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PART - A

2 Marks Questions

1.
Sol. The key differences between atomic structure and crystal structure are:
Atomic structure:-
This refers to the arrangement of subatomic particles (protons, neutrons and electrons) within a single atom. It describes the nucleus (containing protons and neutrons) and the electron shells or orbitals around it.
Crystal structure:-
This refers to the ordered, repeating arrangement of atoms, ions, or molecules in a solid material. It describes the macroscopic arrangement of these individual atomic units in a three-dimensional lattice, forming a crystalline solid.
2.
Sol. Orthotropic materials are a special class of isotropic materials which can be described by giving their properties in three perpendicular directions.
Ex: wood, composites.
3.
Sol. The addition of nickel and chromium increases the tensile strength and increase in resistance to corrosion takes place.
4.
Sol. Dislocation refers to a break in the continuity of the lattice. In an edge dislocation, one plane of atoms gets squeezed out. In screw dislocation, the lattice atoms move from their regular ideal positions.
5.
Sol. Examples of BCC, FCC, HCP and CCP structures:
BCC (Body Centred Cubic) structure-molybdenum;
FCC (Face Centred Cubic) structure-Aluminium;
HCP (Hexagonal close packed) structure-Zinc;
CCP (Cubic Close Packing) structure-Copper.
6.
Sol. Ferrite and Austenite respectively.
7.
Sol. (a) **Pearlite** is a eutectoid mixture of ferrite and cementite.
Composition: Roughly 88% ferrite and 12% cementite, containing 0.8% carbon.
Properties: Tough, strong, and imparts desirable mechanical properties to steel.
(b) **Cementite** is a chemical compound of iron and carbon.
Composition: A hard, brittle intermetallic compound with the formula Fe_3C , containing 6.67% carbon by weight.
Properties: Very hard, but makes steel more brittle as its proportion increases.
8.
Sol. **Wrought Iron:-** Low carbon, malleable, ductile, corrosion resistant.
Cast Iron:- High carbon, brittle, strong in compression.
Pig Iron:- Intermediate product from smelting iron ore, contains high carbon and impurities.
9.
Sol. When an equal number of cations and anions leave the crystal lattice, vacancies are created, resulting in a schottky defect, a type of point defect. The density of the crystal is decreased when there are several schottky defects present.
10.
Sol. BCC (body-centered crystalline) describes the structure of CsCl .



So, a cubic cell has the following number of atoms:

$$= 4 \times \frac{1}{4} + 1 \times 1$$

$$= 2$$

In the CsCl crystal, each unit cell has 2 atoms.

11.

Sol. The given data; $a = 495 \text{ pm}$

To find: Radius (r)

Formula:

$$r = \frac{a}{2\sqrt{2}}$$

Calculation:

$$r = \frac{495}{2\sqrt{2}}$$

$$r = 175 \text{ pm}$$

Therefore, the radius of the Cu atom is 175 pm.

12.

Sol. Think about a cubic unit cell with an edge length of a .

- Unit cell volume is equal to a^3 .
- If each unit cell contains " n " particles and each particle have " m " mass, then unit cell mass is equal to $m \times n$.

If the substance's unit cell density is ρ , then

$$\text{Density of unit cell} = \frac{\text{mass of unit cell}}{\text{Volume of unit cell}}$$

$$\rho = \frac{m \times n}{a^3}$$

13.

Sol. A unit cell is made up of the following parameters:

1. The three dimensions of a unit cell. (The three edges)
2. The angles between the edges.

14.

Sol. (i) Coordination number is the number of nearest neighbours of a particle.

(ii)

(a) Coordination number = 12

(b) Coordination number = 8

15.

Sol. Heating solids produce vacancy defects in the crystal. This means that when the heat is applied to the solid, some ions or atoms leave their lattice site totally, making those sites empty. Thereby, decreasing the solid's density.

16.

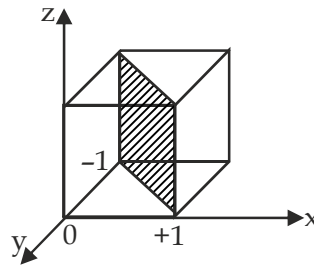
Sol. (i) Frenkel and Schottky defects are present in AgBr.

(ii) ZnS contains Frenkel defect.



17.

Sol.



Plane with miller indices $(1 \ \bar{1} \ 0)$ will have

Intercept at x-axis = 1

Intercept at y-axis = -1

Intercept at z-axis = ∞

18.

Sol. FCC crystals structures have 12 potential slip systems which means that slip is possible on more than one family of planes and directions. So, FCC metals are relatively weak and ductile because extensive plastic deformation is normally possible along the various slip systems.

19.

Sol. Chromium:

- Imparts corrosion resisting properties.
- To combine hardness with high strength and high elastic limit.

Nickel: Improves strength and toughness.

Molybdenum: Improves creep strength by lowering glass transition temperature.

20.

Sol.

Creep is the property of a material by which it deforms continuously under a steady load (yielding). The deformation during creep is nonrecoverable. The creep can produce fracture or rupture even though the applied stress is lower than the ultimate stress. So the creep in materials should be avoided, particularly at high temperatures. Creep resistance is the property of the material by which the continuation of creep is stopped.

21.

Sol.

1. **Temperature:-** Increases the rate of diffusion
2. **Crystal structure:-** Crystal with low packing factor increase the rate of diffusion
3. **Grain size:-** Fine grain material has more diffusion rate
4. **Concentration:-** Value of diffusion coefficient varies with concentration.

22.

Sol.

Hardening gives hardness to a material so that its yield strength, corrosion resistance, wear resistance and cutting ability are increased. Annealing gives softness and ductility to the materials and also refines the grain size and removes the internal stresses.

23.

Sol.

1. Smaller size and lower cost
2. Power supply and water supply are not required.
3. A number of castings in one exposure can be inspected can be easily inspected.

24.

Sol.

Etch ants are some chemicals which are used on the polished specimen surface to identify the higher energy grain boundaries.

25.

Sol.

At the triple point where the vapor, liquid and solid co-existing therefore $P=3$.

No. of components $C=1$.

Therefore $F=C-P+2=1-3+2=0$

Here 2 represents the two variables pressure and temperature of pure metal.

26.

Sol.

Low carbon steels have 0.08% to 0.25% carbon. These are soft, ductile and easy to weld. These are used to make wires, rods and thin sheets and boiler plates.

27.

Sol.

Boron:- Increase the hardness

Chromium:- Improves wear and impact resistance and increases its strength.

Cobalt:- Increase its hardness, coercivity and residual magnetic induction.

28.

Sol.

Corrosion means the destruction of materials by chemical and electrochemical reactions. It can be prevented by electroplating, cathodic protection, addition of inhibitors and by proper heat treatment.

29.

Sol.

Phase or equilibrium diagrams are maps or plots that give the relationships between the phases in equilibrium in a system as a function of temperature, pressure and composition. Information concerning the phase changes in many alloy systems can be had from equilibrium diagram.

30.

Sol.

An alloy is a mixture of two or more metals, or a mixture of metal and a non-metal, with the mixture exhibiting metallic properties.

31.

Sol.

A reaction wherein, upon cooling, one liquid phase transforms isothermally and reversibly into two new solid phases that are intimately mixed is called eutectic reaction.

32.

Sol.

A reaction wherein, upon cooling, one solid phase transforms isothermally and reversibly into two new solid phases that are intimately mixed is called eutectoid reaction.

33.

Sol.

The possibility of existence of two or more different crystal structures for a substance (generally an elemental solid such as iron) is known as allotropy.

34.

Sol.

Ferrites are body centered cubic solid solutions and body centered cubic allotropes of α and δ iron. It is stable over the temperature range from 273° to 908°C in iron.

35.

Sol.

The possible microstructures of iron and steel which reveal the arrangement, size and shape of the grains and molecules are

1. Ferrite
2. Austenite
3. Cementite
4. Martensite
5. Bainite
6. Sorbite
7. Troostite

36.

Sol.

T-T-T diagram is also called isothermal transformation diagram. It is a plot of temperature versus the logarithm of time for a steel alloy of definite composition. It is used to determine when transformation begin and end for an isothermal (constant temperature) heat treatment of a previously austenitized alloy.

37.

Sol.

On the basis of the iron-carbon equilibrium diagram it is possible to describe three classes of plain steels.

1. **Hypo-eutectoid steels:-** These have carbon contents varying from 0.008% to just below 0.83%.
2. **Eutectoid steels:-** These have carbon contents, ideally, of 0.83%
3. These have carbon contents greater than 0.83%

38.

Sol.

The stainless steels are iron-chromium alloys with atleast 11 wt% of chromium. Addition of nickel and molybdenum enhances the corrosion resistance.

Stainless steels are divided into three classes on the basis of the microstructure

1. Martensitic stainless steels
2. Ferritic stainless steels
3. Austenitic stainless steels

39.

Sol.

Any ferrous alloy made up primarily of iron with about 2% or more carbon is considered to be cast iron. Most commercial alloys contain from about 2.5% to 3.8% carbon. There are four basic types of cast iron.

1. Grey cast iron
2. White cast iron
3. Malleable iron
4. Nodular iron

40.

Sol.

Heating and cooling a solid metal or alloy in such a way as to obtain desired conditions or properties is called heat treatment. There are different methods of strengthening and hardening by heat treatment. They are

1. Age hardening (precipitation hardening)
2. Annealing
3. Normalizing
4. Tempering and
5. Case hardening

41.

Sol.

By uniformly dispersing extremely small particles within the original phase matrix the strength and hardness of metal alloys may be enhanced; this process of heat treatment is called precipitation hardening or age hardening.

42.

Sol.

For some alloys, aging occurs spontaneously at room temperature over extended time periods. With increase of time the strength increases and after reaching a maximum a value, it finally diminishes. This type of reduction in yield strength and hardness that occurs after long time periods is known as overaging.

43.

Sol.

Annealing means heating the material to and holding at a suitable temperature and then cooling at a suitable rate. Annealing is for the purpose of

1. Reducing hardness
2. Improving machinability
3. Facilitating cold working
4. Producing a desired microstructure
5. Obtaining desired mechanical, physical and other properties.

44.

Sol.

Heating a ferrous alloy to a suitable temperature above the transformation range and then cooling in air to a temperature substantially below the transformation range is called normalizing.

45.

Sol.

Tempering is the process of re-heating the hardened steel to some temperature below its critical temperature in order to impart toughness and to reduce brittleness. This reduces the internal stresses developed during hardening.

46.

Sol.

The heat treatment for ferrous alloys in which a part is quenching from the austenitizing and held at a temperature just above that of martensite formation until transformation complete is called austempering.

47.

Sol.

The process of quenching an austenitized ferrous alloy is a medium at a temperature in the upper part of the martensite range, or slightly above that range, and holding it in the medium until the temperature throughout the alloy is substantially uniform is known as martempering. The alloy is then allowed to cool in air through the martensite range.

