be same.

3) Solubility:- Both solute and solvent must have high solubility.

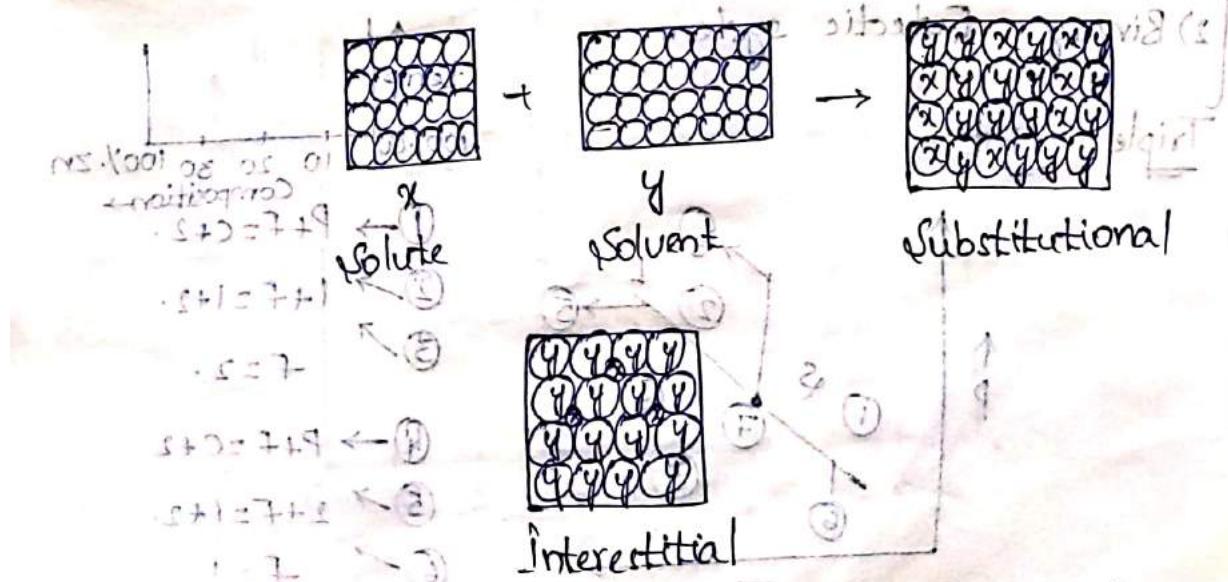
4) Electron Negativity:- The tendency of attracting valence electrons from the outermost orbit.

The electron negativity difference of solute and solvent must be very less.

Types of solid solution:-

1) Substitutional.

2) Interstitial.



→ Interstitial has high strength when compared to

substitutional due to the presence of centre atom.

Intermediate phase: After reaching the solubility limit of a solution if extra amount of solute again added then the solubility doesn't occur instead it forms another phase called as intermediate phase.
Ex:- Fe-C.

Phase diagrams: which indicates phase exists in a system at any temperature & composition.

Types:- 1) Unary P.D. (single component)

2) Binary P.D. (2 components)

3) Ternary P.D. (3 components)

1) Unary P.D.:- Explains behaviour of single component at different temperatures.

Ex:- Component = water.

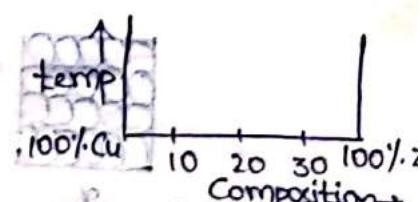
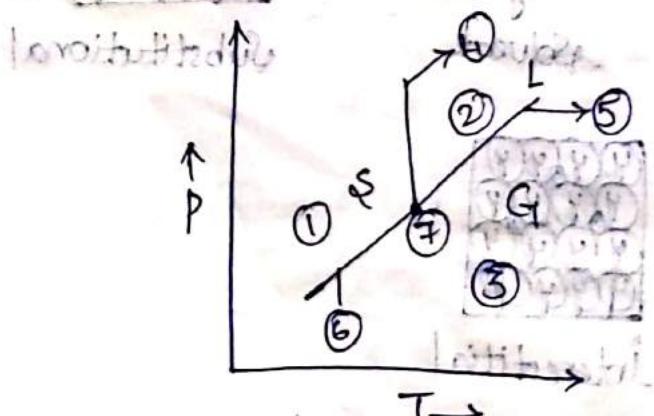
2) Binary P.D.:-

Types of Binary diagrams:-

1) Binary Isomorphous system.

2) Binary Eutectic system.

Triple point:-



$$\textcircled{1} \rightarrow P + F = C + 2.$$

$$\textcircled{2} \rightarrow I + F = I + 2.$$

$$\textcircled{3} \rightarrow F = 2.$$

$$\textcircled{4} \rightarrow P + F = C + 2$$

$$\textcircled{5} \rightarrow I + F = I + 2.$$

$$\textcircled{6} \rightarrow F = 1.$$

$$\textcircled{7} \rightarrow P + F = C + 2$$

i) Binary Isomorphous:-

Binary Isomorphous Diagram:

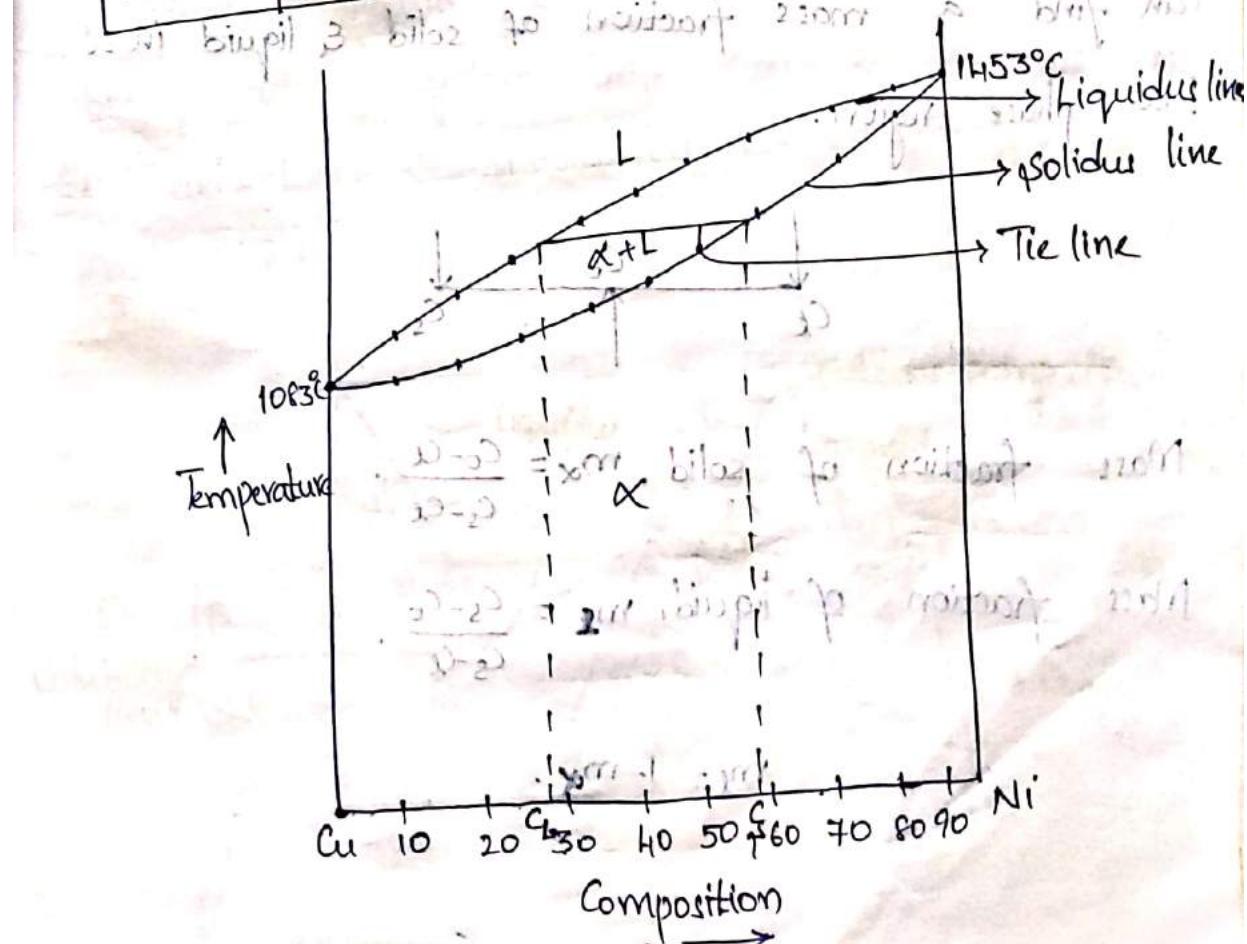
Binary Isomorphous Alloy:- If two metals having complete solubility in liquid as well as in solid is known as Isomorphous Alloy.

Ex:- Cu-Ni, Au-Cu, Au-Ag, Au-Ni, Mo-V, Mo-W, Mo-Ti,

Ti-W.

Construction of an Isomorphous Diagram:-

Metal	100	20	30	40	50	60	70	80	90	100	
% of Cu	100	90	80	70	60	50	40	30	20	10	0
% of Ni	0	10	20	30	40	50	60	70	80	90	100



Solidus Line:- Which separates a two phase region and solid region.

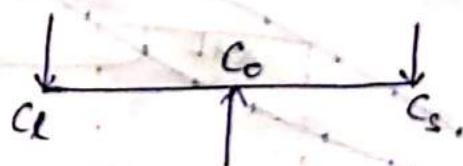
Liquidus Line:- Which separates a two phase region and liquid region.

1) Tie line.

2) Lever rule.

Tie Line:- It is a constant temperature line which is drawn in two phase region. The ends of tie line is giving the composition of solid and composition of liquid.

Lever rule:- By using this we can find amount of phases present in the two phase region (or) we can find a mass fraction of solid & liquid in a two phase region.



