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**Materials Engineering**

**By**

**Hareesh Kumar**



**QUANTUM PAGE PVT. LTD.**  
**Ghaziabad ■ New Delhi**

**PUBLISHED BY :**            **Apram Singh**  
**Quantum Page Pvt. Ltd.**  
 Plot No. 59/2/7, Site - 4, Industrial Area,  
 Sahibabad, Ghaziabad-201 010

**Phone :** 0120 - 4160479

**Email :** pagequantum@gmail.com    **Website:** www.quantumpage.co.in

**Delhi Office :** 1/6590, East Rohtas Nagar, Shahdara, Delhi-110032

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1<sup>st</sup> Edition : 2009-10

12<sup>th</sup> Edition : 2020-21

2<sup>nd</sup> Edition : 2010-11

3<sup>rd</sup> Edition : 2011-12

4<sup>th</sup> Edition : 2012-13

5<sup>th</sup> Edition : 2013-14

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7<sup>th</sup> Edition : 2015-16

8<sup>th</sup> Edition : 2016-17

9<sup>th</sup> Edition : 2017-18

10<sup>th</sup> Edition : 2018-19

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(1-1 B to 1-35 B)

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Static failure theories: Ductile and brittle failure mechanisms, Tresca, Von Mises, Maximum normal stress, Mohr-Coulomb and Modified Mohr-Coulomb; Fracture mechanics: Introduction to Stress intensity factor approach and Griffith criterion. Fatigue failure: High cycle fatigue, Stress-life approach, SN curve, endurance and fatigue limits, effects of mean stress using the Modified Goodman diagram; Fracture with fatigue, Introduction to non-destructive testing (NDT).

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## MATERIALS ENGINEERING

L-T-P

3-0-0

### Objectives:

- Understanding of the correlation between the internal structure of materials, their mechanical properties and various methods to quantify their mechanical integrity and failure criteria.
- To provide a detailed interpretation of equilibrium phase diagrams.
- Learning about different phases and heat treatment methods to tailor the properties of Fe-C alloys.

### UNIT-I

Crystal Structure: Unit cells, Metallic crystal structures, Ceramics. Imperfection in solids: Point, line, interfacial and volume defects; dislocation strengthening mechanisms and slip systems, critically resolved shear stress.

Mechanical Property measurement: Tensile, compression and torsion tests; Young's modulus, relations between true and engineering stress-strain curves, generalized Hooke's law, yielding and yield strength, ductility, resilience, toughness and elastic recovery; Hardness: Rockwell, Brinell and Vickers and their relation to strength.

### UNIT-II

Static failure theories: Ductile and brittle failure mechanisms, Tresca, Von-mises, Maximum normal stress, Mohr-Coulomb and Modified Mohr-Coulomb; Fracture mechanics: Introduction to Stress-intensity factor approach and Griffith criterion. Fatigue failure: High cycle fatigue, Stress-life approach, SN curve, endurance and fatigue limits, effects of mean stress using the Modified Goodman diagram; Fracture with fatigue, Introduction to non-destructive testing (NDT).

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Alloys, substitutional and interstitial solid solutions- Phase diagrams: Interpretation of binary phase diagrams and microstructure development; eutectic, peritectic, peritectoid and monotectic reactions. Iron-iron-carbide phase diagram and microstructural aspects of ledeburite, austenite, ferrite and cementite, cast iron.

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Heat treatment of Steel: Annealing, tempering, normalising and spheroidising, isothermal transformation diagrams for Fe-C alloys and microstructure development. Continuous cooling curves and interpretation of final microstructures and properties- austempering, martempering, case hardening, carburizing, nitriding, cyaniding, carbo-nitriding, flame and induction hardening, vacuum and plasma hardening.

### UNIT-V

Alloying of steel, properties of stainless steel and tool steels, maraging steels- cast irons: grey, white, malleable and spheroidal cast irons- copper and copper alloys; brass, bronze and cupro-nickel; Aluminium and Al-Cu - Mg alloys- Nickel based superalloys and Titanium alloys.

### Course Outcomes:

- Student will be able to identify crystal structures for various materials and understand the defects in such structures.
- Understand how to tailor material properties of ferrous and non-ferrous alloys.
- How to quantify mechanical integrity and failure in materials.