48.

Sol.

For many industrial applications, we need a hard wear-resistant surface called the case and a relatively soft, tough inside called the core. The process of hardening the surface (case) alone is known as case hardening.

49.

Sol.

Whenever the steel is hardening some amount of austenite is always retained by it. This results in the reduction of hardness, thermal conductivity and wear resistance. The sub-zero treatment of hardened steel reduces the retained austenite. In this process the hardened steel part is cooled to sub-zero temperature (between -30°C to -120°C).

50.

Sol.

A special application of isothermal hardening is called patenting and is used for steel wire. Steel wire with 0.40 - 1.10% carbon is quenched from the hardening temperature in a bath of molten lead to about 400°C to 500°C . A structure results which possesses good ductility in addition to a hardness.

51.

Sol.

1. Copper-Zinc (the Brasses)
2. Copper-Tin (the Tin Bronzes)
3. Copper-Tin-Phosphorus (the Phosphor Bronzes)
4. Copper-Aluminium (the Aluminium Bronzes)
5. Copper-Nickel (the Cupro-Nickels)

52.

Sol.

Alloy steel which may be hardened by cooling in air from a temperature above the transformation range. Such steels attain their martensitic structure without going through the quenching process. Additions of chromium, nickel, molybdenum and manganese are effective toward this end.

53.

Sol.

Steels of the American Iron and Steel Institute. Common and alloy steels have been numbered in a system essentially the same as the SAE. The AISI system is more elaborate than the SAE in that all numbers are preceded by letters: "A" represents basic open-hearth alloy steel, "B" acid Bessemer carbon steel, "C" basic open-hearth carbon steel, "CB" either acid Bessemer or basic open-hearth carbon steel, "E" electric furnace alloy steel.

54.

Sol.

A steel where aluminum has been used as a deoxidizing agent.



55.

Sol.

A trade name for a patented heat treating process that consists of quenching a ferrous alloy from temperature above the transformation ranges, in a medium having a rate of heat abstraction sufficiently high to prevent the formation of high-temperature transformation products and in maintaining the alloy, until transformation is complete, at a temperature below that of pearlite formations and above that of martensite formation.

56.

Sol.

A slender, needle-like (acicular) microstructure appearing in spring steel strip characterized by toughness and greater ductility than tempered Martensite. Bainite is a decomposition product of Austenite best developed at interrupted holding temperatures below those forming fine pearlite and above those giving Martensite.

57.

Sol.

Common or ordinary steel as contrasted with special or alloy steels, which contain other alloying metals in addition to the usual constituents of steel in their common percentages.

58.

Sol.

It is the process of adding carbon to the surface of iron-base alloys by absorption through heating the metal at a temperature below its melting point in contact with carbonaceous solids, liquids or gasses. It is the oldest method of case hardening.

59.

Sol.

The trade name applied to the first aluminum-copper-magnesium type of age-hardenable alloy (17S), which contains nominally 4% Cu, 1D 2 % Mg. The term is sometimes used to include the class of wrought aluminum-copper-magnesium alloys that harden during aging at room temperature.

60.

Sol.

A process of hardening a ferrous alloy by heating it above the transformation range by means of a high-temperature flame, and then cooling at the required rate.

61.

Sol.

Used principally on iron and steel, means heating the metal to about 100°F. above the critical temperature range, followed by "soaking" at this point and slow cooling below the critical temperature.

62.

Sol.

Bounding surface between crystals. When alloys yield new phases (as in cooling), grain boundaries are the preferred location for the appearance of the new phase. Certain deteriorations, such as season cracking and caustic embrittlement, occur almost exclusively at grain boundaries.

63.

Sol.

1. Brittleness of metal, resulting from the occlusion of hydrogen (usually as a by- product of pickling or by co-deposition in electroplating).
2. A condition of low ductility resulting from hydrogen absorption and internal pressure developed subsequently. Electrolytic copper exhibits similar results when exposed to reducing atmosphere at elevated temperature.

64.

Sol.

A steel having more than the eutectoid percentage of carbon.

65.

Sol.

Steel with less than eutectoid percentage of carbon.

66.

Sol.

A process of hardening a ferrous alloy by heating it above the transformation range by means of electrical induction, and then cooling as required.

67.

Sol.

A process on which a ferrous alloy is heated to produce a structure partly or wholly austenitic, and is then cooled to and held at a temperature that causes transformation of the austenite to a relatively soft ferrite-carbide aggregate.

68.

Sol.

A Refractory Alloy- Alpha-beta brass, 60% copper and 40% zinc. Stronger than alpha- brass and used for castings and hot-worked (rolled, stamped, or extruded) products. High strength brasses are developed from this by adding other elements.

69.

Sol.

Process of surface hardening certain types of steel 935-1000°F. The increase in hardness being the Certain alloying constituents, principal among them hardening reaction. In general, the depth of the case

70.

Sol.

Lamellar structure resembling mother of pearl. A compound of iron and carbon occurring in steel as a result of the transformation of austenite into aggregations of ferrite and iron carbide.

71.

Sol.

The ability of a material to exist in more than one crystallographic structure. Numerous metals change in crystallographic structure at transformation temperatures during heating or cooling. If the change is reversible, it is allotropy. The allotropy of iron, particularly the changes between the alpha body-centered and the gamma face centered form, is of fundamental importance in the hardening of steel. .20-.40% carbon, .90-1.50% aluminum by heating in ammonia gas at about result of surface nitride formation. being aluminum, greatly facilitate the is less than with carburizing.

72.

Sol.

A process of hardening an alloy in which a constituent precipitates from a supersaturated solid solution. (See also Age Hardening and Aging).

73.

Sol.

Any of the various aging treatments conducted at elevated temperature to improve certain of the mechanical properties through precipitation from solid solution.

74.

Sol.

A process whereby a distorted grain structure of cold worked metals is replaced by a new, stress-free grain structure as a result of annealing above a specific minimum temperature for a specific time.

75.

Sol.

Structure of steel, resulting from the tempering of martensite. In a truly sorbitic structure, the cementite is completely dispersed in the matrix. The trend is to call this structure tempered martensite.

76.

Sol.

Tempered martensite that etches rapidly, usually appears dark, and is not resolved by the microscope.

PART - B

5 Marks Questions

77.

Sol. 1. **Crystal lattice definition:-**

A crystal lattice is a regular, repeating three-dimensional arrangement of atoms, ions or molecules in a crystalline solid. It represents the geometric framework upon which the unit cells of a crystal are built, defining the positions of the constituent particles within the crystal structure.

Types of crystal lattices in Metals:- The primary types of crystal lattices found in metals are:

Face-centered cubic (FCC):-

In this structure, atoms are located at each corner and the center of each face of the cube. Examples include aluminium, copper, gold, and silver.

Body-Centered cubic (BCC):-

This structure has atoms at each corner of the cube and one atom in the center of the cube. Examples include iron, chromium, and tungsten.

Hexagonal Close-Packed (HCP):-

This structure is characterized by a hexagonal arrangement of atoms in layers, with atoms in the third layer directly above those in the first. Examples include magnesium, zinc, and titanium.

78.

Sol. For 0.6% C steel,

$$\% \text{ Pearlite} = \frac{0.6 - 0.002}{0.8 - 0.002} \times 100 = 75.6\%$$

and

$$\% \text{ Ferrite} = \frac{0.8 - 0.6}{0.8 - 0.002} \times 100 = 24.4\%$$

Since 0.6% C steel is essentially a hypoeutectoid steel, no cementite can be present in addition to pearlite.

$$\% \text{ Cementite} = 0$$

Pearlite is a mixture of cementite and ferrite.

Therefore to say that a steel contains pearlite and ferrite means the steel contains a mixture of ferrite and cementite.

$$\% \text{ ferrite} = \frac{6.67 - 0.6}{6.67 - 0.002} \times 100 = 91\%$$

$$\% \text{ cementite} = \frac{0.6 - 0.002}{6.67 - 0.002} \times 100 = 9\%$$

Comparing the relative amounts of pearlite and ferrite with the equivalent relative amounts of ferrite and cementite, it is easy to visualise that

$$(91 - 24.4) = 66.6\%$$

of ferrite combines with 9% cementite to form pearlite.

Assuming the densities of ferrite and cementite to be same, a rough idea of relative volume of two phases can be obtained.

$$\therefore \text{Relative volume of ferrite to cementite in pearlite} = \frac{66.66}{9} = 7$$

Thus, the layer of ferrite in pearlite is seven times thicker than the other constituent i.e., cementite.

79.

- Sol.** 1. **Intercepts:** The intercepts are:
3 along a_1 , 4 along a_2 , 2 along a_3 .
2. **Reciprocals:**

$$\text{Reciprocal of 3 is } \frac{1}{3},$$

$$\text{Reciprocal of 4 is } \frac{1}{4},$$

$$\text{Reciprocal of 2 is } \frac{1}{2}.$$

3. A common multiple of the denominators (12 in this case) and multiply each reciprocal by 12:

$$\frac{1}{3} \times 12 = 4; \frac{1}{4} \times 12 = 3; \frac{1}{2} \times 12 = 6$$

Final Miller indices:

The Miller indices of the plane are (4, 3, 6)

The correct option is (1): (4, 3, 6)

80.

- Sol.** The face-centered cubic unit cell is provided.
How many atoms are there in the corner?

$$\frac{1}{8} \times 8 = 1$$

Making an estimate of the atoms in the faces:

$$\frac{1}{2} \times 6 = 3$$

Counting the total number of atoms:

$$3 + 1 = 4$$

There are four atoms overall in the face-centered cubic unit cell.

81.

- Sol.** Each layer of spheres in a simple cubic closed-packed construction fills in any gaps left by the layer before it. At their intersection, three adjacent spheres in the first layer will create a hollow area. One layer's particles line up to fit into the hollow spaces left by the previous layer. Directly above the first layer is the third layer.

82.

- Sol.** Since each simple cubic unit cell contains one atom. The following formula can be used to determine how efficiently a simple cubic unit cell is packed.

$$\text{Packing efficiency} = \frac{4\pi r^3}{(2r^2)^3} \times 100$$

$$= \frac{1}{6} \pi \times 100$$



$$= 52.4$$

The packing efficiency is 52.4%.

83.

Sol. (i) End centred unit cell

- They contain particles at the corners and one in the centre of any two opposite faces.
- Total number of particles = 2

(ii) Monoclinic unit cell

$$a \neq b \neq c$$

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

$$\beta \neq 90^\circ$$

Face-centred unit cell

- They contain particles at the corners and one in the centre of each face.
- Total number of particles = 4

Hexagonal unit cell

$$a = b \neq c$$

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

$$\gamma = 120^\circ$$

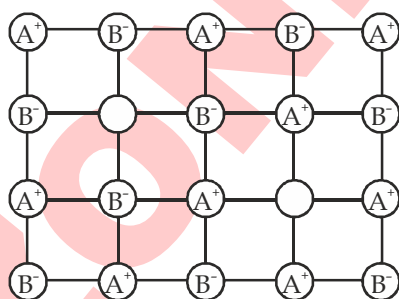
84.