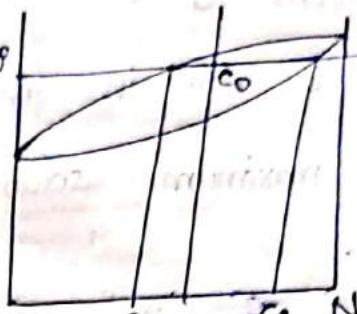
$$\text{Mass fraction of solid, } m_s = \frac{c_0 - c_L}{c_S - c_L}.$$

$$\text{Mass fraction of liquid, } m_L = \frac{c_S - c_0}{c_S - c_L}.$$

$$m_L = 1 - m_s.$$

1. Find the mass fraction of solid & liquid for 53% Ni at 1380°C.

At 1380°C, for 53% of Ni the 1380°C composition of solid is 58% of Ni, composition of liquid is 45% of Ni.



$$Co = 53$$

$$Cs = 58$$

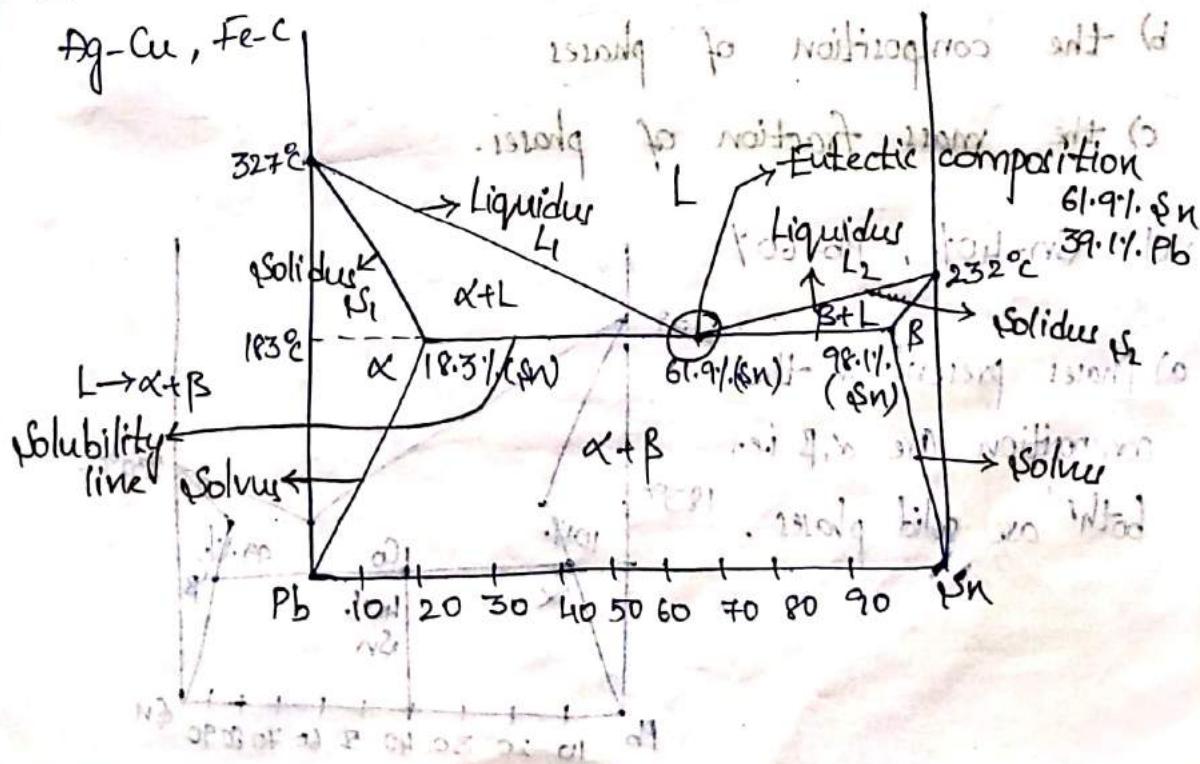
$$Cl = 45$$

$$\text{So, } m_L = \frac{Co - Cl}{Cs - Cl} = \frac{53 - 45}{58 - 45} = 0.615 \times 100 = 61.5\%$$

$$m_s = \frac{Cs - Co}{Cs - Cl} = \frac{58 - 53}{58 - 45} = 0.384 \times 100 = 38.4\%$$

Binary Eutectic System: If two metals are completely soluble in liquid but not in solid is called the binary eutectic system. Ex:- Sn-Tin, Bi-Bismuth, Cd-Cd-Zn, Al-Si, Au-Si.

Ex:- Lead-tin, Sn-Bismuth, Cd-Cd-Zn, Al-Si, Au-Si.



α :- It is the solid solution of tin in lead. The solvent is lead & tin is solute.

→ α is rich in lead.

→ The maximum solubility of tin in lead is 18.3% at 183°C.

β :- It is the solid solution of lead in tin. The solvent is tin & lead is solute.

→ β is rich in tin.

→ The maximum solubility of lead in tin is 1.9% at 183°C.

Solus Line :- Which separates single phase region from two phase region in which the two phases must be in equilibrium with each other.

i. For 40% Sn at 150°C find

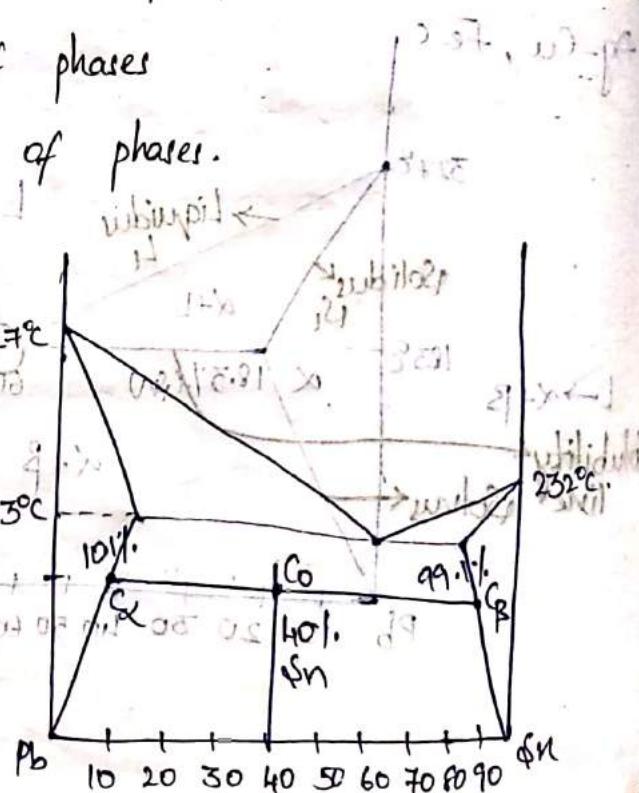
a) phases present in the composition, 40% Sn - 60% Pb

b) the composition of phases

c) the mass fraction of phases.

Soln:- Sn-40%, Pb-60%

a) Phases present in the composition are α, β i.e., both are solid phases.



b) Given that 10.1% of So and 99.1% of Sn
 $c_S = 10.1\% \text{ or } c_S = 99.1\% \text{ mol/L}$

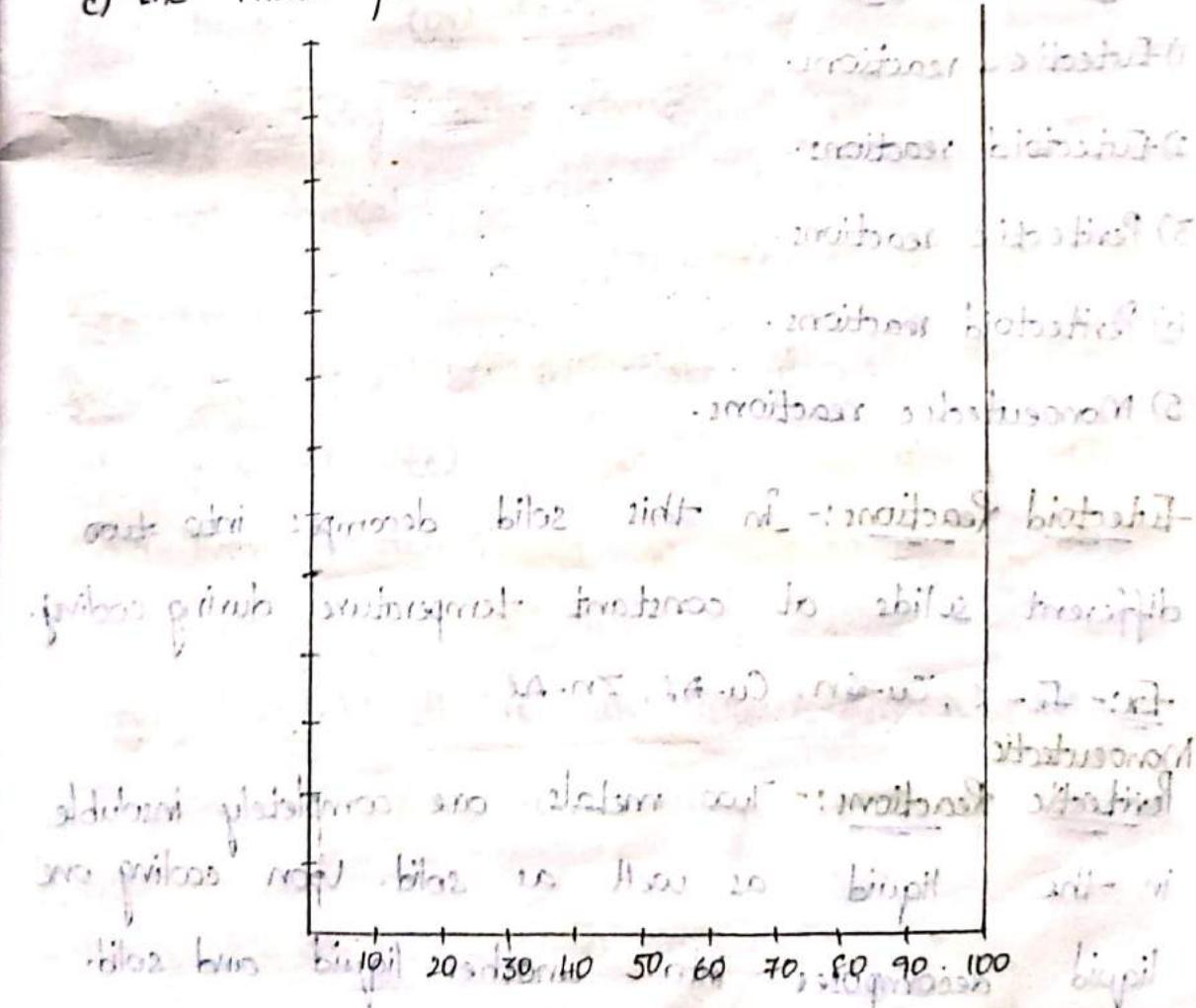
$$\begin{aligned}
 c) \quad m_A &= \frac{-C_B + C_D}{C_B - C_D} \quad m_B = \frac{C_A - C_D}{C_B - C_D} \\
 &= \frac{-40 + 10}{99.1 - 10.1} \quad = \frac{40 - 10}{99.1 - 10.1} \\
 &= \frac{-30}{89} \quad = \frac{30}{89} \\
 &= -0.33\% \quad = 0.33\% \\
 &= -33.33 \quad = 33.33
 \end{aligned}$$

2. For 40% of Nickel at 1300°C

a) phases present in the composition

b) the composition of phases.

c) the mass fraction of phases:



Invariant reactions :- ~~going to moisten salt~~

1) Eutectic reactions.

2) Eutectoid reactions.

3) Peritectic reactions.

4) Peritectoid reactions.

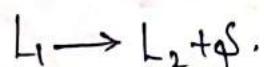
5) Monoeutectic reactions.

Eutectoid reactions :- In this solid decomposes into two different solids at constant temperature during cooling

Ex:- Fe-C, Cu-Sn, Cu-Al, Zn-Al.

Monoeutectic

Peritectic Reactions :- Two metals are completely insoluble in the liquid as well as solid. Upon cooling one liquid decomposes into another liquid and solid.



Ex:- Fe-C, Cu-Zn, Pb-Ag, Cu-Sn, Al-Ti, Al-Mn.

Ex:- Al-Pb, Cu-Pb, Zn-Pb, Al-Cr, Ni-Ag, Zn-Bi.

Peritectic Reactions:- Upon cooling one liquid is mixed with solid and forms a new solid.



Ex:- Al-Ti, Al-Mn, Fe-C, Cu-Zn, Pb-Ag, Cu-Sn.

Peritectoid Reactions:- In this one solid mixed with another solid and form a new solid.



Ex:- Ni-Zn, Cu-Sn, Ni-Mo, Fe-Nb.

Fe-C Diagram:- (or) Fe-Fe₃C binary phase diagram:

Allotropy:- Having same chemical composition but

different physical properties.

Ex:- Fe, C, Co, Ti, Ca, Li, Th;

Iron:- Iron can be in three forms

1) α -Iron (Ferrite)

2) γ -Iron (Austenite)

3) δ -Iron

α -Iron (Ferrite):- It is an interstitial solid solution of carbon in BCC iron. Melting point of iron is 1539°C.

→ It is stable from 0-910°C.

→ The solubility of carbon in α -iron at room temperature is 0.02%.