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# 1

## UNIT

# Crystal Structure and Mechanical Property Measurement

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Unit Cells, Metallic  
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Brinell and Vickers and  
their Relation to Strength



**PART-1***Crystal Structures : Unit Cells, Metallic Crystal Structures.***CONCEPT OUTLINE**

**Unit Cell :** A small 3D representative structural sub unit of lattice is called unit cell.

**Crystal Structure :** The crystal structure is formed by associating every lattice point with an assembly of atoms or molecules or ions, which are identical in composition, arrangement and orientation.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

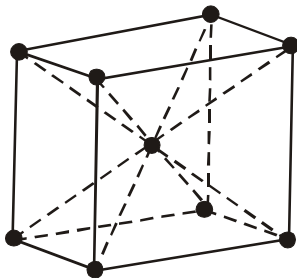
**Que 1.1.** With the help of neat sketch explain different types of crystal structure.

**AKTU 2016-17, Marks 10****Answer**

Following are the different types of crystal structures :

**a. Body Centred Cubic Structure (BCC) :**

1. BCC structure has atoms at its each corner and one atom in its centre.



**Fig. 1.1.1. BCC.**

$$\therefore \text{Total atoms in BCC} = \frac{1}{8} \times 8 + 1 = 2 \text{ atoms}$$

2. The coordination number of BCC arrangement is 8 and packing factor is 0.68.

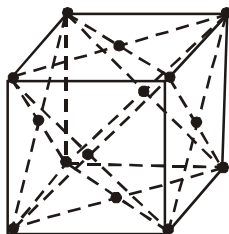
3. The BCC structure can be generally seen in Lithium, Potassium, Sodium etc.

**b. Face Centred Cubic Structure (FCC) :**

1. It consists of atoms at its each corner and one atom at centre of each face.

$$\therefore \text{Total atoms in FCC unit cell} = \frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 1 + 3 = 4 \text{ atoms}$$

2. The coordination number is 12 and packing factor is 0.74 for FCC arrangement.
3. The FCC structure can be generally seen in Copper, Gold, Silver and Lead etc.



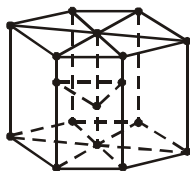
**Fig. 1.1.2. FCC.**

**c. Hexagonal Close-Packed Structure (HCP) :**

1. The unit cell is like a hexagonal prism in HCP.
2. There are twelve corners and each corner have an atom and one atom at the centre of each of the two hexagonal faces and three atoms in the body of the cell. In total, seventeen atoms take part in formation of a HCP unit cell.

$$\therefore \text{Total atoms in HCP} = 12 \times \frac{1}{6} + 3 + 2 \times \frac{1}{2} = 6 \text{ atoms}$$

3. This is identical to FCC, having coordination number 12 and packing factor 0.74.
4. This HCP structure is generally seen in Zinc, Magnesium and Beryllium etc.



**Fig. 1.1.3. HCP.**

**Que 1.2.**

**Define atomic packing factor. Illustrate simple cubic crystal structure, deduce packing factor for simple cubic crystal structure.**

**Answer**

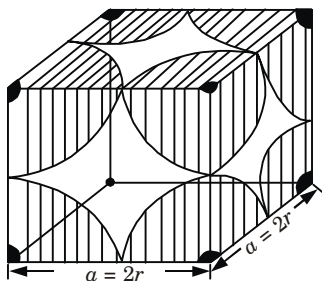
**A. Atomic Packing Factor :** It is defined as the fraction of the space occupied by atoms in the unit cell.

**B. Simple Cubic Crystal Structure :**

1. The unit cell edge length of this structure along the crystallographic axis and interaxial angles are equal (*i.e.*,  $a = b = c$  and  $\alpha = \beta = \gamma = 90^\circ$ ).
2. Atoms are present only at the corners of this unit cell.
3. A corner atom is shared by eight unit cells, so that the contribution of a corner atom to a unit cell is  $1/8$ .
4. The cube has eight corners, hence the contribution of eight corner atoms to a unit cell or the number of atoms per unit cell =  $\frac{1}{8} \times 8 = 1$ .
5. In simple cubic cell, the number of nearest neighbour atoms to an atom or coordination number is six.