Sol. Let us take an example of NaCl to explain this when NaCl crystals are heated in a sodium vapor atmosphere, sodium atoms are deposited on the crystal's surface. This causes the Cl-ions to leave their lattice sites to form NaCl with the deposited sodium atoms. In this process, the sodium atoms on the surface lose their electrons to form Na^+ ions and the released electrons move into the crystal to fill in the vacant anionic sites. These electrons absorb energy from the incoming visible light and get excited to a higher energy level. Thereby, imparting a yellow colour to the crystals.

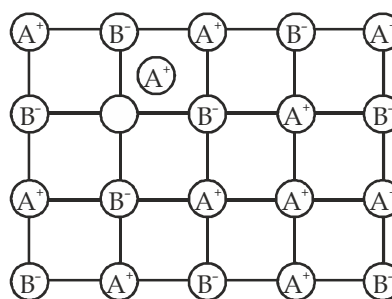
85.

Sol.

Schottky Defect	Frenkel Defect
Arising due to the missing of equal number of anions and cations from the lattice site	Arising due to the misplacing of a cation from the lattice site to the interstitial site.
Decrease the density of the solid	No change in the density of the solid.
It is shown by ionic crystals in which the anionic and cationic sizes are almost equal.	It is shown by ionic solids in which there is a large difference in the size of the ions.



Schottky Defect

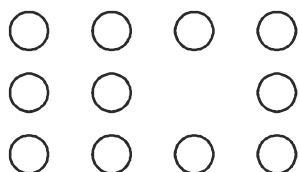


Frenkel Defect

86.

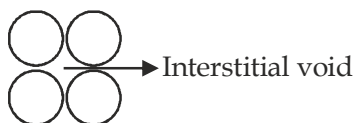
Sol. Defects in metallic materials

1. **Vacancy defect:-** It appears due to the missing of atom from the lattice.



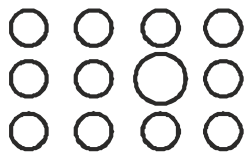
2. **Interstitial defect:-**



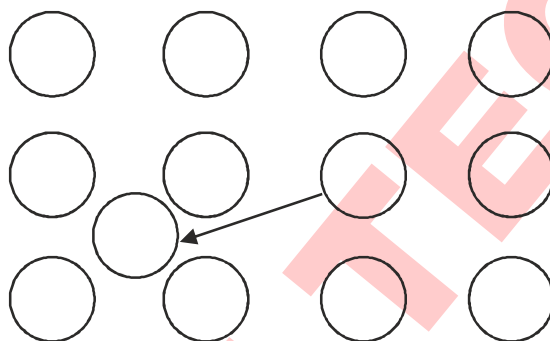


When the foreign atom occupies the interstitial site then the defect is called interstitial defect.

3. **Substitutional defect:-** If the regular atom is replaced by another foreign atom this defect is called substitutional defect.

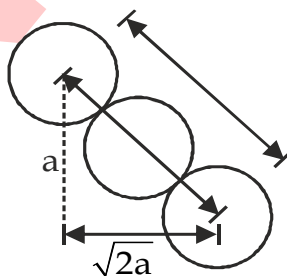


4. **Frenkel defect:-** When the atom in the lattice point goes and occupies the interstitial void of other atom then it is called Frenkel defect.



5. **Schottky defect:-** If the combination of cation and anion from different places in lattice disappear and there is a vacancy defect then it is called Schottky defect.

87.
Sol.



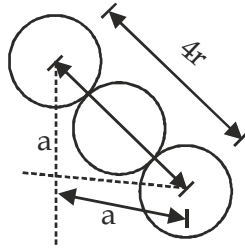
BCC: 8 atoms at corners and 1 atom at body centre.

$$N = 8 \times \frac{1}{8} + 1 = 2$$

$$4r = \sqrt{a^2 + (\sqrt{2}a)^2} = \sqrt{3}a$$

$$\text{Atomic packing factor, APF} = \frac{N \times \frac{4}{3} \pi r^3}{a^3} = \frac{2 \times \frac{4}{3} \times \pi \left(\frac{\sqrt{3}}{4} a \right)^3}{a^3} = 0.68$$





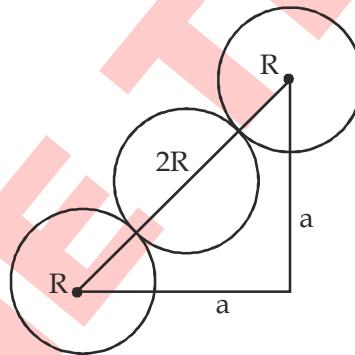
FCC: 8 atoms at corners and 6 atoms at face centres.

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

$$4r = \sqrt{2}a$$

$$\text{APF} = \frac{N \times \frac{4}{3}\pi r^3}{a^3} = \frac{4 \times \frac{4}{3}\pi \left(\frac{\sqrt{2}}{4}a\right)^3}{a^3} = 0.74$$

88.
Sol.



Atomic packing factor is defined as the percentage volume of unit cell covered by the atoms.

For a face centered cubic structure, $4R = \sqrt{2}a$

$$\therefore \text{Volume of the unit cell} = a^3 = \left(\frac{4R}{\sqrt{2}}\right)^3 = 16\sqrt{2} R^3$$

For FCC, coordination number, $n = 4$

$$\text{APF} = \frac{4 \times \frac{4}{3} \times \pi R^3}{a^3} = \frac{4 \times \frac{4}{3} \times \pi R^3}{16\sqrt{2} R^3} = 0.74 = 74\%$$

89.

Sol. Eutectic point is that composition and temperature at which one liquid transforms into two solids of different structures.

For Pb-Sn alloy, an 62% Sn composition alloy is called as eutectic alloy.

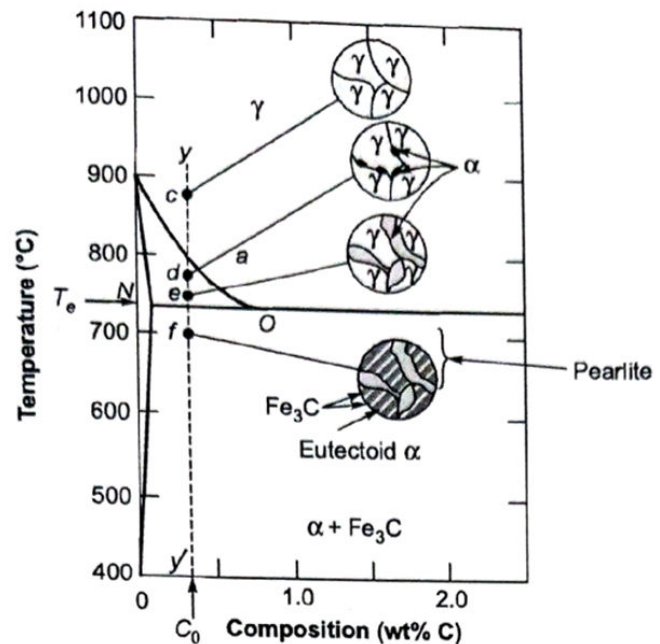
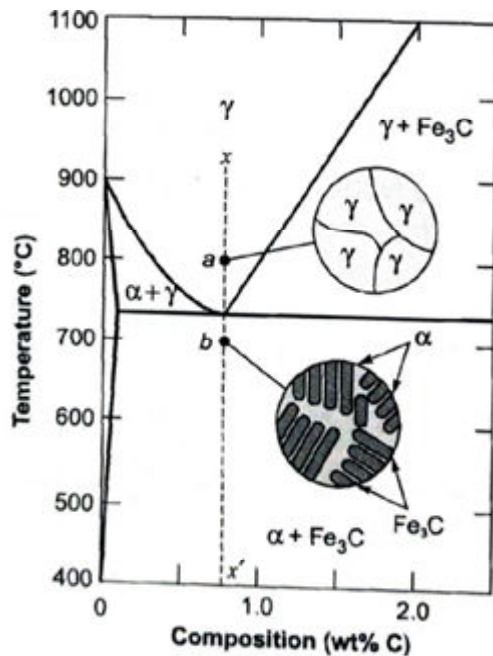
An eutectic alloy has zero degree of freedom at eutectic point.

For electrical soldering we use 60% Sn and 40% Pb alloy.

It is having melting point as 188°C .

90.

Sol.



91.

Sol. There is an error in data. Actually,

$$\text{Fe} = 99.65\%$$

$$\text{C} = 0.35\%$$

$$(a) \text{ Fraction of total ferrite, } F_{\alpha} = \frac{6.67 - 0.35}{6.67 - 0.022} = 0.95$$

$$\text{Fraction of cementite phase, } F_{\text{Fe}_3\text{C}} = \frac{0.35 - 0.022}{6.67 - 0.022} = 0.05$$

(b) To calculate pro-eutectoid ferrite, a tie line has to be selected above eutectoid temperature.

$$F_{\text{pro-}\alpha} = \frac{0.8 - 0.35}{0.8 - 0.022} = 0.58$$

$$(c) \quad F_{\text{eut-}\alpha} = F_{\alpha} - F_{\text{pro-}\alpha} = 0.95 - 0.58 = 0.37$$

$$F_{\text{Pearlite}} = 1 - F_{\text{pro-}\alpha} = 1 - 0.58 = 0.42$$

92.

Sol. Phase:- A phase of a system which is physically homogeneous within itself and bounded by a surface so that it is mechanically separable from any other portions. For example, water has three phases, liquid water, solid ice and steam.

A phase has the following characteristics:

1. The same structure or atomic arrangement throughout.
2. Roughly the same composition and properties throughout.
3. A definite interface between phase and surrounding or adjoining phases.

Gibbs Phase Rule:- This rule represents a criterion for the number of phases that will coexist within system at equilibrium and is expressed by the simple equation,

$$P + F = C + N$$

where,

P = Number of phases

F = Number of freedom 'or' the number of externally controlled variable. (temperature, pressure, composition)

C = Number of components in the system.

N = Number of non compositional variable (Temperature and pressure).

In practical condition for metallurgical and material's is system, the pressure is constant, the parameter N is one i.e. temperature is the only non-compositional variable.