→ The maximum solubility of carbon in α-iron is 0.02% at 723°C .

→ It is magnetic in nature.

→ It is hard and brittle.

γ-iron (Fuselite):- It is an interstitial solid solution of carbon in FCC iron.

→ It is stable from 910 - 1140°C in case of pure iron.

→ It is stable from 723 - 1494°C in case of alloyed iron.

→ It is very soft and ductile.

→ The maximum solubility of carbon in γ-iron is 2.0% at 910°C .

→ It is non-magnetic in nature.

δ-iron:- It is very similar to α-iron.

→ The maximum solubility of carbon in δ-iron is 0.1% at 1494°C .

→ It is stable from 1410 - 1539°C .

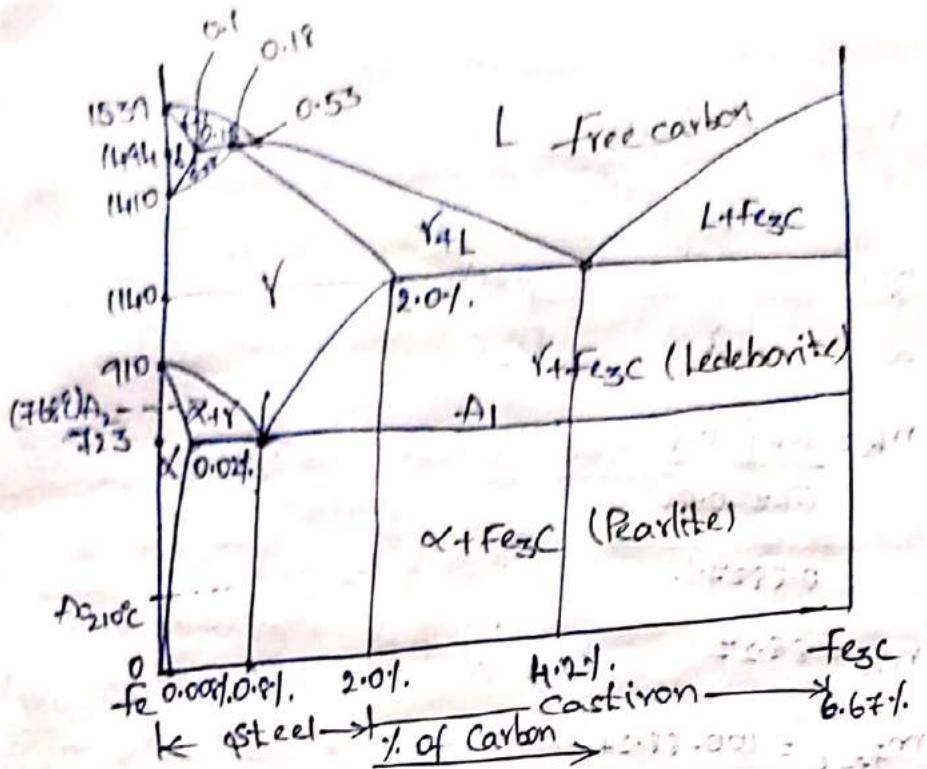
→ It is non-magnetic in nature.

→ It has low density compared to α-iron.

→ It has high ductility compared to α-iron.

→ It has high malleability compared to α-iron.

→ It has high impact strength compared to α-iron.



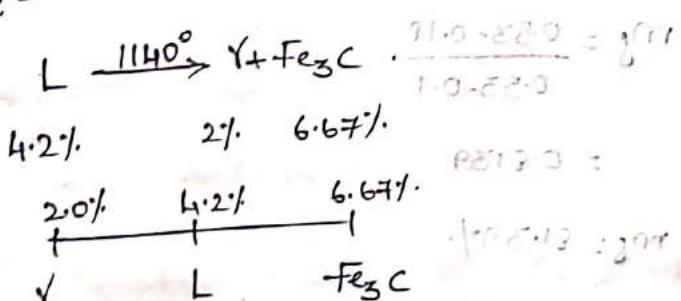
Types of reactions in Fe-C diagram:

1) Eutectic

2) Eutectoid

3) Peritectic

Eutectic:-



$$m_Y = \frac{6.67 - 4.2}{6.67 - 2.0}$$

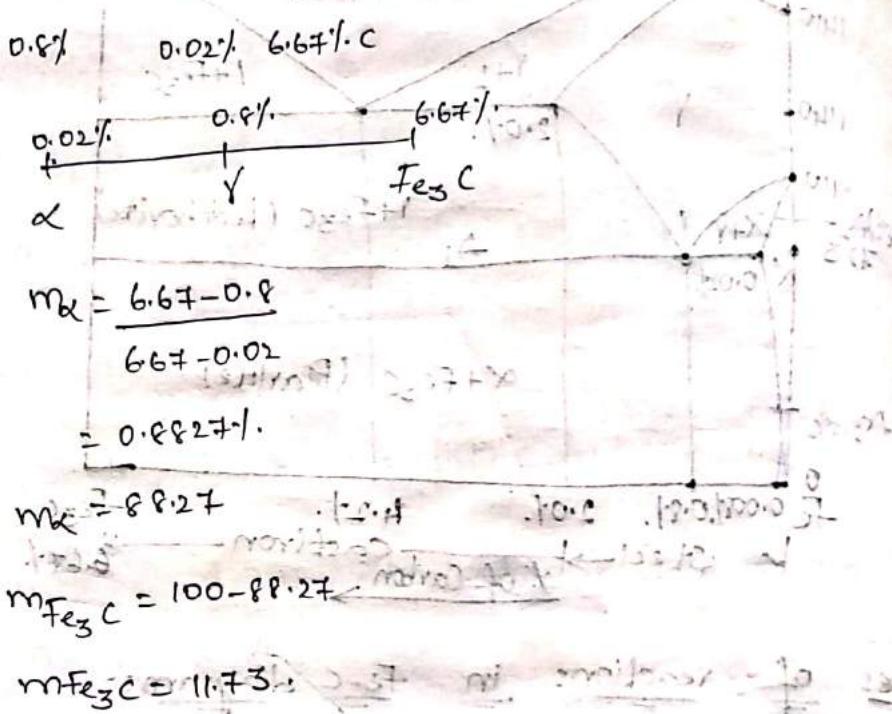
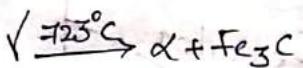
In water $\approx 0.5289\%$ (in H number part)

$$m_Y = 52.89\% \quad \text{in water}$$

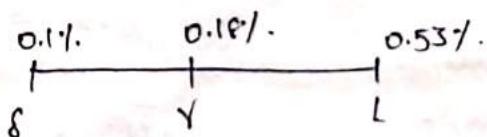
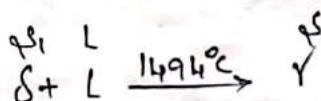
$$Fe_3C = 100 - 52.89\% \quad (99.99\% - 52.89\%) = 47.11\%$$

$$= 47.11\% \quad (99.99\% - 52.89\%) = 47.11\%$$

Eutectoid:-



Peritectic:-



$$m_\delta = \frac{0.53 - 0.1}{0.53 - 0.1} = 0.8139$$

$$m_\delta = 81.39\%$$

$$m_L = 100 - 81.39\% = 18.61\%$$

$$= 18.61\%$$

Critical temperature:- It is the temperature at which phase change occurs.

A_0 - ($210^\circ C$), A_1 - ($723^\circ C$), A_2 - ($768^\circ C$), A_3 ($723 - 910^\circ C$).

A_{cm} - ($723 - 1140^\circ C$), A_4 - ($749^\circ C$) ($1140 - 1494^\circ C$).

Steel:- It is an alloy of iron and carbon.

Cast iron:- It is also an alloy of iron and carbon.

→ In steel the carbon percentage ranges from 0.2%.

→ In cast iron, the carbon percentage ranges from 2-6.67%.

$$\% \text{ of solubility} = \frac{\text{Atomic wt.}}{\text{Composition of solute}} \times \frac{\text{Atomic wt.}}{\text{Total composition of substance}}$$

Free carbon:- The carbon which does not dissolve in iron above 6.67% of carbon.

Types of steel:-

1) Hypo (0-0.8) - Hypo Eutectoid steel.

2) Hyper (0.8-2) - Hyper Eutectoid steel.

Types of Cast iron:-

1) Hypo Eutectic cast iron (2-4.2%).

2) Hyper Eutectic cast iron (4.2-6.67%).

Ao:- It is also known as Curie temperature of cementite.

Paramagnetic:- Paramagnetic substances get feble (or) weak magnetism when placed in magnetic field.

Ex:- Diamond, Mercury, Water.

Ferromagnetic:- Ferromagnetic substances get strong magnetism when placed in magnetic field.

Ex:- Fe, Co, Ni.

Curie Temperature: - The temperature at which ferromagnetic becomes paramagnetic.

A₁ temperature: - It is Curie temperature of ferrite.

A₂ temperature: - It is the lower critical temperature. It is the temperature at which eutectoid reaction takes place. It is also known as eutectoid temperature.

A₃ temperature: - It is the upper critical temperature of ferrite. It is the temperature at which the last traces of α' completely dissolves into γ .

A₄ temperature: - It is the upper critical temperature of cementite. It is the temperature at which the last traces of cementite completely dissolves into γ .

A₅ temperature: - It is the temperature at which the last traces of δ completely dissolves into γ . It is the peritectic temperature.

Effect of alloying elements on Fe-C diagram

(on) steel: -

Stabilizers: - Two types: 1) α (Ferrite), 2) γ (Austenite), bainite

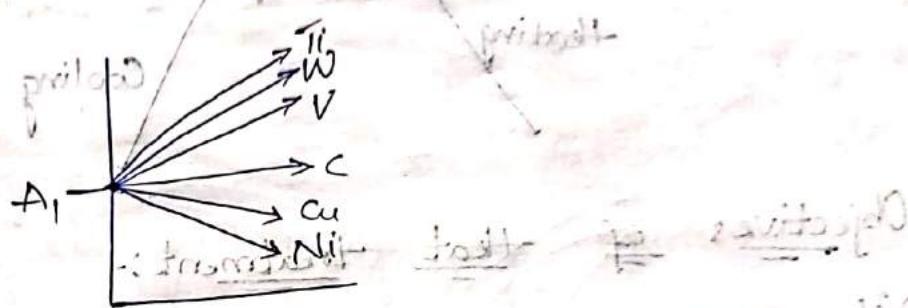
α -Stabilizers: - Which stabilizes ferritic phase.

Ex:- Cr, Si, V, W, Mo, Ti.

γ -stabilizers:- Which stabilizes austenitic phase.

Ex:- Mn, Ni, Cu, C.

Shifting of critical temperatures :- By adding γ -stabilizers to the Fe-C diagram which lowers the critical temperature. By adding α -stabilizers to the Fe-C diagram which raises the critical temperature.



Shifting of Carbon composition:

Al, B, Co, S, P, V, W, Mo, Ti, Cr, Ni, Mn, Cu, Si

shifting occurs in 3 stages

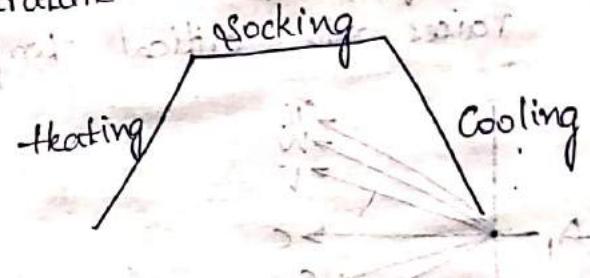
1. If radius of solute atom \rightarrow radius of iron atom
then solubility limit is less than that of pure iron

2. If radius of solute atom \rightarrow radius of iron atom
then solubility limit is greater than that of pure iron

3. Heat Treatment of Steels

Hea

Heat Treatment:- Heating the material to certain temperatures, is defined keeping the material at some temperature and cool back the material to room temperature is known as heat treatment.