**C. Packing Factor for Simple Cubic Crystal Structure :**

1. The simple cubic structure contains only one atom per unit cell.
2. The volume occupied by atoms in the unit cell ( $v$ ) =  $1 \times \frac{4}{3} \pi r^3$



**Fig. 1.2.1.**

3. The volume of unit cell ( $V$ ) =  $a^3$ .
4. The packing factor or density of packing in the unit cell,

$$PF = \frac{v}{V} = \frac{\frac{4}{3} \pi r^3}{a^3} = \frac{4}{3} \frac{\pi r^3}{(2r)^3} = \frac{\pi}{6} = 0.52 \text{ or } 52\%.$$

5. An example for simple cubic structure is Polonium crystal.

**Que 1.3.** Draw a neat sketch of BCC crystal structure and calculate its atomic packing factor and also find out the effective number of atoms.

**AKTU 2017-18, Marks 10**

**Answer**

**A. BCC Crystal Structure :** Refer Q. 1.1, Page 1-2B, Unit-1.

**B. Relation between  $a$  and  $r$  :**

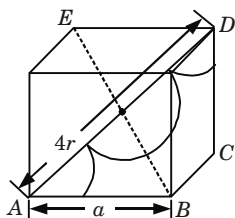
1. The length of the body diagonal  $AD = 4r$

$$\therefore AD^2 = AC^2 + CD^2 = AB^2 + BC^2 + CD^2 = a^2 + a^2 + a^2 = 3a^2$$

$$(4r)^2 = 3a^2$$

$$4r = \sqrt{3}a$$

$$a = \frac{4}{\sqrt{3}} r$$



**Fig. 1.3.1.**

**C. Packing Factor :**

1. Packing factor,  $PF = \frac{\text{Volume of all atoms in unit cell}}{\text{Volume of unit cell}} = \frac{v}{V}$

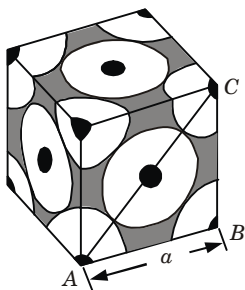
$$\begin{aligned} &= \frac{2 \times \frac{4}{3} \pi r^3}{a^3} = \frac{8\pi r^3}{3a^3} = \frac{8\pi r^3 \sqrt{3}}{3(4r)^3} \\ &= \frac{\sqrt{3}\pi}{8} = 0.68 \text{ or } 68\% \end{aligned}$$

**D. Coordination Number (Effective Number of Atoms) :** The centre atom is surrounded by eight corner atoms, so the coordination number is 8.

**Que 1.4.** Describe the FCC crystal structure. Derive the relation between edge length and radius of FCC crystal structure. Also obtain an expression for the packing factor of FCC.

**Answer**

**A. FCC Crystal Structure :** Refer Q. 1.1, Page 1-2B, Unit-1.

**B. Relation between  $a$  and  $r$  :****Fig. 1.4.1.**

$$AC^2 = AB^2 + BC^2$$

$$(4r)^2 = a^2 + a^2 = 2a^2$$

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

**C. Packing Factor of the Unit Cell :**

$$PF = \frac{\text{Volume occupied by the atoms in a unit cell}}{\text{Unit cell volume}}$$

$$= \frac{v}{V} = \frac{4 \times \frac{4}{3}\pi r^3}{a^3} = \frac{16\pi r^3}{3(2\sqrt{2}r)^3} = \frac{16\pi r^3}{3 \times 8 \times 2\sqrt{2} r^3} = \frac{\pi}{3\sqrt{2}} \\ = 0.74 \text{ or } 74 \%$$

**Que 1.5.** NaCl structure has FCC structure. The density of NaCl is  $2.18 \text{ cm}^3$ . Calculate the distance between two adjacent atoms.

**AKTU 2014-15, Marks 10**

**AKTU 2018-19, Marks 07**

**Answer**

**Given :** Density of NaCl =  $2.18 \text{ cm}^3$ .

**To Find :** The distance between two adjacent atoms.

1. Number of effective atoms per unit cell in FCC structure = 4
2. Molecular weight of NaCl = Atomic weight of Na + Atomic weight of Cl  
 $= 23 + 35.5 = 58.5 \text{ gm}$
3. As 58.5 gm of NaCl contains  $6.023 \times 10^{23}$  molecules of NaCl.  
 $\therefore$  Weight of  $6.023 \times 10^{23}$  molecules = 58.5 gm

$$\text{Therefore weight of 4 molecules} = \frac{58.5 \times 4}{6.023 \times 10^{23}} \text{ gm}$$

This is the weight of unit cell whose volume is  $a^3$ .