Therefore, Gibbs phase rule can be written as

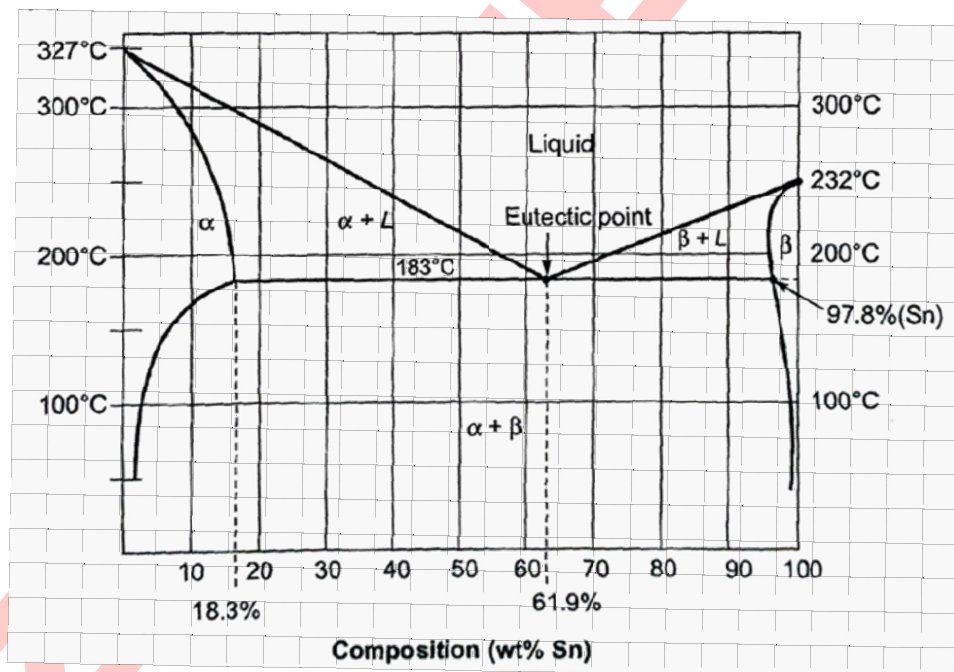
$$P + F = C + 1$$

93.

Sol. Binary phase diagram/Lead tin phase diagram:- Lead and tin have complete liquid solubility and limited solid solubility this attribute belongs to Eutectic system. For lead tin system the solid solution phase designated by α and β .

α = A solid solution of tin in lead. (tin solute lead solvent)

β = A solid solution of lead in tin. (lead solute tin solvent)

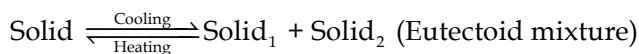


A familiar example is the 60-40 solder alloy containing 60% wt. Sn and 40% wt. Pb by comparing their phase diagram it indicates that an alloy of this composition is completely molten at about 188°C which makes this material especially attractive as a low temperature solder. Since it can be easily melted.

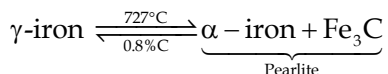
From above phase diagram it is clear that melting point of Pb is greater than the melting point of tin (Sn). In case of electrical solder generally prefer 64.9% wt. of Sn and 35.1% wt. of Pb, here major objective is to made joint as low as possible temperature and of satisfactory strength. But in case of plumbing solder we prefer, 30% wt. Sn and 70% wt. of Pb and objective is to made joint with proper strength.

94.

Sol. Eutectoid reaction is:



The eutectoid reaction for (0.8% C, 727°C)



95.

Sol. The general purpose of annealing is to reduce the work hardening, facilitate machining and to relieve internal stresses.

Process annealing is partial annealing. Steel is heated below austenitic transition temperature i.e. 723°C (annealing temperature range 600°C-650°C) where recrystallization takes place and then cooling slowly. Its purposes are:

- Stress relieving
- Deformed grains are reoriented to increase plasticity.

When austenite is cooled rapidly past the nose of the C-curve in TTT curve and kept isothermally in a constant temperature bath, it transforms to a non-lamellar product known as bainite.

In bainite, ferrite plates are surrounded by atmosphere of martensite. In upper bainite there are elongated cementite particles and in lower bainite there are fine particles of cementite within these ferrite plates.

96.

Sol. Flame Hardening:- The process consists of heating the surface of medium carbon steel by high temperature gas flame at 2400°C-3300°C and immediately cooling in air or in water. Heat may be supplied by oxyacetylene torch. The fuel used by the flame may be oxyacetylene, natural gas or kerosene. The flame rapidly imparts large amount of heat to the surface. The heat is supplied so quickly to the surface and for such a short time that the core remains unaffected.

Advantages:

1. There is practically no distortion of the work piece because only small sections of the work piece are heated.
2. As heating rate is high the work surface remains clean.
3. The process can easily be automated.
4. The process is more efficient for large work piece as compared to induction heating.

Disadvantages:-

1. Very thin sections may get distorted extensively.
2. Over heating may cause crack.

97.

Sol. Induction Hardening:- The work is placed in helical coils called inductor, the coil consist of several turns of water cooled cu tubing. Alternate current is passed through the inductor and thus alternate magnetic field sets up. The field induces eddy current on the surface layers and heat is generated. The current density is not uniform through out the cross-section of the work piece. Approximate the 90% of the heat is generated in the work layer of thickness (x) represented by

$$x = 5000 \sqrt{\frac{\rho}{\mu f}}$$

where f is the frequency, μ is the magnetic permeability and ρ is the electrical resistivity of the metal of the work piece. After induction heating of the surface, the part is quenched in an oil bath.

Advantages:-

1. Time required is very small hence the process is very quick and productivity is high.



2. Scale is not formed hence machining time is saved. Moreover, material is not lost due to scale formation.
3. The process can be automated.
4. Depth of hardness can be controlled easily.
5. Distortion is reduced.

Disadvantages:- Each type of work piece requires different fixtures for its holding. Each time one piece can be heat treated whereas number of work pieces can be treated at one time in carburizing and nitriding.

98.

Sol. Hardenability:- The capability of an alloy to be hardened by heat treatment is called its hardenability. It is a measure of the depth of hardness that can be obtained by heating and subsequent quenching. It should not be confused with hardness, which is the resistance of a material to indentation or scratching. The unit of hardenability is same as of length. It is an important property of welding, since it is inversely proportional to weldability. The hardenability of a ferrous alloy is measured by Jominy end quench test.

The factors on which hardenability of ferrous alloy depends:

1. Carbon content: High carbon steels are easily hardenable compared to low carbon steels.
2. On the grain structure or size of the austenite.
3. On the alloying elements present in the material.
4. On the cooling rate.

Various hardening methods are:

- | | |
|--------------------|------------------------|
| 1. Flame hardening | 2. Induction hardening |
| 3. Carburizing | 4. Nitriding |
| 5. Cyaniding | |

99.

Sol. The main reason of internal residual stresses can be:

1. **Mechanical load:-** Plastic deformation process such as machining and grinding.
2. **Thermal load:-** Non-uniform cooling of a component that was processed or fabricated at an elevated temperature. Such as weld or a casting.
3. **Phase change:-** A phase transformation that is induced upon cooling where in parent and product phases have different densities such as austenite to martensite.

Two possible adverse consequences of residual stresses are:

- The residual stresses whether tensile or compressive predominantly affect the soundness, dimensional stability and mechanical performance of the weld joint.
- Effects of residual stresses are mostly observed either near the last stage of weld thermal cycle or after sometime of welding in form of:

Cracks: Hot cracking, lamellar tearing, cold cracking.

Distortion: Longitudinal, angular and transverse

Reduction in mechanical performance of weld joint.

100.

Sol. A superalloy or high performance alloy, is an alloy that exhibits excellent mechanical strength and creep resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. Superalloys typically have a matrix with an austenitic face-centered cubic crystal structure. A superalloy's base alloying elements are usually nickel, cobalt, chromium and iron. Super alloys develop high temperature strength through solid solution strengthening.

Iron based super alloys contain

32 to 67% iron
15 to 22% chromium
9 to 38% nickel

Cobalt based super alloys contain	35 to 65% cobalt 19 to 30% chromium upto 35% nickel
Nickel based super alloys contain	38 to 76% nickel 27% chromium 20% cobalt

Properties:

- Iron based super alloys are characterised by high temperature as well as room temperature strength and resistance to creep, oxidation, corrosion and wear. Wear resistance increases with carbon content.
- Nickel based super alloys based on the formula $Ni_3(Al, Ti)$ are particularly resistant to temperature.
- Cobalt base super alloys have excellent high temperature creep and fatigue strengths and resistance to corrosion attack.

Application:-

Iron based super alloys: High temperature aircraft bearings and machinery parts subjected to sliding contact.

Nickel based super alloys: Aeroengine turbine blades, turbine discs, turbo chargers.

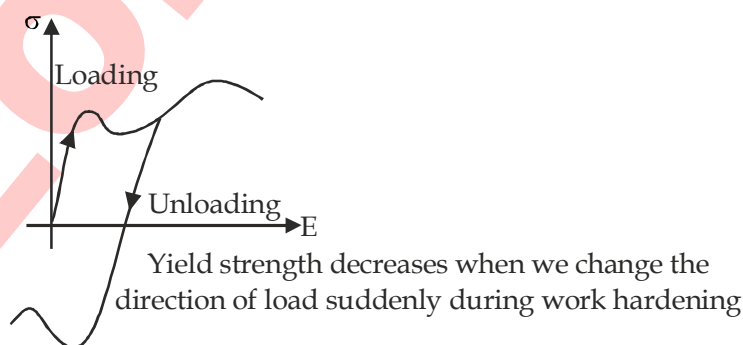
Cobalt based super alloys: Gas turbine engines.

101.

Sol. The Bauschinger effect refers to a property of materials where the material's stress/strain characteristics change as a result of the microscopic stress distribution of the material. For example, an increase in tensile yield strength occurs at the expense of compressive yield strength.

While more tensile cold working increases the tensile yield strength, the local initial compressive yield strength after tensile cold working is actually reduced. The greater the tensile cold working, the lower the compressive yield strength.

The bauschinger effect is normally associated with conditions where the yield strength of a metal decreases when the direction of strain is changed. It is a general phenomenon found in most polycrystalline metals. The basic mechanism for the Bauschinger effect is related to the dislocation structure in the cold worked metal. As deformation occurs, the dislocations will accumulate at barriers and produce dislocation pile-ups and tangles.



102.

Sol.

Effect of Alloying Elements on Machinability

Component	Effect on Machinability
Aluminium	Reduces the machinability.
Silicon	It forms hard abrasive particles which increase tool wear and thus lower its machinability.
Sulphur	Improves machinability of steel by forming low shear strength inclusions in the cutting zone.
Selenium	Improves machinability.
Lead	Improves machinability by acting as a lubricant in the cutting zone.
Tin	Machinability is enhanced by segregation of elemental Sn at grain boundaries.
Carbon	Improves machinability by making the steel less ductile.
Manganese	Improves machinability by combining with sulphur to form a soft inclusion.
Molybdenum	Reduces the machinability.
Vanadium	Reduces the machinability.