Objectives of Heat Treatment:-

- 1) It improves strength & hardness of the material.
- 2) To soften the material which is hard.
- 3) It improves corrosion resistance & wear resistance.
- 4) It eliminates internal stresses which are formed during welding.
- 5) The main function of heat treatment is to adjust mechanical, physical & chemical properties and so on.
- 6) It increases & decreases grain size.
- 7) To change the chemical composition of a material.
- 8) By inducing some elements like carbon, nitrogen on the metal surface which improves case harder.

Heat treatment of steel:-

Heating temperature - above γ -temperature (723°C - 1410°C)

Socking time - 30min- 14hrs.

Cooling Media - Air, water, salt bath, oils.

Stainless steel:- If any steel is having more than 13% Cr is called a stainless steel.

→ During heating of a steel to Austenitic temperature, all alloying elements are dissolved completely

→ Socking is to get homogeneous structure.

Types of cooling:-

1) slow cooling → Coarse grains (Ductility, Toughness)

2) Medium cooling → Medium grains

3) Fast cooling (or) sudden cooling (or) Quenching cooling.

↓
Fine grains (Hardness, strength)

Furnace cooling:- The cooling that takes place when the furnace is turned off to achieve slow cooling is known as furnace cooling.

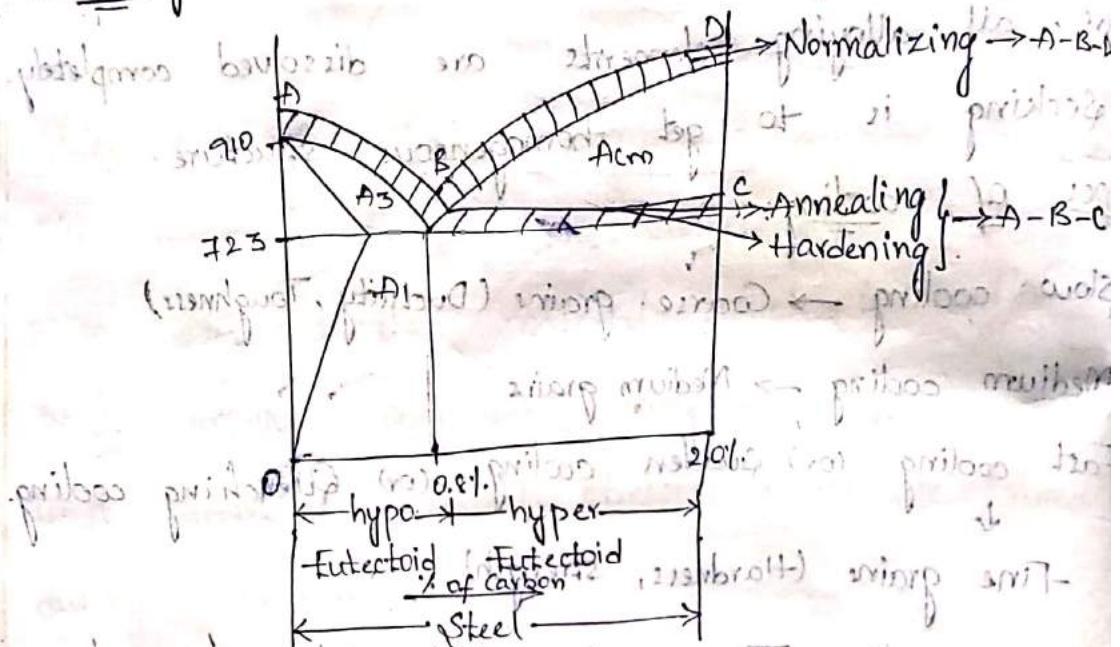
Medium (or) Air cooling:- The furnace is switched off & then exposed to air.

Quenching (or) Liquid cooling:- The furnace is switched off & then the specimen is dropped in water.

Types of heat treatment of steels:-

- 1) Annealing }
 2) Normalizing }
 3) Hardening }
 4) Tempering → Secondary Heat treatment
 → At higher heat treatment

Annealing: Removal of heat to prevent grain



Process:- Heating the steel above A_3 ($10-15^\circ$) in case of

hypo eutectoid steel and heating above A_1 in case

hyper eutectoid steels. Soaking for sometime depending

upon the properties of the steel. Cooling inside the

furnace is achieved.

Objective: 1) The main objective of Annealing is to improve

Machinability in steels.

2) To eliminate (or) remove internal stresses.

- 3) To soften the material.
- 4) To improve ductility and toughness.
- 5) Grain size is modified.

Re-crystallization temperature: - It is the temperature at which new grains are formed.

For steels the re-crystallization temperature is $500\text{--}700^\circ\text{C}$ depending upon % of carbon.

Drawbacks:

1) Less strength and hardness.

2) It takes more time.

Advantages: - The metal is having less failure.

Normalizing:

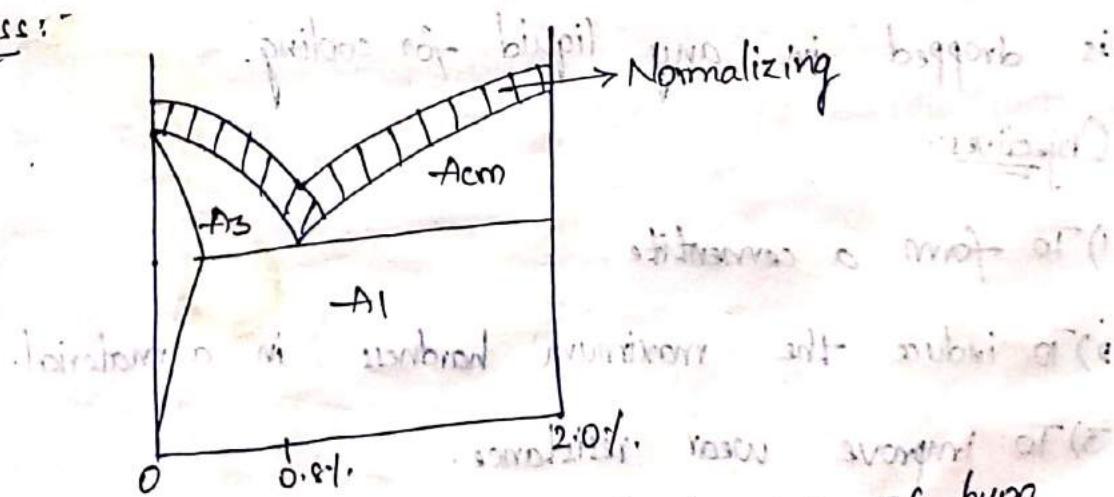
Objective:

1) Induce a little hardness in ductile material.

2) To reduce processing time.

3) To eliminate a cementite formation.

Process:



Heating the steel above $A_1(10\text{--}15^\circ\text{C})$ in case of hypo eutectoid steel as same as Annealing and heating

above A_{cm} in case of hyper eutectoid steel.

→ Cementite is extremely hard & brittle.

→ Soaking at constant temperature for some time and then switch off the furnace and the specimen is kept in atmosphere for cooling.

Difference b/w Annealing & Normalizing:-

→ In normalizing ductility & toughness are less compared to Annealing.

→ In normalizing hardness is more compared to Annealing.

→ In normalizing grain size is less compared to Annealing.

→ In normalizing brittleness is more compared to Annealing.

Hardening:-

Process:- Heating above A_3 ($500^\circ C$) in case of hypo eutectoid steels and heating above A_1 in case of hyper eutectoid steels. Soaking at constant temperature for some time and then switch off the furnace and the specimen is dropped in any liquid for cooling.

Objectives:-

1) To form a cementite.

2) To induce the maximum hardness in a material.

3) To improve wear resistance.

4) To get Martensitic structure (hardest phase in steel).

Drawbacks:-

- 1) Less ductility, toughness, Machinability.
- 2) High brittleness.
- 3) Internal stresses are generated.
- 4) It is retained Austenite.

Due to fast cooling (or) Quenching some Austenite present in the Martensite.

Tempering:- Tempering is always done after hardening.

Because.

- 1) To induce some ductility & toughness in the hardened material.
- 2) To eliminate retained Austenite.

Process:- Heating the hardened specimen to certain temperature then soaking to some time and then cooling is to be done in the presence of air.

Types of tempering based on temperature of heating:

- 1) High temperature tempering ($550^{\circ}\text{C} - 650^{\circ}\text{C}$) \rightarrow High ductility
 \hookrightarrow (Sorbite)
- 2) Low temperature tempering ($250^{\circ}\text{C} - 450^{\circ}\text{C}$) \rightarrow Low ductility
 \downarrow
(Troostite)

Types of Annealing:-

- 1) Full annealing
- 2) Isothermal annealing
- 3) Spheroidal annealing
- 4) Process annealing

Time Temperature Transforming Curve (TTT-Curve):-

Types of Transformations:-

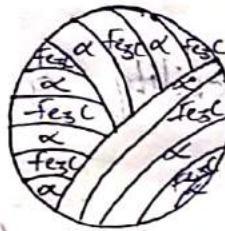
1) Pearlitic Transformation

2) Bainitic Transformation

3) Martensitic Transformation

Pearlitic Transformation:- If the steel is slowly cooled from Austenitic temperature then Pearlite is formed.

→ It is soft & ductile.



$\alpha + \text{Fe}_3\text{C}$

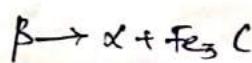
Iron-carbon eutectoid

→ The structure of Pearlite consists alternative layers of α & Fe_3C .

→ Pure Pearlite consists 98% of α , & 12% of Fe_3C .

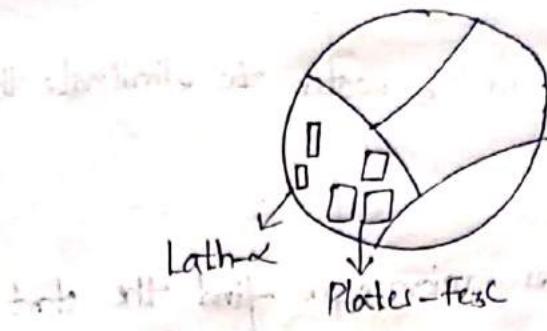
Bainitic Transformation:- Fast cooling of steel from Austenitic temperature then Bainite is formed. Fast means faster than Pearlitic Transformation.

→ It is also the combination of α & Fe_3C .



→ somewhat harder than pearlite.