4. We know that,  $\rho = \frac{M}{V}$

$$\frac{58.5 \times 4}{6.023 \times 10^{23} \times a^3} = 2.18 \text{ gm/cm}^3$$

$$\therefore a^3 = \frac{58.5 \times 4}{6.023 \times 10^{23} \times 2.18}$$

$$a = 5.63 \times 10^{-8} \text{ cm} \quad (\because 1 \text{ \AA} = 10^{-8} \text{ cm})$$

or,  $a = 5.63 \text{ \AA}$

5. The lattice constant ' $a$ ' is the unit cell dimension. In crystals of NaCl, it is twice the distance between adjacent atoms.

$$\therefore \text{Distance between two adjacent atoms} = \frac{5.63}{2} = 2.82 \text{ \AA}$$

**Que 1.6.** How many atoms per square millimeter are there on the (100) plane of lead? Lead has FCC structure. Assume the interatomic distance to be  $3.499 \text{ \AA}$ .

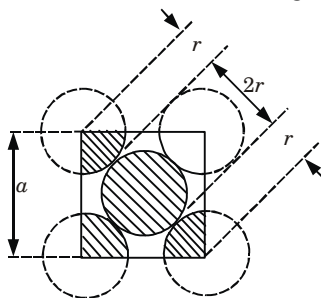
**AKTU 2018-19, Marks 07**

**Answer**

**Given :** Interatomic distance =  $3.499 \text{ \AA}$ .

**To Find :** Atoms per square millimeter on (100) planes of lead.

1. As we know, the structure of lead is FCC (Fig. 1.6.1.)



**Fig. 1.6.1.** Atomic concentration in an FCC lattice.

2. The given interatomic distance =  $3.499 \text{ \AA}$

$$\therefore 2r = 3.499 \text{ \AA}$$

3. If  $a$  is the side of the square,

$$\sqrt{2a^2} = 4r \quad (\text{length of the diagonal})$$

$$\therefore a = \frac{4r}{\sqrt{2}} = \frac{2 \times 3.499}{\sqrt{2}} = 4.95 \text{ \AA}$$

$$\text{Area of (100) plane} = (4.95 \times 10^{-7})^2 \text{ mm}^2$$

4. No. of atoms in the plane = 2

$$\begin{aligned} \text{Atoms/mm}^2 &= \frac{2}{(4.95 \times 10^{-7})^2} \\ &= 8.16 \times 10^{12} \text{ atoms/mm}^2 \end{aligned}$$

## PART-2

### *Ceramics.*

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 1.7.**

**What are ceramic materials ? What are some common properties and applications of ceramic materials ?**

**OR**

**What are some of the typical characteristics of ceramic materials ?**

**AKTU 2014-15, Marks 05**

**OR**

**Name some applications where ceramics are used.**

**AKTU 2014-15, Marks 05**

**OR**

**Write note on ceramic material.**

**AKTU 2016-17, Marks 10**

### Answer

**A. Ceramics :**

1. Ceramics are the compound of metallic and non-metallic elements for which the interatomic bonding is predominantly ionic.
2. The desirable properties of these materials are normally achieved through a high temperature heat treatment process called firing.

**B. Properties of Ceramics :**

1. Ceramic materials are relatively stiff and strong as compared to the metals.
2. Ceramic materials are very hard and brittle in nature.

3. These are highly susceptible to fracture due to presence of cracks and brittle nature.
4. These have low electrical and thermal conductivity means they act as good insulator and refractories.
5. They are more resistant to high temperature and harsh environments than metals and polymers.
6. Ceramics also exhibit some magnetic behaviour.

**C. Applications of Ceramics :**

1. In firebricks and fireclay for lining of ovens and furnaces.
2. As artificial limbs, teeth etc. in biomedical/medical field.
3. In insulators (dielectrics) in electrical transmission and distribution.
4. In crockery in domestic uses, sanitary wares etc.
5. As ferrites in memory cores of computers.
6. As radiation shield for nuclear reactor.

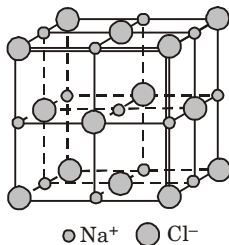
**Que 1.8.** Discuss about various ceramic crystal structures.