103.

Sol.

Properties of Duralumin

1. These can be cast, forged and stamped as these are ductile and malleable before heat treatment.
2. They have high hardness and strength when these are heat treated after fabrication and left at room temperature for several days. Strength of Duralumin is equal to that of mild steel. But density is one-third of steel.
3. These alloys have high electrical conductivity.
4. These alloys have high strength to weight ratio.
5. These are non-magnetic.

Properties of Y-alloys

1. These can be easily casted and hot worked. This is why these are extensively used for casting.
2. They retain their high strength and hardness at high temperature.
3. The aging process is carried out at room temperature for about 5 days.
4. Specific gravity is 2.78 in cast conditions.
5. The Brinell hardness number is between 82 to 85 for cast conditions.
6. These have better strength at high temperature than duralumin.

Properties of Magnalium

1. It is an alloy of aluminium, magnesium copper, nickel and tin.
2. It is a light weight alloy. Its tensile strength is in the range of 20-25 kg/mm².



- Percentage elongation is 7% for cold worked state and 30% for annealed state.
- Brittle with poor castability. However, it can be welded.
- Good machinability.

Hindalium:- It is an alloy of aluminium, magnesium, manganese and silicon produced by Hindustan Aluminium Corporation Ltd. It is produced in sheets of 16 gauge which are used for utensil manufacturing (cost of hindalium is one third of stainless steel).

Properties of Hindalium:-

- Strong and hard.
- Non reactive with food acids.
- Good surface finish.
- They are not easily scratching.
- Cost is lower than stainless steel.

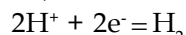
104.

Sol. Uniform corrosion:- Uniform corrosion is defined as a type of corrosion attack that is more or less uniformly distributed over the entire exposed surface of a metal. It is also referred as the corrosion that proceeds at approximately the same rate over the exposed metal surface. Cast irons and steels corrode uniformly when exposed to open atmosphere, soils and natural water, leading to the rusty appearance.

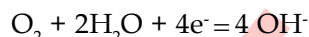
Mechanism:- The anodic reaction in the corrosion process is always the oxidation reaction.



In acidic environments, the cathodic process is mainly the reduction of hydrogen ions.

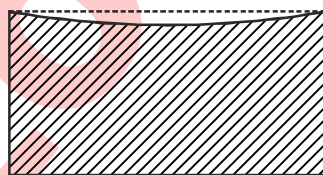


In alkaline or neutral environment, reduction of dissolved oxygen is the predominant cathodic process that causes uniform corrosion.

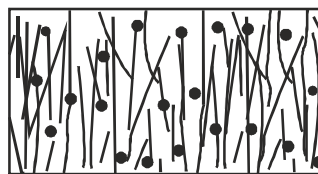


Pitting:- It is a form very localized corrosion attack in which small pits or holes form. They ordinarily penetrate from the top of a horizontal surface downward in a nearly vertical direction. It is an extremely insidious type of corrosion, often going undetected and with very little material loss until failure occurs.

The mechanism for pitting is that the oxidation occurs within the pit itself, with complementary reduction at the surface. It is supposed that gravity causes the pits to grow downward, the solution at the pit tip becoming more concentrated and dense as pit growth progresses. A pit may be initiated by a localised surface defect such as a scratch or a slight variation in composition.



Uniform Corrosion



Pitting Corrosion

105.

Sol. Plasticizers: The flexibility, ductility and toughness of polymers can be improved with the help of plasticizers. They also reduces hardness and stiffness.

Lubricants: There are used to improve processability of plastics by increasing the flowability.

1. **Nylon:**

Important Properties:

- Good mechanical strength
- Good abrasion resistance
- Good toughness
- Low coefficient of friction

Application:- Bearings, cams, gears, bushes, wires and cables jacket, fasteners.



2. **Vinyls:-**

- Economical and general purpose material.
- Ordinarily rigid but may be made flexible with plasticizers.
- Often copolymerized.
- Susceptible to heat distortion.

Application:- Floor coverings, pipe, electrical wire insulation.

106.

Sol. Ceramics are inorganic, nonmetallic solid prepared by the action of heat and subsequent cooling. Ceramic materials may have a crystalline or partly crystalline structure or may be amorphous.

Four Groups:

1. **Structural:** Bricks, pipes, roof tiles, etc.
2. **Refractories:** Kiln linings, gas fire radiants, steel crucibles etc.
3. **Abrasives:** Diamonds, WC, Al_2O_3 , silicon carbide etc.
4. **Cements:** Portland cement, lime etc.

20 Marks

107.

- Sol.**
1. **Case Hardening Steels:-** These usually contain less than 0.15% carbon. As carbon content is low, the core does not respond to hardening. By adding about 3% nickel and 0.45% manganese, these do not require further refining after carburising. Such a steel can be water-quenched and is used for gudgeon pins, camshafts, etc. If percentage of nickel is increased to 5% then oil-quenching can be used for hardening. Such a steel is used for gearbox parts, etc.
 2. **Nitriding Steels:-** These contain carbon from 0.4 to 0.5%. Accordingly these respond to direct hardening and a high strength case is developed after hardening and tempering. It may contain chromium between 1.6 to 3%. It is used when a high-strength core and a high hardness case are required. With 3% chromium, surface hardness of about 850 HV can be developed and when 1.1% aluminium is also added, then surface hardness of the order of 1100 HV can be developed.
 3. **High-Tensile Steels:-** These contain carbon of the order of 0.3 to 0.4%. Addition of 3% nickel and 0.6% fine grain structure. It can then be oil-quenched and is used for crank-shafts, connecting rods etc. A further addition of 0.8% chromium makes steel suitable for highly stressed parts. However it suffers from temper brittleness which can be prevented by specifying the tempering temperature. (It should not be tempered at particular temperature which depends upon composition). Another method to overcome temper brittleness is to add 0.25% molybdenum. With 4.25% nickel and 1.25% chromium, steel becomes suitable for air-hardening and can be used for complex shapes, but it also suffers from temper brittleness. A further addition of 0.45% vanadium and 1% silicon (1.25% molybdenum to remove temper brittleness) makes it suitable for forging dies, die-casting dies and extrusion press dies.
 4. **Wear-Resisting Steels:-** These contain carbon from 1 to 1.2%. Addition of 12.5% manganese makes austenite to be retained as a result of heating and quenching. This is known as 'Hadfields' austenitic steel which responds to work hardening and becomes harder as a result of rough treatment. Accordingly it is used for track work, dredging equipment and crushing machinery. Steels with 1.4% chromium and 0.45% manganese can be oil-quenched and are very hard and used for roller and ball races.
 5. **Heat Resisting Steels:-** These contain carbon varying between 0.15% and 0.3%. To make them corrosion resistant, 12 to 16% chromium is added. While chromium also improves the strength, other elements like carbon, tungsten, molybdenum strengthen the alloy. These also resist oxidation and attack by vapour and gases at high temperature. They also retain their strength at high temperatures and resist creep. Steel used for turbine blades and dies for use up to $600^{\circ}C$ contains 0.15% C, 1% Mn, 12% Cr and 1% Ni. Some of the heat resisting steels respond to heat treatment and some can be hardened only by working.



108.

Sol.

1. Carburizing

- In the carburising process, the mild steel component is placed in a steel box partially filled with a carburising powder and the component is then totally surrounded and tightly packed with the carbonaceous material.
- The box is fitted with a lid and sealed with fireclay and heated in a furnace at 900°C for a number of hours depending upon the depth of penetration required.
- The carbon content of the surface region of the specimen thus increases to 0.8% approximately.
- However, grain growth occurs during this process and as such further treatment may be required to refine the grains.
- Carburising treatment is used where component requires a very tough core to withstand the fluctuating loads, combined with a hard surface to resist wear. It also permits use of inexpensive low-carbon steel. However, surface gets scaled and needs to be finished by grinding.
- An example of application of this process is the gudgeon pin used in I.C. engines.

2. Nitriding

- Nitriding is a process used for case-hardening components, which may be subjected to moderately high temperature during their working life, or when it is important to prevent any distortion or scaling of the component during heat treatment.
- Plain carbon steel cannot be treated satisfactorily by this process.
- The composition of a typical alloy steel suitable for nitriding would include 0.4% carbon, 1.5% chromium, 0.5% molybdenum, and 1.2% aluminium.
- Nitriding is accomplished by heating the component at a temperature of 500°C in an atmosphere of ammonia gas. This temperature is closely controlled and maintained for a period of from 25 to 95 hours, depending on the case depth required. The heat breaks down the ammonia gas into nitrogen and hydrogen, and the nitrogen reacts with the steel to form a very hard nitride case on the component. No quenching is necessary.
- Since this process is performed at a temperature below that of the steel's critical range, the core of the component is unaffected by it, and distortion of the component is unlikely to occur. There is no possibility of scaling or cracking. Cracking. The nitriding process is relatively expensive because of the high initial cost of the plant, and the longer heating times involved.
- An example of this process is the standard drill bushes used in drill jigs. In this case, distortion caused by heat treatment is negligible, and the bushes can be finish-machined before they are hardened.

109.

Sol.

Age hardening is the most important method of improving the physical properties of some of the non-ferrous alloys by solid state reaction. It is mostly applicable to the alloys of aluminium, manganese and nickel and occasionally used for alloys of Copper and Iron. The process of age hardening is often called as precipitation hardening. The process of age hardening consists of two stages :

(i) In the first stage

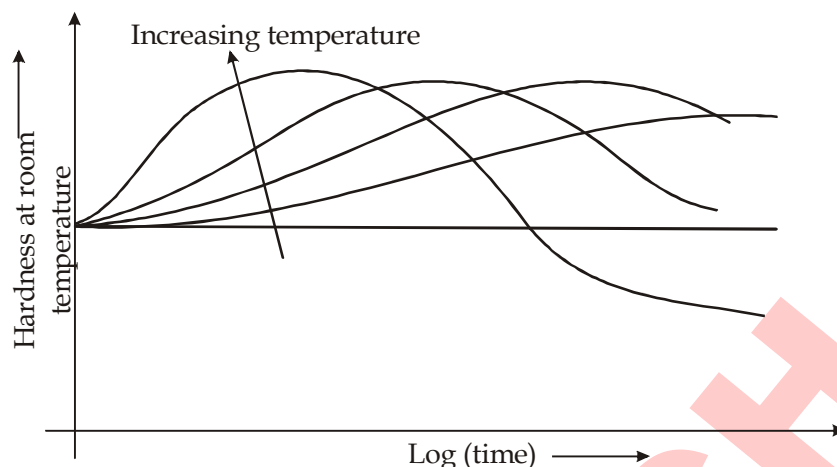
An unstable condition is produced by the formation of a supersaturated solid solution. In this state, the physical properties of the alloy do not change appreciably and the alloy remains soft and ductile.