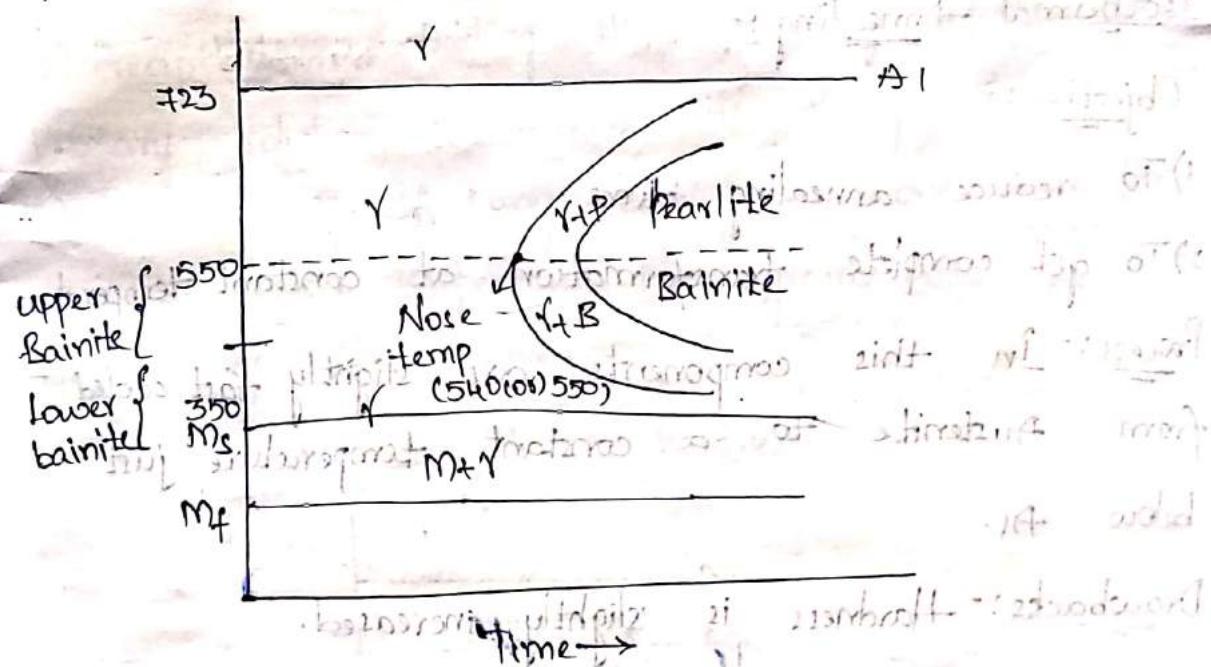
→ Structure will be in lathes & plates.



Types of Bainite:

- 1) Upper Bainite ($350\text{--}550^\circ\text{C}$)
- 2) Lower Bainite ($<350^\circ\text{C}$)

Martensitic Transformation: - The steel is suddenly cooled from Austenitic Temperature, Martensite is formed.



Construction of TTT-Diagram:

- Procedure:-
- heat 'N' no. of samples above A_1 temperature.
 - cool all samples to get homogeneous Austenite.
 - Quench the samples in salt bath kept in another furnace at a constant temperature b/w M_s & A_1 .
 - Then remove the samples one by one with a

fixed interval of time.

→ Then quench the sample in a water to eliminate the retained Austenite.

→ Observe all samples under microscope find the start of transformation and end of transformation.

→ Repeat the same experiment for 'n' number of times at a constant temperature below A_1 & M_s .

Type of Annealing:-

Full Annealing:- It is same as Annealing.

Isothermal Annealing:-

Objective:-

1) To reduce annealing time.

2) To get complete transformation at constant temperature.

Process:- In this components are slightly fast cooled from Austenite to a constant temperature just below A_1 .

Drawbacks:- Hardness is slightly increased.

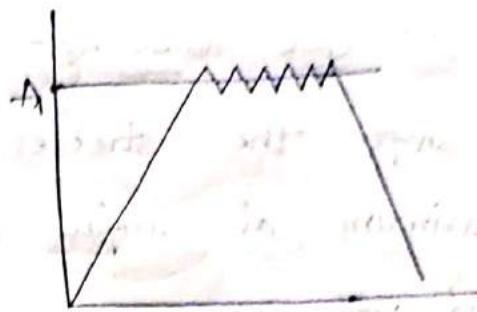
Spheroidal Annealing:-

Objective:- To improve machinability in high carbon steel.

Process:-

1) Heating (650-750)

2) After heating the thermal cycling around A_1 in a narrow temperature range.



→ Carbon in the shape of blades (or) plates that have to convert in a sphere then the machinability will be increased.

Process Annealing:-

Strengthening technique:-

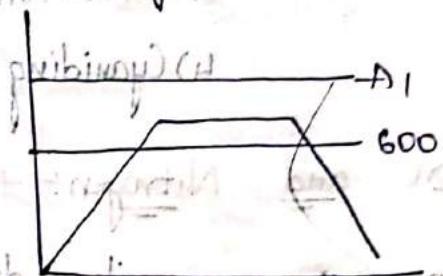
1) Heat treatment.

2) Precipitation:- Adding the secondary solution in a primary solution to increase its strength.

3) Cold working:- If any working is done below the recrystallization temperature. New grains are not formed.

Effects of cold working:-

→ To improve strength & hardness.



Case hardening (or) Surface hardening:-

1) Carburising.

2) Nitriding.

3) Cyaniding.

4) Carbonitriding.

5) Flame hardening.

6) Induction hardening.

Surface hardening:- (or) Case hardening:-

- In case of shaft the stresses are zero at center and maximum at surface. so it requires hard surface and soft core.
- In case of transmission parts like gears they have contact with another object which can be subjected to impact loads. In such cases we require hard surface and tough core.

Surface hardening:-

- Two types: 1) Change in chemical composition
 - 2) Without change in chemical composition
- Under change in chemical composition the case hardening method includes: 1) Carburising
 - 2) Nitriding
 - 3) Carbo-Nitriding
 - 4) Cyaniding

Effect of Carbon and Nitrogen:-

- Carbon and nitrogen can easily dissolve in steel.

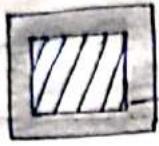
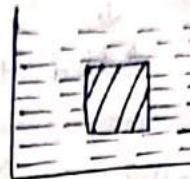
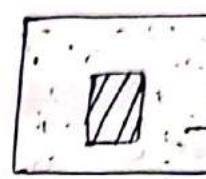
Carburising:- Adding carbon into steel continuously under high temperature ($860-910^{\circ}\text{C}$).

Effect of temperature:- At higher temperatures carbon can easily diffuse into steel.

- No material should be heated above the $\frac{2}{3}$ rd temperature of its melting point.

Types of Carburising: Based on carburising media it is of three types. They are:

- 1) Solid (or) pack carburising
- 2) Liquid carburising
- 3) Gas carburising

Solid	Liquid	Gas
 Solid Media	 Liquid Media	 Gas Media
$\rightarrow \text{BaCO}_3$ is solid carburising media which is having higher temperatures and allows carbon from it easily.	$\rightarrow \text{NaCN}$ is a liquid carburising media	$\rightarrow \text{Methane}$ is a gas carburising media.
$\text{BaCO}_3 + \text{Coke} \rightarrow \text{BaO} + \text{CO}_2$ $\rightarrow \text{At } 860-910^\circ\text{C.}$ $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$ $2\text{CO} \rightarrow \text{C} + \text{CO}_2$ \downarrow Induced into metal	$\text{NaCN} + \text{BaCO}_3 \rightarrow (\text{liquid})$ $\text{Na}_2\text{CO}_3 + \text{Ba}(\text{CN})_2$ $\text{Ba}(\text{CN})_2 \rightarrow \text{BaCN}_2 + \text{C}$ \downarrow Induced into metal. $\rightarrow \text{At } 860-910^\circ\text{C.}$	$\text{CH}_4 \rightarrow \text{C} + 2\text{H}_2$ \downarrow Induced into metal. $\rightarrow \text{At } 860-910^\circ\text{C.}$

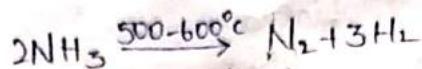
Casedepth:- The depth upto which Carbon is induced into the metal.

\rightarrow Soaking time is directly proportional to casedepth and temperature.

\rightarrow Quenching cannot be done immediately. \rightarrow Quenching can be done immediately. \rightarrow Quenching can be done immediately.
 So we do hardening.

→ Processing time is less. → Processing time is medium.

Nitriding :- Addition of nitrogen into steel under high temperature (500 - 600°C). NH_3 is the media.



Added to the metal

Difference b/w Carburising & Nitriding:-

→ High strength.

→ Low strength.

→ Operating temperature is 800°C - 1000°C .

→ Operating temperature is 500°C - 600°C .

→ More power.

→ Less power.

→ Diffusion rate is high.

→ Diffusion rate is less.

→ Processing time is less.
(1hr-7hrs)

→ Processing time is more.
(1hr-100hrs)

Surface hardening without change of composition:-

Flame Hardening:-

Process:-

→ Heating the surface of steel to above its temp
in the case of hypo eutectoid steels & upto Ac₁ in the case of hyper-eutectoid steels.

→ In this case quenching transfer from austenite to Martensite.

- hardening is done in 3 ways:
- 1) spot method (flame is focused at spot).
 - 2) Progressive
 - 3) spinning.
- Depth of hardening depends upon
- 1) Distance b/w gas flame & component.
 - 2) Gas pressure
 - 3) Rate of travel of flame.

Application:- Suitable for machine beds, cams, cam shaft.

Advantages:- No scaling effect, cheap & portable.

Disadvantages:- Overheating can damage components.

Applications:- Crank shafts, gears, automotive components which require high core strength.

Induction hardening:

→ Heating is done within the surface of layers of the surface of metal by using high frequency induction current.

→ Component is heated by means of an inductor coil which consists several turns.

Advantages:-

1) This process is economical for small size components.

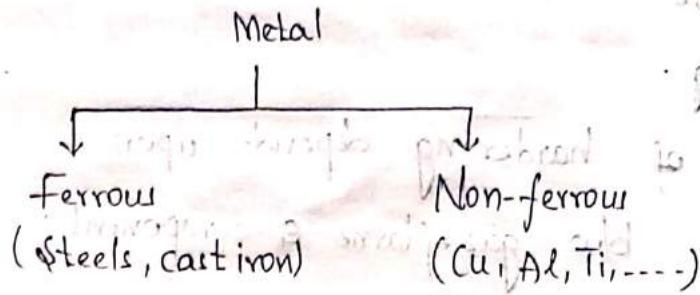
2) Less processing time compared to flame hardening.

Drawbacks:- Not suitable for irregular shapes.

Applications:- Suitable for connecting rods, crank shafts, cam shafts, gears, etc.,.

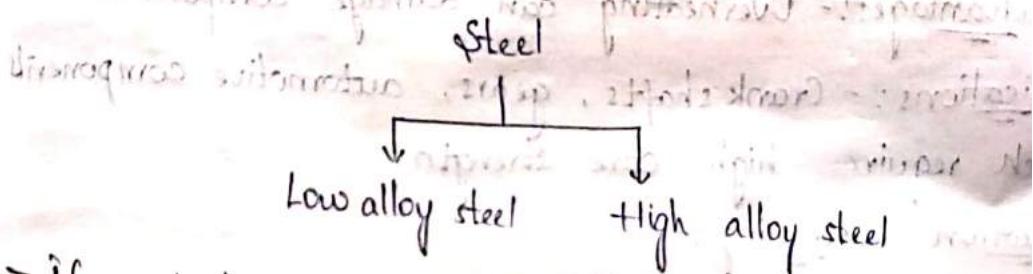
H. Ferrous, Non-ferrous materials and their alloys:

Classification of metals:-



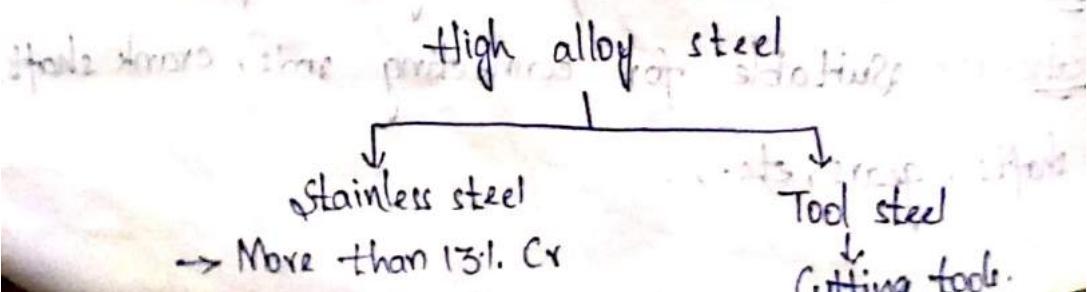
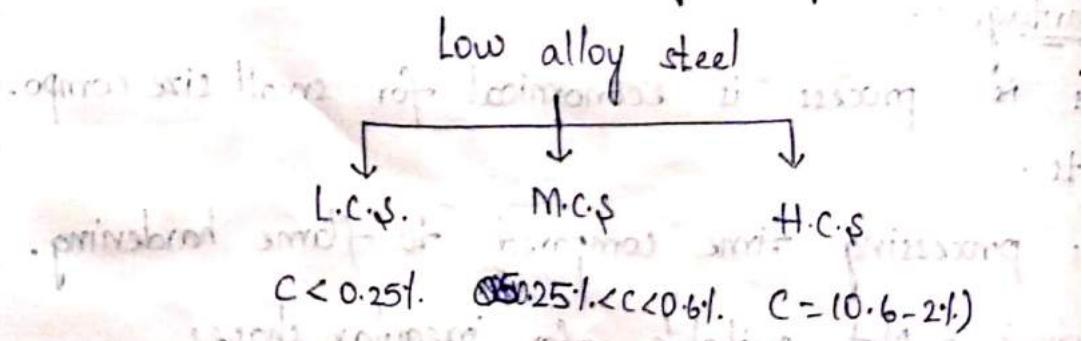
Ferrous metals:- The material which contain iron called as ferrous metal.