**AKTU 2017-18, Marks 10**

**Answer**

Some of ceramic crystal structures are as follows :

**a. Rock Salt Structure :**



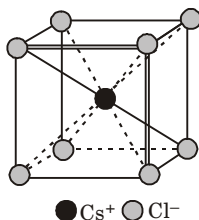
**Fig. 1.8.1. Rock salt structure.**

1. (Fig. 1.8.1) shows the arrangement of anions and cations.
2. The coordination number for both cations and anions is 6 and cation-anion radius ratio is between 0.414 and 0.732.
3. NaCl, MgO and FeO etc., have this type of structure.

**b. Cesium Chloride Structure :**

1. (Fig. 1.8.2) shows the arrangement of Cs<sup>+</sup> and Cl<sup>-</sup> ions. Both have a coordination number 8.



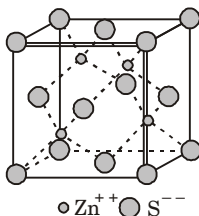


**Fig. 1.8.2.** Cesium chloride structure.

2. Approximately they have same cation and anion radius.

**c. Zinc Blend Structure :**

1. (Fig. 1.8.3) shows the arrangement of  $\text{Zn}^{++}$  and  $\text{S}^{--}$  as they are tetrahedrally coordinated.
2. This structure shows that Zn and S both have same coordination number 4.
3. ZnS and SiC etc., shows the same structure.



**Fig. 1.8.3.** Zinc blend structure.

**Que 1.9.**

**What are ceramics ? Explain briefly the different types of ceramics with their properties and applications.**

**AKTU 2018-19, Marks 07**

**Answer**

**A. Ceramics :** Refer Q. 1.7, Page 1–8B, Unit-1.

**B. Types of Ceramics with their Properties and Applications :**  
Table 1.9.1 shows the ceramics types, their properties and applications.

**Table 1.9.1.**

S. No.	Material	Properties	Applications
1.	Cement	Chemically active, non-organic, non-metallic	Plastering, preparing different grades of concrete
2.	Lime	A kind of ceramic, non-organic, non-metallic	Foundation, mortar, plastering
3.	Mud	Clay mixed with water	As mortar
4.	Gravel	Obtained by crushing the stone	In making of concrete
5.	Terracotta	Baked earthenware	Tiles, sewage and drain pipes
6.	Asbestos and glass wool	Non-metals	Heat insulation
7.	Porcelain	Acid proof	Electric insulation
8.	Plaster of Paris (POP)	Non-metal, ceramic non-organic	Plastering

**Que 1.10.** Describe the various mechanical properties of ceramics. What are the various electrical properties of ceramics ?

**AKTU 2017-18, Marks 10**

### **Answer**

#### **A. Mechanical Properties of Ceramics :**

1. Ceramics shows brittle fracture phenomenon at room temperature, as they fracture before any plastic deformation when loaded with a tensile load.
2. Ceramics have greater strength in compression as compared to strength in tension.
3. There is porosity present in ceramics which reduces its elastic property as well as strength.
4. Ceramics show good hardness and they are used as an abrasive material due to its hardness property.
5. Creep phenomenon occurs in ceramics at high temperature.
6. Ceramics can withstand at high temperature.
7. Ceramics show poor malleability.

8. Frenkel and Schottky defects mostly occur in ceramics.

**B. Electrical Properties of Ceramics :**

1. Ceramics are good thermal and electrical insulators.
2. Ceramics have high value of dielectric constant.
3. Dielectric strength of ceramic is high.
4. Dielectric losses are low.

**Que 1.11. What are the various processing techniques used for ceramics ?**

**OR**

**What are some method by which processing of ceramic materials is carried out ? What are the applications of ceramic materials ?**

**AKTU 2015-16, Marks 10**

**Answer**

**A. Various Processing Techniques used for Ceramics :**

1. The various processing techniques which are used to process ceramics are as follows :
  - i. Glass forming processes :
    - a. Drawing,
    - b. Pressing,
    - c. Fibre forming, and
    - d. Blowing.
  - ii. Particulate forming processes :
    - a. Powder pressing,
    - b. Slip casting,
    - c. Hydro plastic forming, and
    - d. Tape casting.
  - iii. Cementation.
2. All these above forming processes are followed by drying and then firing.

**B. Procedure for the Formation of Ceramics :** The traditional ceramic process generally follows the sequence as :

Milling → Batching → Mixing → Forming → Drying → Firing → Assembly

**a. Milling :**

1. It is the process by which materials are reduced from a large size to a smaller size.
2. Milling may involve breaking up cemented material (in which individual particles retain their shape) or pulverization (which involves grinding the particles themselves to a smaller size).
3. Milling is generally done by mechanical means, including attrition, compression and impact.