(ii) In the second stage

Precipitation of the supersaturated phase occurs which increases the hardness and strength of the alloy. The process takes less time at higher temperatures, and when it is done in a furnace, it is called precipitation heat treatment. At room temperature, it may even take several days.

If the age hardness temperature is lowered the diffusion of the atoms which are held in supersaturated condition is slowed down. Too high or too low temperature is not required in this process. If good results are to be obtained by age hardening both the time and temperature should be specified.





Case Hardening :

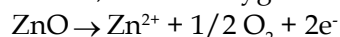
- This process is used to produce a high surface hardness for wear-resistance supported by a tough, shock-resisting core.
- It is the process of carburisation, i.e., saturating the surface layer of steel with carbon to about 0.9%, or some other process by which, case is hardened and core remains soft. The carburised steel is then heated and quenched, so that only the surface layers will respond, and the core remaining soft and tough since, its carbon content is low.
- The objects of case hardening are :
 - (i) To obtain a hard and wear resistant surface on machine parts with enrichment of the surface layer with carbon to a concentration of 0.75 to 1.2%.
 - (ii) To obtain a tough core.
 - (iii) To obtain close tolerances in machining parts.
 - (iv) To obtain a higher fatigue limit and high mechanical properties in the core.

110.
Sol.

Schottky Defect	Frenkel Defect
In Schottky defect the difference in size between cation and anion is small.	Frenkel defect contains ionic crystals where the anion is larger than the cation.
Both anion and cation leave the solid crystal.	Usually the smaller ion (cation) leaves its original lattice structure.
Atoms permanently leave the crystal.	Atoms remain within the solid crystal.
There is formation of two vacancies.	Only one vacancy is created.
The density of the solid decreases.	Density remains the same.

(ii) (a) The Frenkel defect does not exist in pure alkali metal halides because the ions are too large to enter the interstitial sites.

(b) When ZnO is heated, it loses oxygen in the following ways:



To maintain electrical neutrality, Zn^{2+} ions are entrapped in the interstitial sites, while electrons are entrapped in neighbouring interstitial sites. As a result, there is an excess of metal defect. The colour is yellow due to the presence of free electrons in the interstitial sites.

(c) When CaCl_2 is added to AgCl , it introduces an impurity defect. To maintain electrical

conductivity, one Ca^{2+} ion will replace two Ag^+ ions. Ca^{2+} ion will occupy one of the Ag^+ positions, leaving the other as a hole. As a result, a hole similar to the Schottky defect is formed.

111.

Sol. Major imperfections in the crystal structure of metals

1. **Point defects**

- Vacancy
- Interstitial
- Impurities

2. **Line defects: Dislocations**

- Edge dislocation
- Screw dislocation

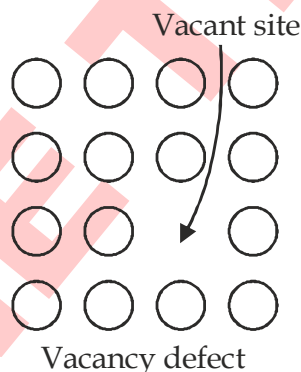
3. **Surface or Grain boundary defects**

- Grain boundaries
- Tilt boundaries
- Twin boundaries

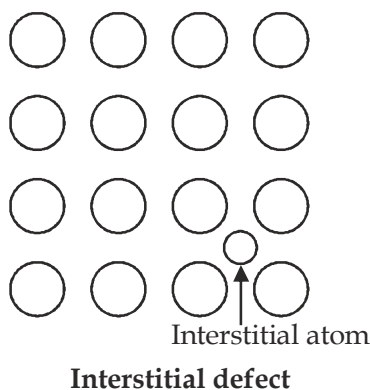
4. **Volume defects: Stacking faults**

- Point defects:-** A point imperfection is a very localized interruption in the regular arrangement of a lattice, e.g. vacant site.

- Vacancy defect:** Vacancies are empty atomic sites in a crystal lattice. Vacancies may arise in a crystal lattice due to imperfect packing during solidification or crystallization, and they may also arise due to thermal vibrations of atoms.



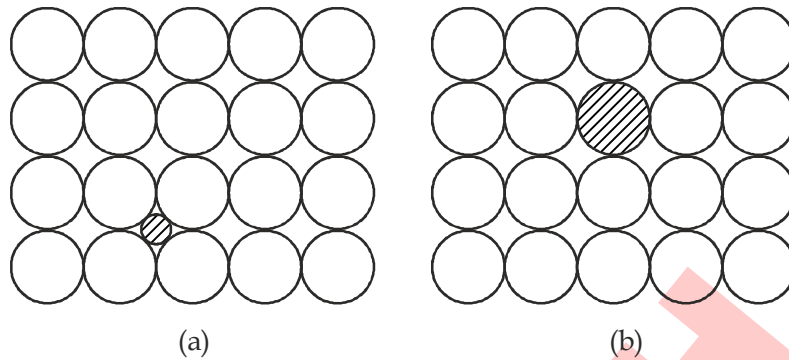
- Interstitial defect:** Interstitial defect arises when an atom occupies an interstitial position i.e. between the atoms in the lattice of the ideal crystal. The interstitial atom may be either a normal atom of the crystal or a foreign atom.



- Impurities:** Small particles may be embedded in the structure such as slag inclusions in metals or foreign atoms in the lattice structure. Impurity atoms are of two types either substitutional or



interstitial atoms.

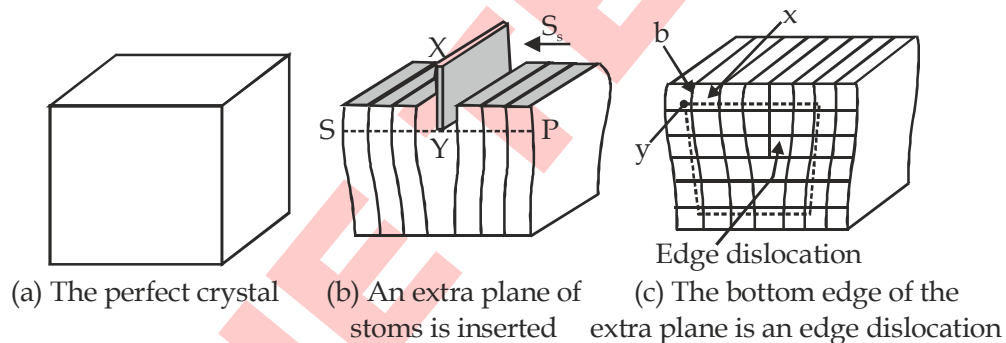


Substitutional impurity atom refers to that atom which substitutes for or replaces a parent atom in the crystal.

Considerable distortion of the lattice structure occurs due to impurities in the crystal or lattice structure.

2. Line Defects-Dislocations

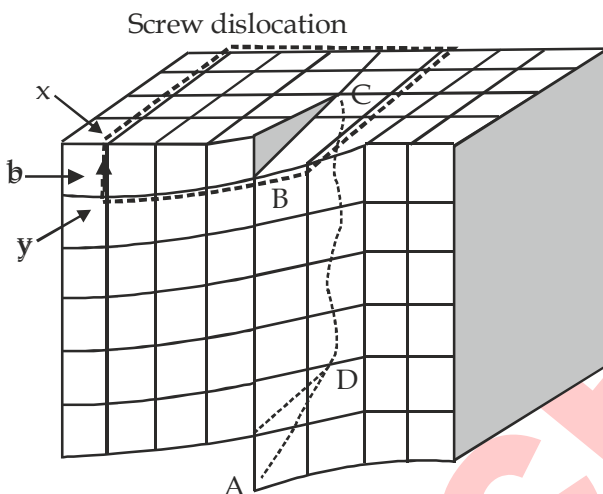
A dislocation may be defined as a disturbed region between two substantially perfect parts of a crystal.



- (a) **Edge dislocation:** The line marked as SP represents the slip plane of the crystal and the dashed lines represent the crystal planes perpendicular to the slip plane. The plane marked 'X' at the top of the figure ends at point 'Y' on the slip plane, whereas the planes on either side of 'X' run continuously from the top to the bottom of the figure. In such a case where a lattice plane ends inside a crystal, an edge dislocation results.

The edge dislocation shown in figure has an incomplete plane which lies above the slip plane. Such an edge dislocation is called positive edge dislocation and is represented by the symbol $\perp$ where the vertical line represents the incomplete plane and the horizontal line represents the slip plane. It is also possible to have the incomplete plane below the slip plane which can be represented by the symbol Γ .

- (b) **Screw dislocation:** The right side portion of the crystal has been sheared by one atomic distance on the downward direction relative to the left side portion. No slip has taken place to the rear portion of the line DC and therefore DC is a dislocation line. The plane ABCD is the slip plane. The designation screw for this lattice defect is derived from the fact that the lattice planes of the crystal, spiral the dislocation line DC.



Representation of a screw dislocation

3. **Surface Defects:** Surface defects may include grain boundary, tilt boundary, twist boundary, twin boundary etc.
- (a) **Grain Boundaries:** Grain boundary is formed when two growing grain surfaces meet each other and these grain boundaries separate crystals or grains of different orientation in polycrystalline materials.
- (b) **Tilt Boundaries:** Tilt boundaries are formed by edge dislocations and are regarded as an array of edge dislocations located one above the other.
- (c) **Twist Boundaries:** Other low angle boundaries formed by screw dislocations are called as twist boundaries.

Twin boundaries:- A twin boundary separates two parts of a crystal having the same orientation.

4. **Volume Defects:** Volume defects are stacking faults which are created by a fault in the stacking sequence of close packed atomic planes in crystals such as FCC and HCP.

Stacking faults are more frequently found in deformed metals. The presence of these imperfections or defects in metallic crystals impairs the physical and mechanical properties of metals and alloys. The theoretical strength of a metal (the force required to separate the bond between adjoining atoms) turns out to be several million newtons per square metres, but the ordinary strength of metals is 100 to 1000 times less. This is because of occurrence of defects in the crystal structure.