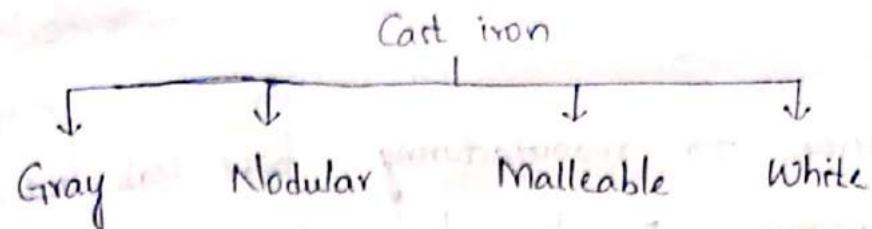
Non-ferrous metals:- The material which does not contain iron is called as Non-ferrous metal.



→ If steel is having less than 10% of alloying elements it is known as low alloy steel.

→ If steel is having more than 10% of alloying elements it is known as high alloy steel.





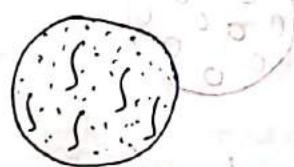
Gray cast iron:-

- 1) Carbon
- 2) Composition
- 3) Microstructure
- 4) Why it is named
- 5) Properties
- 6) Applications
- 7) Drawbacks

→ Carbon is in the form of graphite in Gray cast iron.

→ It is having 2.5-4% of carbon composition and 1 to 3% of silicon.

Microstructure:- Carbon (or) Graphite in the form of flakes which are surrounded by α -manganese matrix.



→ Fracture looks like Gray in colour.

Properties:-

→ It is weak in tension due to flakes. Flakes acts as stress concentration sites (defects, V-notches, blow holes, reduced diameter).

→ It is strong in compression.

→ High damping capacity (It absorbs vibrations).

Applications:-

It is used for manufacturing base (or) bed of machine because it has high damping capacity.

Drawbacks:-

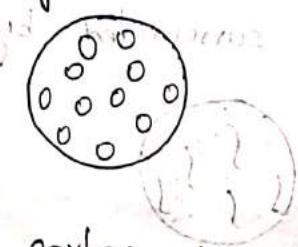
→ It is only used in machine beds but not elsewhere.

Nodular / Ductile / Spheroidal cast iron:-

- Carbon in the form of graphite.
- It is the modification of Gray cast iron.
- By adding Magnesium before casting, the flakes will be converted into spheres.

Chemical composition:- It is having 2.5-4% carbon, 1-3% Silicon and 1-3% Magnesium.

Microstructure:- Carbon in the form of spheres surrounded by silicon matrix.



→ Because of carbon in the form of spherules, it is named as spheroidal cast iron.

Properties:-

→ It is strong in tension because stress concentration sites are eliminated.

→ It is having high ductility than all cast iron because the carbon is in the form of spherules.

Applications:-

- 1) Gears
- 2) Pinions
- 3) Crankshaft
- 4) Pulleys
- 5) Piston rod.

Drawbacks:- It has no damping capacity.

White Cast Iron:

→ Carbon is in the form of cementite (Fe_3C).

Chemical Composition:- It is having 2.5-3.5% carbon and

<1% silica

Microstructure:- Carbon in the form (blades) which is surrounded by α -matrix.



→ Fracture is in white colour.

Properties:-

→ It has high hardness and strength because most of the carbon is in combined form. It is the only metal in which has high hardness compared to all other structures.

→ It has high wear resistance.

Drawbacks:- It cannot be machined.

Applications:-

1) Rim of car wheel.

2) Rolling mills.

3) Railway braking system

Note:- It is used for making Malleable cast iron.

Malleable cast iron:- Heating the white cast iron w/ the temperature ($800-900^{\circ}\text{C}$) for some time. Due to this decomposition of Fe_3C into graphite which exists in the form of clusters. \rightarrow Carbon is in the form of graphite.

Chemical composition:- It is having 2.5-3.5% carbon and less than 1% silica.

\rightarrow Because it can undergo deformations due to compressive loads.

Properties:- It can be machined.

Applications:-

1) Chain.

2) Pulleys.

3) Valves of IC engines.

Alloyed Cast iron:- Anything added to the cast iron that is known as Alloyed Cast iron.

\rightarrow Two types. They are: 1) Ni-Iron. 2) Nickel.

\rightarrow When Nickel is added to steel hardness is increased.

\rightarrow If only Nickel is added to steel, the carbon

becomes free in the form of graphite. This is because of the graphitization property of Nickel. This reduces strength and hardness. Therefore Chromium is also added along with Nickel to the steel, such that Nichrome is formed. Now the hardness & strength can be increased.

→ In Ni-hard, the composition is not mentioned particularly such that any amount of Ni & Cr can be mixed. Added to white cast iron.

→ In Ni-resist, the compositions are 30-38% Ni and 1-5% Cr. Added to spheroidal cast iron.

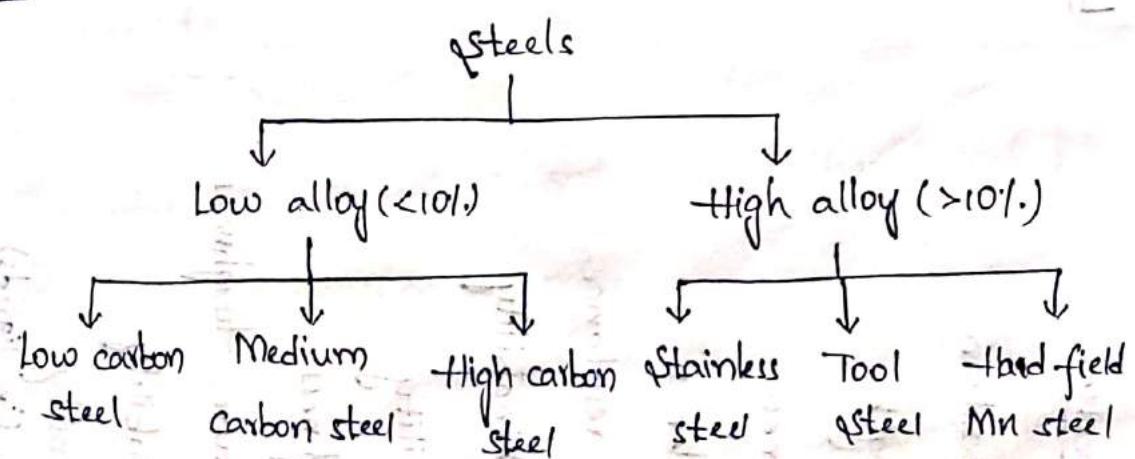
→ By the addition of chromium, corrosion resistance is improved.

→ Cr is soft.

Silal: - It is a form of alloyed cast iron.

→ By adding 1-5% of silicon to the cast iron it improves oxidation resistance at higher temperature.

Steels:



<u>Properties</u>	<u>Low carbon steel</u>	<u>Medium carbon steel</u>	<u>High carbon steel</u>
<u>Composition</u>	< 0.25%	0.25 - 0.6%	0.6 - 2%
<u>Strength</u>	Low	Medium	High
<u>Hardness</u>	Low	Medium	High
<u>Brittleness</u>	Low	Medium	High
<u>Wear resistance</u>	Low	Medium	High
<u>Machinability</u>	High	Medium	Low
<u>Ductility</u>	High	Medium	Low
<u>Toughness</u>	High	Medium	Low
<u>Fracture toughness</u>	High	Medium	Low
<u>Flowability</u>	High	Medium	Low
<u>Viscosity (in liquids)</u>	Low	Medium	High
<u>Temp. at L.C.S.</u>	Decreases	Increases compared to L.C.S.	Increases

Applications:-

Lcs:- Fan blades, Boiler plates, welding pool, screws, nails, rivets.

Mcs:- Connecting rods, Nuts, Bolts.

Hcs:- Knives, Blades, chisels, cutting tools.

Had field Manganese Steel:-

Composition:- 10-12% Mn, <0.5% C, <1% S.

→ By adding Manganese to steels it increases hardness, yield strength in large scale.

→ It dissolves in ferritic phase.

→ By adding Sulphur it increases machinability.

Applications:-

1) Stone crushers.

2) Bulldozers.

Tool Steels:-

Cutting tool materials:- HCS, HSS, Ceramic, Diamond, UCON, CBN, Stellite.

Properties:-

→ Hardness is at least 30-50% harder than work piece.

→ Should have higher strength.

→ Higher toughness to withstand impact loads.

→ Higher thermal conductivity for dissipation of heat.

→ High wear resistance.

→ Low coefficient of linear thermal expansion.

High Carbon Steel:-

→ Hardness - 65 HRC.

→ Hot hardness temperature - 250°C.

→ Inability of a material to withstand hardness at higher temperatures is known as hot hardness temp. → time.

→ Forging is manufacturing method.

→ Used for machining very soft materials like aluminium, copper, mild steels etc.

→ Regrindable.

→ Low alloy steel.

High Speed Steel:-

→ It is also known as 18-4-1 steel.

→ It is having 18% W, 10% Mo, 4% Cr & 1% V.

→ W 10% Mo gives hardness, Cr gives tensile strength & corrosion resistance. V gives high wear resistance.

→ Tungsten gives high wear resistance than Molybdenum.

→ Forging is manufacturing method.

→ Hot hardness temperature - 600°C.

→ High alloy steel.

→ Regrindable.

→ For hard materials.

Stainless Steel:-

- stainless steels are an important class of alloys used in the present generation.
- stainless implies absence of staining, rusting (or) corroding from environment.
- stainless steel is essentially a carbon steel which contains chromium at 10% (or) more by weight and other alloying elements such as Molybdenum, Nickel.
- On addition of Cr to the stainless steel gives unique stainless corrosion resistance.

Classification of stainless steels:-

→ Austenitic stainless steel.

→ Ferritic stainless steel.

→ Martensitic stainless steel.

→ Duplex stainless steel.

→ ptt-stainless steel.

Ferritic stainless steel:-

→ Contains Cr-12.5 to 17%, Nickel free steels.