**b. Batching :**

1. It is the process of weighing the oxides according to recipes (a statement of the ingredients and procedure required for preparing a mixture) and preparing them for mixing and drying.

**c. Mixing :**

1. It occurs after batching and involves a variety of equipment such as dry mixing ribbon mixers, Mueller mixers, and pug mills.
2. Wet mixing generally involves the same equipment.

**d. Forming :**

1. It is making the mixed material into shapes, ranging from toilet bowls to spark plug insulators.
2. Forming can involve :
  - i. Extrusion, such as extruding slugs to make bricks.
  - ii. Pressing to make shaped parts.
  - iii. Slip casting, as in making toilet bowls, wash basins and ornamentals like ceramic statues.
3. Forming produces a green part ready for drying.

**e. Drying :**

1. It is removing the water or binder from the formed material.
2. Spray drying is widely used to prepare powder for pressing operations.
3. Other dryers are tunnel dryers and periodic dryers.
4. Controlled heat is applied in this two stage heating causes cracks and surface defects.
5. The dried part is smaller than the green part, and is brittle, necessitating careful handling, since a small impact will cause crumbling and breaking.

**f. Firing :**

1. Firing is where the dried parts pass through a controlled heating process, and the oxides are chemically changed to cause sintering and bonding.
2. The fired part will be smaller than the dried part.

**C. Applications of Ceramics :** Refer Q. 1.7, Page 1-8B, Unit-1.**PART-3**

*Imperfection in Solids : Point, Line, Interfacial and Volume Defects.*

**CONCEPT OUTLINE**

**Imperfection :** Imperfection is defined as any departure or randomness that occurs in a perfectly ordered arrangement of atoms.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 1.12.** Classify the crystal imperfections and give their brief introduction.

**Answer**

All defects and imperfections in crystals can be classified in following types :

**a. Point Imperfections :**

1. Point defects are where an atom is missing or is in an irregular place in the lattice structure.
2. These defects are completely local in effect.
3. Point imperfections are always present in crystals and their presence results in a decrease in the free energy.
4. The number of defects at equilibrium concentration at a certain temperature can be computed as,

$$n = Ne^{-E_d/kT}$$

Where,

$n$  = Number of imperfections,

$N$  = Number of atomic sites per mole,

$k$  = Boltzmann's constant,

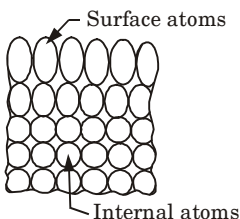
$E_d$  = The free energy required to form the defect, and

$T$  = Absolute temperature.

**b. Line Imperfection or Dislocations :**

1. A linear disturbance of the atomic arrangement which can very easily occur on the slip plane through the crystal is known as dislocation.
2. Dislocation is a two-dimensional line defect and is a very important crystal imperfection. It is responsible for the deformation of metals by slip phenomenon.
3. It may also be concluded that it is the region of localized lattice disturbances separating the slipped and unslipped regions of a crystal.
4. These are formed in the process of solidification of metals and mainly in their plastic deformation of strain hardening, yield point, creep and fatigue and brittle fractures.
5. Causes of dislocation are :
  - i. Thermal stresses or external stresses causing plastic flow.
  - ii. Crystal growth.
  - iii. Phase transformation.

- iv. Segregation of solute atoms causing mismatches.
- 6. There are two types of dislocation :
  - i. Edge dislocations, and
  - ii. Screw dislocations.
- 7. These dislocations are responsible for the useful property of ductility in metals, ceramic and polymers.
- c. Surface and Grain Boundary Imperfections :**
  - 1. These defects are two-dimensional and are due to a change in the stacking of atomic planes on or across a boundary, twin boundary, stacking faults, etc.
  - 2. The external surface of the material is an imperfection itself because the atomic bonds do not extend beyond it.
  - 3. Since these surface atoms are not entirely surrounded by other (Fig. 1.12.1), they possess higher energy than internal atoms.
  - 4. Surface atoms have neighbours on only one side while atoms inside the crystal have neighbour on both sides.