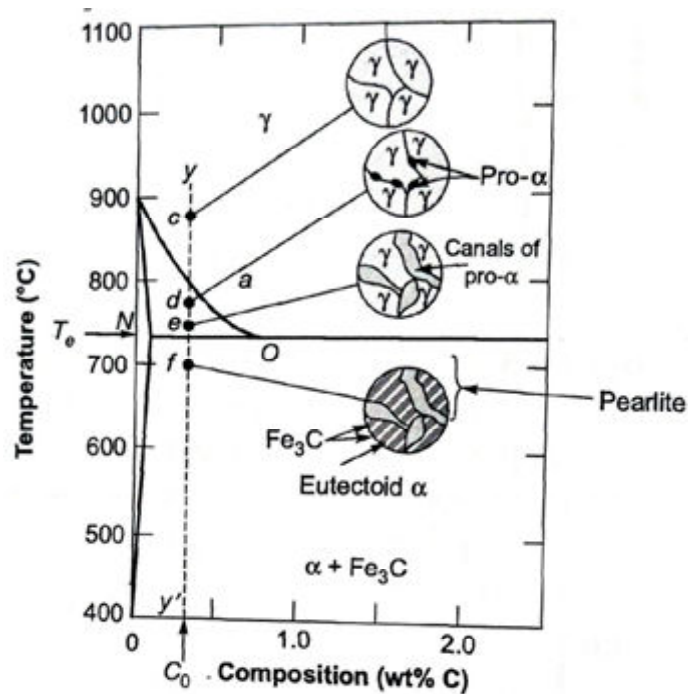
The lower yield point of crystals than the computed yield point is because of the imperfections in the crystal and is explained by the type of defect called 'dislocation'. With grain growth, strength and hardness of a metal decrease, but ductility increases.

112.

- Sol.** Steels containing carbon up to 0.8% are said to be hypoeutectoid steels while steels with 0.8% to 2.14% C are said to be hypereutectoid steels.

Hypoeutectoid Alloys (<0.8%C): A steel sample in hypo eutectoid steel range is cooled along yy'. At point c, the alloy is entirely in the austenite phase. The moment temperature decreases to point d, ferrite start appearing in the microstructure. This ferrite that appears before eutectoid temperature is called pro-eutectoid ferrite (pro- α). As temperature decreases mass fraction of pro- α will increase and at point e there will be canals of pro- α at the grain boundary. As the temperature is lowered just below the eutectoid, to point f, all the γ -phase that was present at temperature T_e (and having the eutectoid composition) will transform to pearlite. There will be virtually no change in the α phase that existed at point e in crossing the eutectoid temperature. It will normally be present as a continuous matrix phase surrounding the isolated pearlite colonies. It will noted that two micro constituents are present, i.e., proeutectoid ferrite and pearlite which will appear in all hypoeutectoid iron-carbon alloys that are slowly cooled to a temperature below the eutectoid.

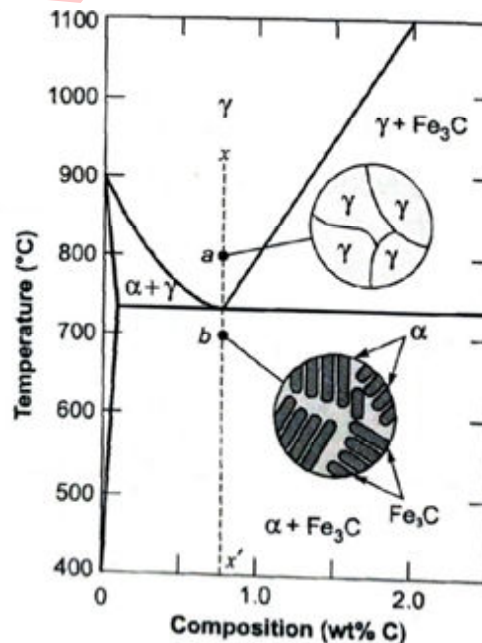




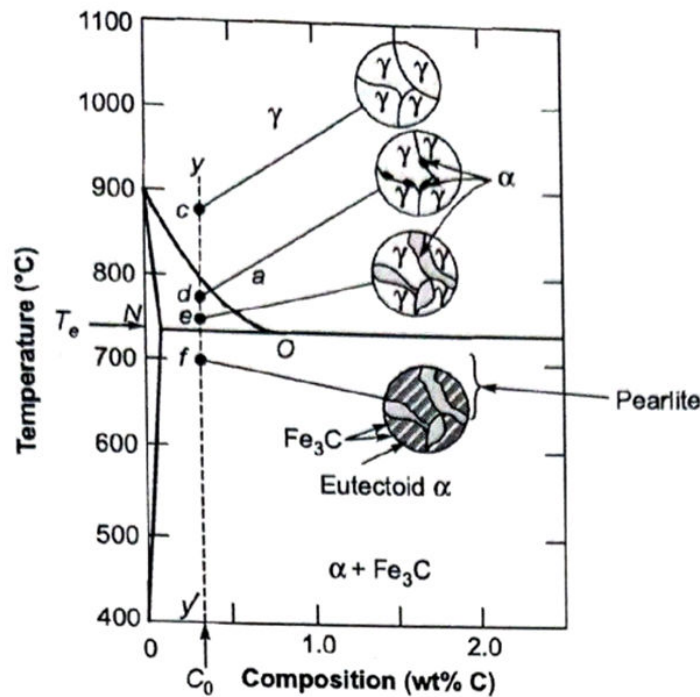
113.

Sol. Development Of Microstructures In Iron-Carbon Alloys:

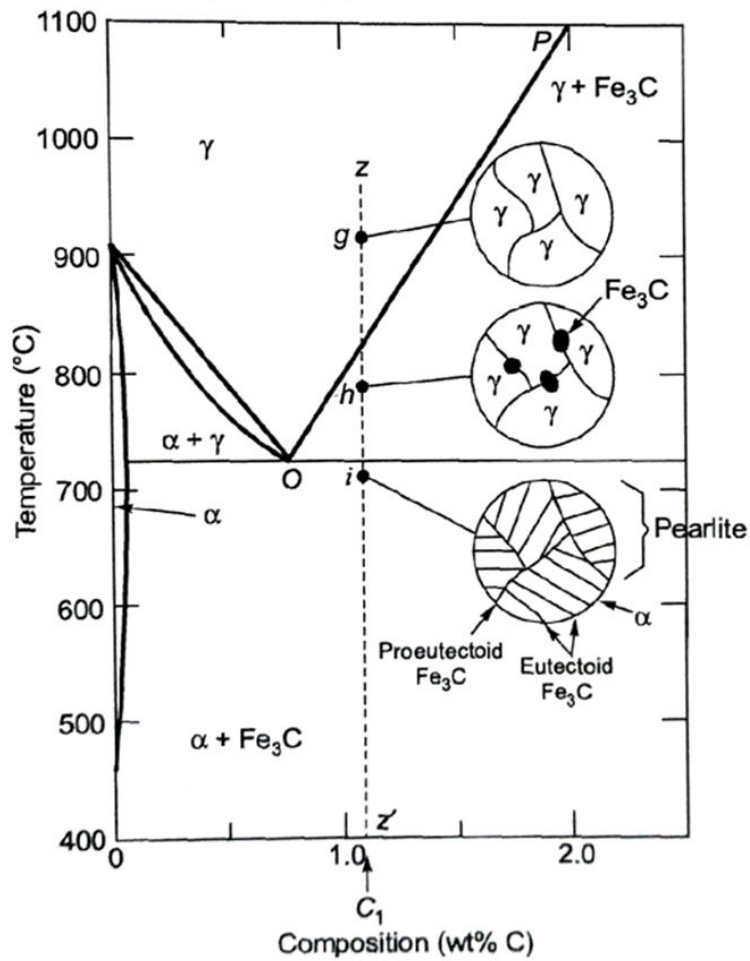
- Eutectoid composition (0.8% C):** An alloy of eutectoid composition (0.8 wt% C) as it is cooled from a temperature within the phase region (Point a), say, 800°C, and moving down the vertical line xx' . At point a, the alloy is entirely in the austenite phase. After cooling through the eutectoid temperature, the microstructure for this eutectoid steel (Point b) consists of alternating layers or lamellae of the two phases (α and Fe_3C) also known as pearlite.



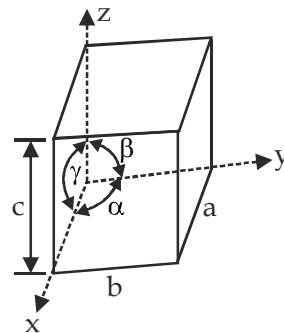
2. **Hypoeutectoid Alloys (<0.8% C):** A steel sample in hypo eutectoid steel range is cooled along yy' . At point c, the alloy is entirely in the austenite phase. The moment temperature decreases to point d, ferrite start appearing in the microstructure. This ferrite that appears before eutectoid temperature is called pro-eutectoid ferrite (pro- α). As temperature decreases mass fraction of pro- α will increase and at point e there will be canals of pro- α at the grain boundary. As the temperature is lowered just below the eutectoid, to point f, all the γ phase that was present at temperature T_e (and having the eutectoid composition) will transform to pearlite. There will be virtually no change in the α phase that existed at point e in crossing the eutectoid temperature. It will normally be present as a continuous matrix phase surrounding the isolated pearlite colonies. It should also be noted that two micro constituents are present i.e. proeutectoid ferrite and pearlite which will appear in all hypoeutectoid iron-carbon alloys that are slowly cooled to a temperature below the eutectoid.



3. **Hypereutectoid Alloys (0.8% to 2.14% C):** Analogous transformations and microstructures result for hypereutectoid alloys, those containing between 0.8 to 2.14 wt% C, which are cooled from temperatures within the γ phase field. Before eutectoid temperature proeutectoid cementite is formed. In the final structure (Point i) proeutectoid cementite and pearlite will appear.



114.
Sol.



Unit cell: The atomic order in crystalline solids, indicates that small group of atoms that form a repetitive pattern.

a, b, c = Lattice parameters

α, β, γ = Interfacial angles

Effective number of lattice points/atoms in the unit cell of cubic lattices.

1. **Simple cubic structure:-** In simple cubic structure, with atoms located at each of the corners of a unit cell.

$$\begin{aligned}\text{Number of atoms} &= \text{Number of corner atoms } (N_c) \times \frac{1}{8} \\ &= 8 \times \frac{1}{8} = 1 \text{ atoms}\end{aligned}$$

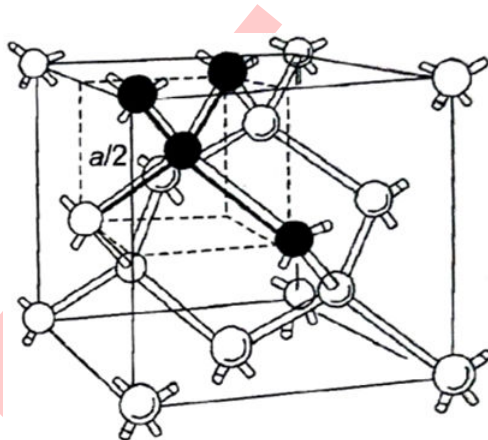
2. **Body centered cubic structure (BCC):-** In this crystal structure a cubic unit cell with atoms located at all eight corner and a single atom at the cube center.

$$\begin{aligned}\text{Number of atoms} &= \text{Number of corner atoms } (N_c) \times \frac{1}{8} + \text{Body centered atom } (N_b) \\ &= 8 \times \frac{1}{8} + 1 = 2 \text{ atoms}\end{aligned}$$

3. **Face centered cubic structures (FCC):-** In case centered cubic structure a unit cell with atoms located at each of the corners and the centers of all the cube faces.

$$\begin{aligned}\text{Number of atoms} &= \text{Number of corner atoms } (N_c) \times \frac{1}{8} + \text{Number of face centered atom} \times \frac{1}{2} \\ &= 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 1 + 3 = 4 \text{ atoms}\end{aligned}$$

Diamond cubic structure (Si)



Si has a diamond cubic structure. In this structure 8 atoms are arranged at corners and 6 atoms are arranged at face centers and 4 atoms are arranged inside cell on 4 body diagonal.