→ Low strength, good ductility.

→ Good oxidation resistance.

→ Non-heat treatable.

→ Possess excellent corrosion resistance comparing to martensite steels.

→ Expands with heat & becomes brittle.
→ Shows more than 50% elongation.

Non-Ferrous Metals:-

Aluminium (raw material - bauxite) :-

1) Al is a light metal. (Density = 2.7 g/cc).

2) It is ductile and malleable.

3) It is easily machinable.

4) Good electrical & thermal conductivities.

5) High reflective to heat & light.

6) Corrosion resistance - non protective coating needed.

7) High oxidation resistance.

8) Non-toxic - used for food packaging purpose.

9) Low DBTT temp. (-140°C).

DBTT - ductile to brittle transformation temperature.

→ It is the temp. at which ductile material becomes a brittle material.

10) Non-magnetic.

11) Easily alloyed (or) mixed with other elements like Cu, Si, Mg, Mn, Zn, etc..

12) FCC structure.

13) Al is a versatile metal.

14) Can be cast, rolled, stamped, drawn, roll-formed, hammered, extruded & forged into many shapes.

15) Riveted, welded, brazed (or) resin bonded.

APP:- All automobiles, missiles, aerospace industries, kitchen utensils.

Al alloys:-

- 1) Some alloys are suitable for casting.
- 2) Some alloys are suitable for wrought.

Al-Si alloy (12%):-

- Used for production of casting due to their excellent fluidity (can easily flow).
- Properties are depended upon amount of silicon.
- Higher Si - better mechanical properties.
- Due to excellent fluidity, it can be used for casting intricate shapes.

APP:- Motor housings, pump parts in chemical & dye industries.

Al-Si-Cu Alloy (5-10% Si, 2-3.5% Cu):-

- 1) Reduce in Si reduces fluidity and addition of Cu makes alloy responsive to precipitation hardened.
(Adding 1-2 phase particles to primary phase particles)
- 2) Cu increases machinability & lowers castability.

Al-Mg alloys (5-10% Mg):-

- 1) Addition of Mg makes alloy machinable & gives better finish. Mg - easily oxidised.
- 2) But some difficulties during melting & casting.

- 3) Easily oxidised but it can be reduced by addition of small quantity of Beryllium.
- 4) Mg easily pickup the hydrogen causes hydrogen embrittlement.
- 5) Fairly high strength & particularly suitable for marine environments.

Applications:- Aircrafts, automobile components, dairy equipment, architectural work.

: Al-Cu alloy (4.5% Cu):-
 → Precipitation hardened alloy.
 → Good strength after precipitation hardened.

Applications:-

Aircraft parts where high strength is required.

Y-alloy (4% Cu, 2% Ni, 1.5% Mg):-

1) Excellent ability to retain high strength at elevated temperature.

2) Can be cast & rolled.

Application:- Piston and cylinder head, petrol & diu

engineer

Scanned with CamScanner

Titanium and its alloys :- (1760°C - melting point)
[Raw material is Titanium sponge]

- Titanium exists in two phases.
- Above 883°C - (β -phase) - BCC
- Below 883°C - (α -phase) - FCC
- Beta Transformation temperature (BTT) is 883°C
- Beta Transformation temperature :- The temperature at which α -phase converts in β -phase and vice-versa.
- It is of less density of 4.51 g/cc (40% lighter than steel and 60% heavier than aluminium).
- Pure titanium melts at 1670°C.
- Can catch fire and cause severe damage.
- Strong de-oxidizer.
- Ti is stronger than Al - high strength and low weight makes titanium very useful as a structural metal.
- Can be used as a biomaterial.
- Can be used in elevated temperature component.

Applications :-

- Because of its high strength to weight ratio and excellent corrosion resistance, titanium is used in a variety of applications.
- Aircraft - Body structure, Engine parts.
- Sporting equipment, chemical processing.

- Turbine engine parts, valve and pump parts, marine hardware, medical implants.
- Sporting equipments (shuttle bats).

Titanium Alloys:-

→ Alloying of titanium depends upon either α (or) β stabilizers.

α -stabilizers:- Aluminium (Al), Gallium (Ga), Nitrogen (N), Oxygen (O) stabilizes α -phase.

β -stabilizers:- Molybdenum (Mo), Vanadium (V), Tungsten, Tantalum (Ta), Silicon (Si) stabilizes β -phase.

Classification of Titanium alloys:-

1) α -titanium alloys (alloyed with α -stabilizers).

2) β -titanium alloys (alloyed with β -stabilizers).

3) α, β -titanium alloys

α -titanium alloys:-

→ α -alloys consist entirely of α -phase.

→ They contain Al as the major alloying element, stabilizing α -phase.

→ α -alloys have good fracture toughness & creep resistance combined with moderate mechanical strength.

→ They are easily welded, but their workability in hot state is poor.

Applications:-

- 1) Marine parts.
- 2) Manufacturing equipment for chemical processing.
- 3) Heat exchangers.
- 4) Condenser and evaporator tubing.
- 5) Aircraft engine parts.
- 6) Gas compressors.

β -Titanium alloys:-

- Titanium-alloys are titanium alloys rich of β -phase.
- Titanium β -alloys are heat-treatable. They may be significantly strengthened by precipitation hardening.
- β -alloys are heat-treatable to very high strength and have good hot formability.
- Ductility & fatigue strength of the alloys in heat-treated conditions are low.

Applications:-

- 1) Aerospace components.
- 2) High-strength fasteners.
- 3) High-strength aircraft sheets.
- 4) Burn-resistant aircraft engine parts.

α - β -Titanium alloys:-

- Contains both α & β -stabilizers.
- Ti-6-4 is the most popular alloy - its total production is about half of all titanium alloys.

- Aluminium (Al) is added to the alloy as α -phase stabilizer which improves ductility and malleability.
- Vanadium (V) stabilizes ductile-phase, providing hot workability of the alloy.

Applications:-

- These Titanium-Alloys are used for manufacturing steam turbine blades.
- Gas and chemical pumps.
- Airframes and jet engine parts, pressure vessels.
- Blades and discs of aircraft turbines, aircraft hydraulic tubing, rocket motor cases, cryogenic parts, marine components.

Copper and its alloys:-

- Copper is one of the oldest metals discovered by man.

→ Cu is a ductile metal and FCC structure.

→ Pure Cu is soft and malleable.

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Copper:-

- Copper is one of the oldest metals discovered by man.
- Copper is a ductile metal, and fcc structure.
- Pure Cu is soft and malleable.
- Difficult to machine.
- Very high electrical conductivity - second only to silver.
- Excellent thermal conductivity - Copper cookware most highly regarded - fast & uniform heating.
- Electrical industries are the largest users of Cu.
- Non-magnetic, cost is 330Rs/kg.
- Good corrosion resistance in atmospheric conditions.
- Colour is reddish.

Applications:-

- Electrical conductors, automobile radiators, pressure vessels, kitchen utensils.
- Dollar coins contain 91.67% copper.
- The second largest use of Cu is probably in coins.
- The various Euro coins are made of Cu-Ni, Cu-Zn-Au-Al-Zn-Sn alloys.

Copper and its alloys:-

→ Brass

→ Bronze

Brass:-

- Brass is the most common alloy of Cu & Zn.
- Easy to cast - relatively low melting point and high fluidity.
- Properties can be tailored by varying Zn content.
- Brass is frequently used to make musical instruments (good ductility & acoustical properties).
- Brass are classified according to their color (or) structure.

According to structure

1) Alpha brass ($Zn \leq 30\%$).

2) Alpha-beta brass ($Zn 30-44\%$).

According to colour:-

1) Red zinc ($Zn < 20\%$).

2) Yellow zinc ($Zn > 20\%$).

Alpha brasses ($Zn \leq 30\%$):

→ They are soft, ductile, malleable, and have good corrosion resistance.

→ All alpha brasses are suitable for cold working, wire drawing, press work.

Alpha-beta brasses ($Zn 32-44\%$):

→ These are very hard & strong compared to alpha brasses.

- These are fabricated by hot working process.
- These are cheap as compared to alpha brass.
- Because Zn is cheaper than 50% Cu.
- But the corrosion resistance is high compared to alpha.

Bronze:-

- Bronze is an alloy of copper containing elements other than zinc.
- Originally it was used to denote Cu-Sn alloys.
- Some of the important brasses are aluminium bronzes, tin bronzes, beryllium bronze & silicon bronzes, etc.,

Aluminium Bronzes (4-11% Al):-

- In addition with Al other elements such as Fe, Ni, Mn & Si may be added to improve properties.
- Good ductility and toughness.
- Good corrosion resistance.
- Good fatigue resistance.
- These can be fabricated by cold working process such as drawing, pressing, rolling, etc.,

Applications:-

- Heat exchangers, cigarette cases, propellers, cylinder heads, gears, dies, spark plug, etc.,

Tin Bronzes (8.25% Tin):-

- \rightarrow Tin has good affinity towards oxygen during melting of copper & tin, tin oxide is formed.
- \rightarrow Tin oxide is appeared in metal & reduces ductility & malleability.
- \rightarrow Due to this tin bronzes are deoxidized by adding zinc (or) phosphorus.
- \rightarrow After addition of deoxidizers they cast quickly without formation of tin oxide.

Silicon Bronzes ($1-5.3\%$):-

- \rightarrow The max. solubility of silicon in copper is about 5.3% . at 845°C & solubility is 4% at room temperature.
- \rightarrow These are high resistance to corrosion, high tensile strength.
- \rightarrow They are cheaper than tin bronzes.
- \rightarrow They can be hot & cold worked.
- \rightarrow By adding alloying elements like Mn, Fe, Zn, Sn will improve the strength & machinability.

Applications:-

- \rightarrow High strength bolts, rivets, springs, propellers, shafts, belts & bells.

Aluminium bronzes:-

Gliding Metal ($5-15\%$):-

- \rightarrow Used in bullet-proof envelops, coins, needles, jewellery.

5. Powder Metallurgy

Powder Metallurgy: - In this we make metal powder and then the powder is mixed with additives, the complete mixture is compacted (or) pressed by using die and punch into required shape, the component is heat treated in a furnace to remove unwanted gases present in the component, then finally secondary operations are done.

Why the powder metallurgy:

- 1) Melting point of the metals to be used for making a product is too high.
- 2) Some reactions occur during melting of material.
- 3) Na contamination is the main drawback in melting of a material.
- 4) It is used for metals that are too hard to machine.
- 5) It is used for making a large components.
- 6) It is used for the metals which are having a different melting points.
- 7) Any metal plus non-metal combination is possible.
- 8) Net shape forming.

Steps in powder metallurgy:-

- 1) Preparation of powder
- 2) Mixing (or) blending
- 3) Compacting (or) Pressing
- 4) Sintering
- 5) Sizing
- 6) Testing (or) Inspection.

Production of powders:-

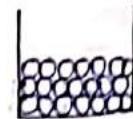
→ Properties of components made by powder metallurgy depends on production of powders.

5. 1) size of powder.

→ 2) distribution of powder.

6. 3) shape of powder.

→ Size :-



→ Because of contact surface small has higher strength.

but porosity is high in big particles.

imp. → Distribution should be made easy & shape is uniform.

APP Aspect ratio:- It is -the ratio of larger dimension

→ + to the lesser dimension.

Alu → Ratio must be equal to 1 (or) near to 1 for solid powder metallurgy.

→ Particles like flakes are not suitable for powder metallurgy because of high aspect ratio.

→ for square, cube & sphere - the ratio is 1.

Methods of powder production:-

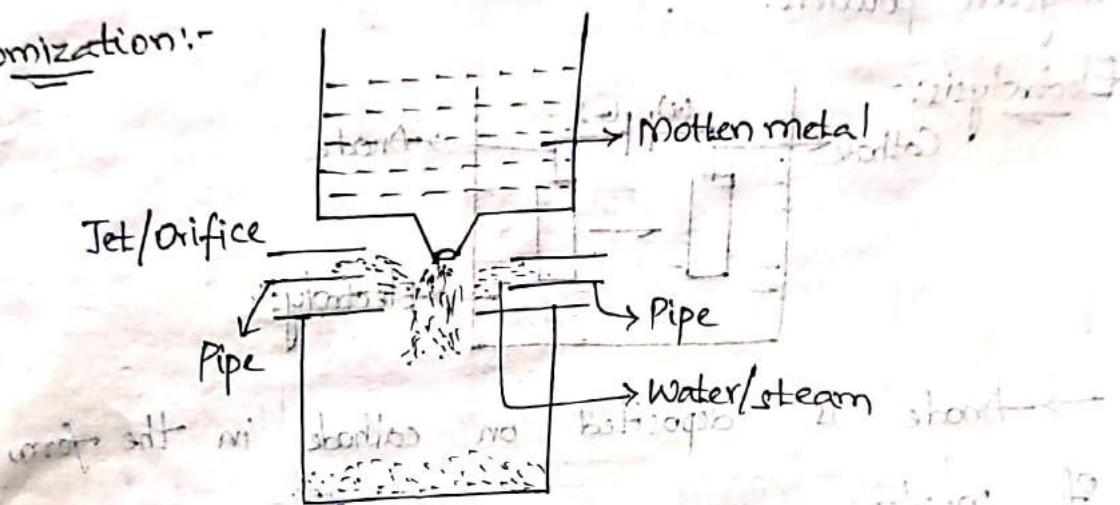
1) Atomization.

2) Reduction.

3) Electrolysis.

4) Mechanical comminution.

Atomization:-



→ In this molten metal is forced through the jet into stream of gas (or) water. Upon contact with gas (or) water the molten metal is solidified into powder particles of various sizes.

→ The size of powder particles depends upon the

1) temperature of melt (Temp. \propto particle size \downarrow)

2) rate of inflow

Drawback: - This method is used

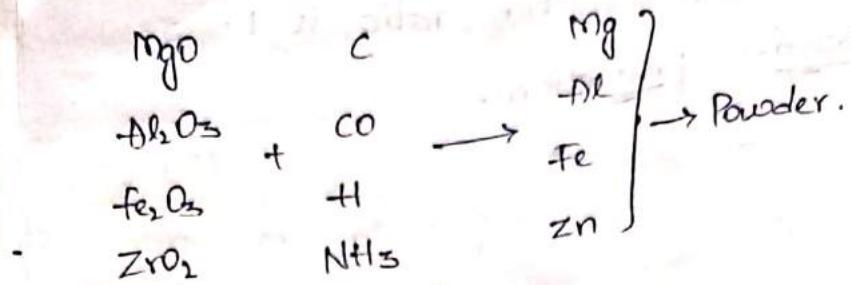
3) nozzle dimensions for less melting point materials

4) jet properties only. Not used for tungsten.

Reduction:-

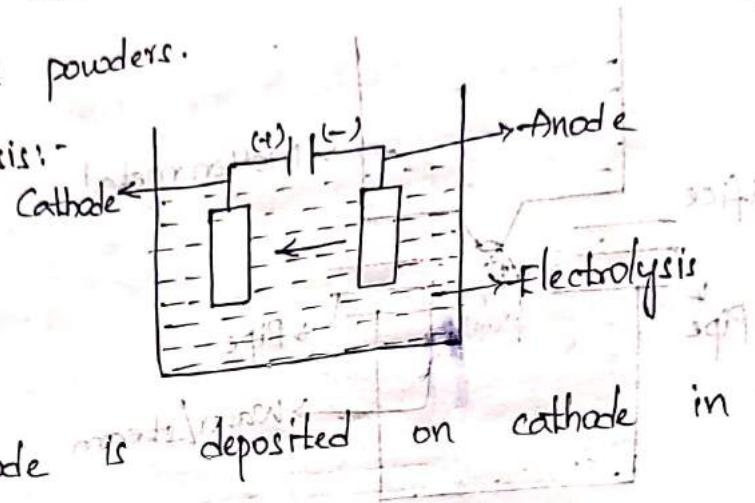
→ Reducing agents are C, CO, H₂, NH₃.

→ Metal in the form of oxide \Rightarrow Al₂O₃, MgO, Fe₂O₃, ZrO₃



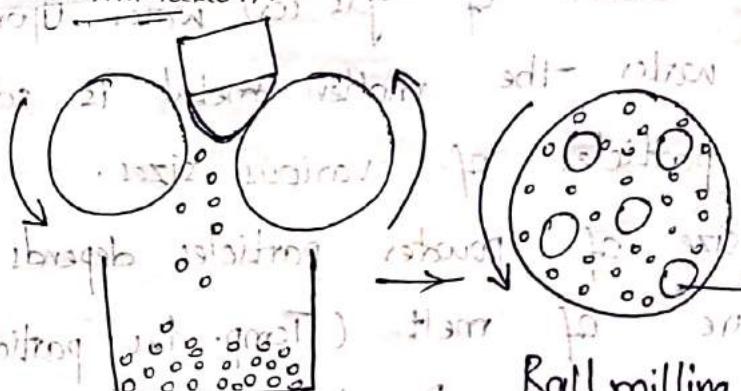
Advantages:-

- → This method is only used for production of tungsten powders.
- Electrolysis:-
- f
- Si
- Anode is deposited on cathode in the form of powder.



Mechanical Comminution:-

- Crushing: -
- Ball milling: -
- Balls are made by hard steel. This method is only suitable for brittle materials.



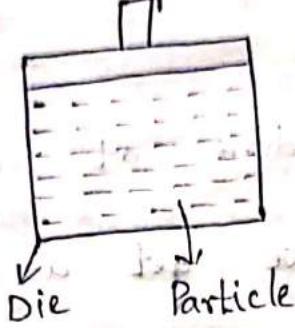
Blending (or) Mixing:-

- Powders made by different methods have different shapes & sizes. They must be mixed to get uniform

→ Mixing of
-rent properties.

Lubricants:-

- To reduce the friction b/w the particles & b/w the particle & die.
- To get good bonding b/w the particles.



→ To improve flow properties of powders (flowability).

→ Mixing should be done in controlled conditions

→ Mixing should be done in controlled conditions to avoid contamination. Contamination is due to

the excessive mixing (and also not cleaned container)

→ Mixing should be done at room temperature & to avoid oxidation.

→ Mixing can be done in water because water itself acts as a lubricant.

→ Mixing is done in two ways. They are:

1) V-cone mixture

2) Double-cone mixture

Compacting:-

→ To get a required shape.

→ To get a high density. Density depends upon

size and shape of particles and also depends on pressure.

Types of Compaction:-

- 1) Cold compaction.
 - 2) Hot compaction (or) Isostatic pressure

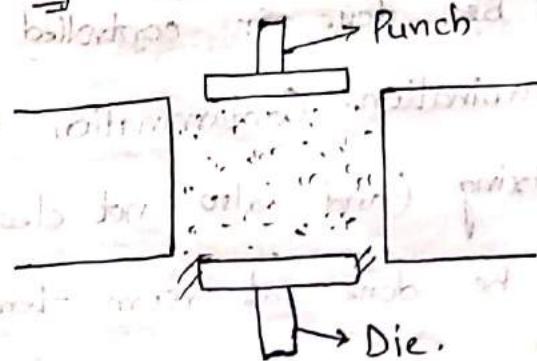
Cold compaction:

Cold compaction: → Compaction is done at room temperature.

→ Compaction is a process by which we get a product is called

Green compact.

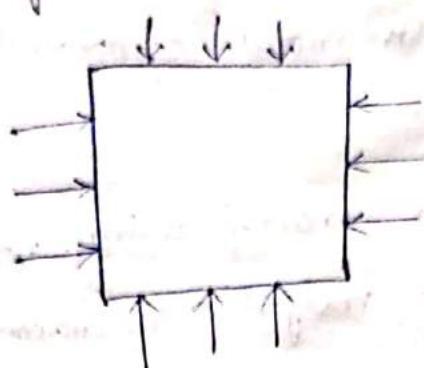
Drawbacks of cold compaction:-



- → The strength in the bottom side wall not be high compared to the top because the punch compaction is done in one side.

Hot compaction:-

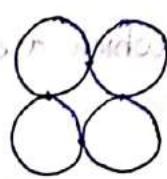
→ in this the pressure is applied simultaneously in all directions to get an uniform strength and density.



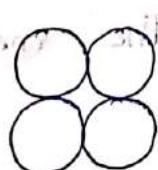
- Gas is used as pressure medium.
- Types of isostatic pressings : 1) Hot isostatic pressing
2) Cold isostatic pressing
- If the pressing is done at room temperature it is known as cold isostatic pressing.
- If the heat is applied with pressure it is known as hot isostatic pressing.
- For hot isostatic pressing the syntactic is not required.

Sintering (or) Heat treatment:-

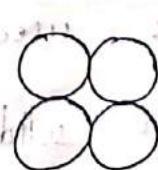
steps in sintering:-



Before



During



After

Point contact

Surface Contact

Localization, melting
then strength ↑
density & hardness ↑

Advantages:-

- Any metals plus metal components can be manufactured.
 - Any metal plus non-metal components can be manufactured.
 - It is used for manufacturing refractory materials like tungsten, titanium, molybdenum, diamond.
 - Cutting tools like cemented carbide are made by powder metallurgy only.
 - Porosity can be controlled in powder metallurgy.
It depends upon compaction pressure.
 - Near net shapes are possible.
 - No machining is required so no loss of material.
 - Less processing time.
 - Suitable for mass production.
 - Skilled person is not required for powder metallurgy.
 - + → It is used for the metals which are not soluble in solids.
 - Less contamination.
- ## Drawbacks:-
- Powders are very dangerous especially for eyes.
 - It is not used for making complex components.

- Components made by powder metallurgy are having less ductility & toughness.
- High cost for powder metallurgy.

Composites:-

- A typical composite material is a system of materials comprising two or more materials on a macroscopic scale.
- Ex:- Concrete - cement, sand, stones and water.
- Ideal for structural applications where high strength-to-weight & stiffness-to-weight ratios are required.

Components:-

→ Matrix.

→ Reinforcement.

Matrix: Continuous phase, binding reinforcements in position and transferring the load to and from the reinforcement & protecting them from the environment & handling.

→ Matrix can be polymer, ceramic, metal, etc..

Reinforcement: Second phase materials added to the matrix alloys, which normally enhance strength, stiffness, wear and creep resistances of the composites.

→ Choice of reinforcement always depends on the final properties, requirements of the polymer (or) system.

Types of reinforcement:-

→ Fibre contributes bulk of strength in composites.

- fibers are thinner than human hair (10 microns to 0.00039 inches).
- fibers can be glass, carbon, aramid, etc.

Types of glass fibers:-

E-Glass: - High electrical resistance, high mechanical properties & most of economical.

S-Glass: - S: for structural, higher cost & high strength.

Glass fibres:-

Advantages

- Good strength.
- High strength to weight ratio: Density of $\approx 2.5 \text{ g/cm}^3$.
- Does not absorb moisture.
- Good thermal & electrical insulator.
- Easy to handle & process.
- Low cost.
- Available for wide range of applications / uses.

Disadvantages

- Low tensile modulus.
- Sensitivity to abrasion during handling.
- High hardness.
- Relatively low fatigue resistance.
- Alkali reactions from cementitious particles.