Average number of atoms in the diamond cubic unit cell = $\frac{1}{8} \times 8$ (Corner atoms) + $\frac{1}{2} \times 6$ (Face centered atoms) + 1×4 (Atoms inside the cell) = $1 + 3 + 4 = 8$
Relations between atomic radius (R) and lattice parameter (a)

$$R = \frac{a\sqrt{3}}{8}$$

Lattice parameter (a) = 5.431×10^{-10} m

$$\text{Atomic radius (R)} = \frac{5.431 \times 10^{-10} \sqrt{3}}{8} = 1.1758 \times 10^{-10} \text{ m}$$

$$\text{Volume unit cell} = a^3 = (5.431 \times 10^{-10})^3$$

$$\text{Atomic packing factor} = \frac{N_{av} \times \frac{4}{3} \pi R^3}{a^3} = \frac{8 \times \frac{4}{3} \times \pi (1.1758 \times 10^{-10})^3}{(5.431 \times 10^{-10})^3} = 0.3400$$

$$\% \text{APF} = 34.00\%$$

$$\text{Density} = \frac{N_{av} \times \text{Atomic weight}}{\text{Avagadro number} \times \text{Volume of unit}} = \frac{8 \times (2 \times \text{atomic number})}{6.023 \times 10^{23} \times (5.431 \times 10^{-10})^3}$$

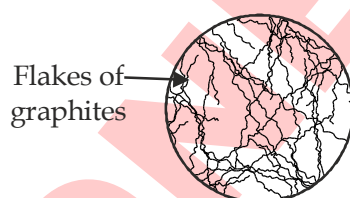
$$= \frac{8 \times 2 \times 14 \times 10^{-3}}{9.64833 \times 10^{-5}} = 2321.645 \text{ kg/m}^3$$

115.

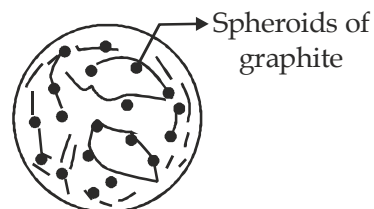
Sol. S.G. iron is an engineering material distinguished by its high strength, toughness and ductility, combined with excellent casting properties and good machinability. It has a high modulus of elasticity and good resistance to corrosion and wear.

Cerium and magnesium actually enhances the growth of flakes in all directions. This results in globular structure instead of flakes. The reason behind is drastic reduction in interfacial energy leads to growth in all directions by the addition of those elements.

The microstructure of SG cast iron has many graphite balls. The gray cast iron has many graphite flakes. This different structure is the main reason to the physical properties. Since the tips of graphite flakes cause higher stress concentration than graphite balls, so gray cast iron has lower tensile strength and elongation.



Gray Cast Iron



Spherical Graphite Cast Iron

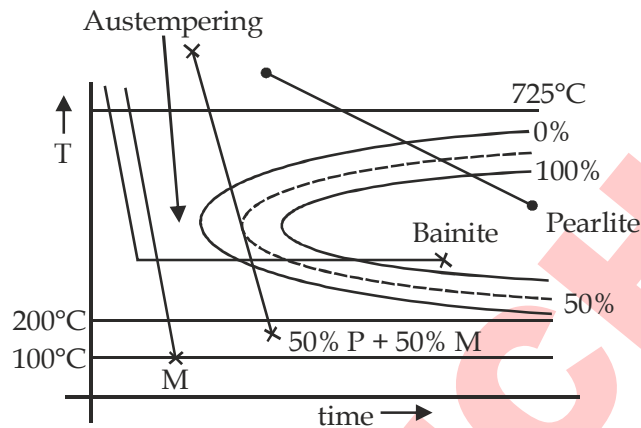
The microstructure of a solid solely depends on the cooling rate by which it has been cooled from molten metal. If the cooling rate is fast, the microstructure obtained will be very fine. Such kind of structure is highly brittle and not suitable for any practical purpose. For example, if iron is cooled from above 725°C with a cooling rate greater than critical cooling rate, martensite is obtained which is the hardest phase of iron.



Martensite after quenching

116.

Sol. **Tempering:-** It is heat treatment process by which hardness is reduced and toughness is improved in it. The specimen is heated upto specified temperature and then quenched in air or any other suitable medium.



Austempering: The change of structure of steel from austenite to bainite is known as austempering. In this process, the steel sample is heated and then cooled at a rate more than critical cooling rate but above martensite start line, the sample is then maintained at that temperature for some time and all the austenite is then converted into bainite.

The advantages are:

1. Brittle martensite does not form.
2. Quenching cracks between core and surface do not develop.
3. Ductility is increased.
4. Impact strength and toughness are increased.

Martempering: This is also called step quenching. It is done in phases

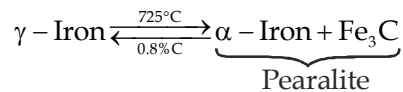
1. The austenite sample is initially quenched into a hot bath maintained below the nose of TTT diagram but above martensite start line. Then core also gets cooled up to the temperature of the outer surface and no residual stresses are there.
2. The sample is cooled in another medium like oil or air, and held there until they are completely cooled. The purpose of transfer to another medium is to reduce internal stresses associated with austenite to martensite transformation.

Advantages of martempering over normal quenching:-

1. Less volume change occurs due to large amount of retained austenite.
2. Less distortion, since transformation occurs almost simultaneously in entire volume.
3. Less danger of quenching cracks.

117.

- Sol.**
1. **Spheroidite:-** If pearlite is heated just below the eutectoid temperature (say 700°C) and held at this temperature for a day or so, the cementite lamelle in pearlite get transformed to spherical shape. The structure is called 'spheroidite'. This structure is less conducive to stress concentration because of spherical grains, as compared to cementite (lamelle structure). This spheroidite is more tough but less hard as compared to pearlite.
 2. **Pearlite:-** Pearlite is phase mixture of α -iron and Fe_3C . Pearlite is having plate like structure of α -iron and Fe_3C .

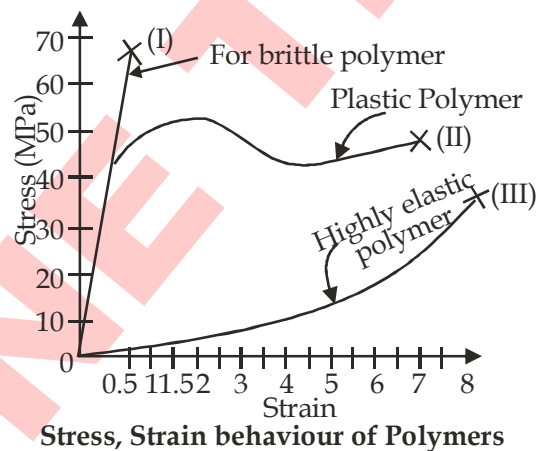


Pearlite formation takes place primarily by process of diffusion. Pearlite is having good toughness and ductility. Pearlite has less brittleness and hardness in comparison of bainite and martensite.

3. **Bainite:-** Austenite sample is quenched at a rate greater than or equal to critical cooling rate to a temperature below the nose of TTT but above the martensite start line. This temperature is maintained for a substantial period of time so that transformation line enters into TTT curve, this produces bainite. The microstructure of bainite consists of ferrite and cementite phase, and this diffusional process is involved in its formation. Bainite forms as needles or plates, depending on the temperature of the transformation. Bainite has high hardness but less ductility and toughness.
4. **Martensite:-** Any cooling rate greater than or equal to critical cooling rate will freeze carbon at its location and the microstructure will appear like a mechanical mixture of ferrite and cementite or colloidal solution of cementite into ferrite or submicroscopic cementite spread in the microstructure of ferrite. Martensite is having body centered tetragonal structure (BCT). It is a non-equilibrium single-phase structure that results from a diffusionless transformation of austenite. Since the martensite transformation does not involve diffusion, it occurs almost instantaneously. Martensite is the hardest and most brittle phase of iron.

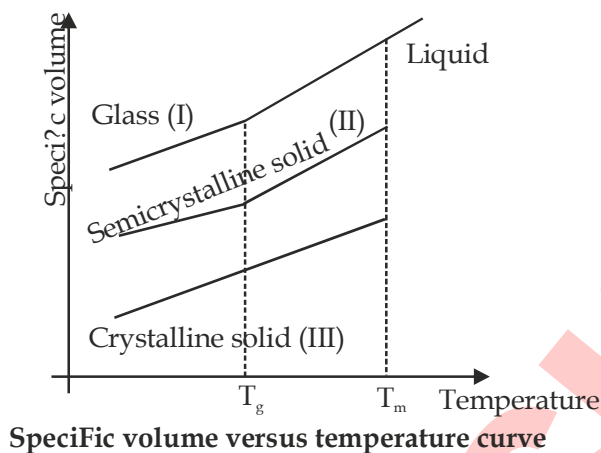
118.

Sol. The stress-strain behaviour of polymers can be categorized into several classes of behaviour.



1. **Brittle behaviour:-** It is characterized by no yield point, a region of Hookean behaviour at low strains and failure characterized by conchoidal lines such as seen in inorganic glasses.
2. **Yield behaviour:-** It is characterized by a stress-strain curve followed by yielding deformation which is usually associated with crazing or shear bending and usually ductile failure. Ductile failure exhibits a large extent of deformation on the failure surface. Yield behaviour can result in necking which exhibits a close to constant load regime and a terminal increase in the stress.
3. **Rubber like behaviour:-** It is characterized by the absence of a yield point but exhibiting a plateau in an engineering stress-strain curve. Often rubber-like behaviour exhibits a terminal increase in the stress followed by failure which results in a tear with little permanent deformation exhibited in the failure surface.

The mechanical properties of polymer are highly sensitive to:



1. Rate of deformation
 2. Temperature of polymer
 3. Chemical nature of environment such as the presence of oxygen, water or organic solvents, etc.
- Amorphous polymers do not have a specific melting point, but they do undergo a distinct change in their mechanical behaviour across a narrow range of temperature. At low temperatures, they are hard, rigid, brittle and glassy; at high temperatures, they are rubbery or leathery. The temperature at which a transition occurs is called the glass-transition temperature (T_g). The glass transition temperature varies with different polymers.