**Fig. 1.12.1.**

**Que 1.13.** Describe different types of point imperfections with neat sketches.

**Answer**

Different types of point imperfection are as follows :

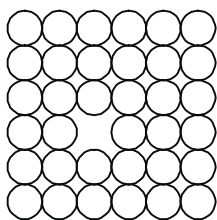
**a. Vacancies :**

- 1. The simplest point defect is a vacancy which simply involves a missing atom within a metal (Fig. 1.13.1(a)).
- 2. Such defects can be a result of imperfect packing during original crystallization or may arise due to increased thermal energy causing individual atoms to jump out of their position of lowest energy. The thermal vibrations of atoms increase at higher temperatures.
- 3. The vacancies may be single or two or more may condense into a di-vacancy or tri-vacancy.

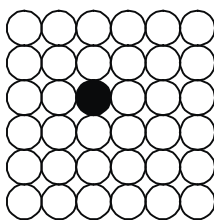
- The atoms surrounding a vacancy tend to be closer together, thereby distorting the lattice planes.
- Vacancies exist in a certain proportion in a crystal at thermal equilibrium, leading to an increase in randomness of the structure.

**b. Impurities :**

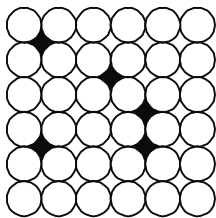
- Impurities may produce compositional defects in the crystal structure.
- When impurities in the form of foreign atoms (Fig. 1.13.1(b)) occupy lattice sites where regular atoms are missing, they produce substitutional impurity.
- Impurities such as slag inclusions in metals having atoms of a smaller radius than the host atoms will produce interstitial defects as shown in (Fig. 1.13.1(c)).
- Such defects cause atomic diffusion and phase transformation and play an important role in changing the thermal and electrical conductivity of metals and alloys.



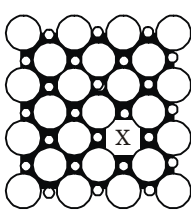
(a) Vacancies



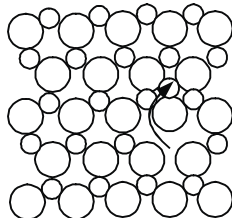
(b) Substitutional impurity



(c) Interstitial impurity



(d) Schottky defect



(e) Frenkel defect

**Fig. 1.13.1. Point imperfections.**

**c. Frenkel Defect :**

- A Frenkel defect is a type of defect in crystalline solids wherein an atom is displaced from its lattice position to an interstitial site, creating a vacancy at the original site and an interstitial defect at the new location within the same element without any changes in chemical properties.

**d. Schottky Defect :**

- In non-ionic crystals Schottky means a lattice vacancy defect.

2. In ionic crystals, the defect forms when oppositely charged ions leave their lattice sites, creating vacancies. These vacancies are formed in stoichiometric units, to maintain an overall neutral charge in the ionic solid.
3. These defects lead to a decrease in the density of the crystal.

**Que 1.14.** What is a dislocation? What are different types of dislocation? Explain and draw their neat sketches and mark burger vector in each case.

**AKTU 2018-19, Marks 07**

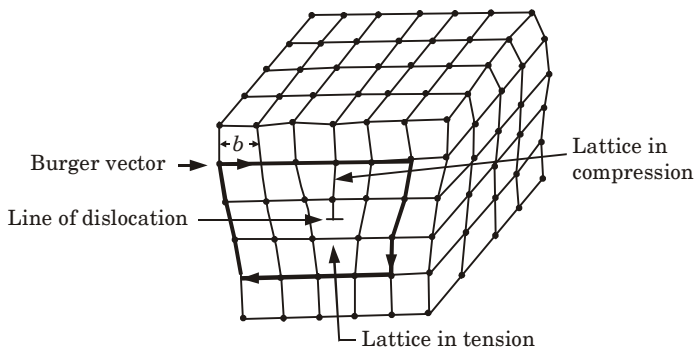
**Answer**

**A. Dislocation :** Refer Q. 1.12, Page 1-14B, Unit-1.

**B. Types of Dislocation :**

**a. Edge Dislocation :**

1. An edge dislocation is formed by adding an extra partial plane of atoms to the crystal.
2. (Fig. 1.14.1) shows the introduction of an extra half plane in a perfect crystal, resulting in an edge dislocation.
3. The position of the dislocation line is marked by the symbols  $\perp$  and  $\top$  indicating the involvement of extra planes from the top (positive sign) and bottom (negative sign) of the crystal, respectively.
4. The vertical line of the symbol  $\perp$  points in the direction of the dislocation line in the extra partial plane.
5. Near the dislocation, the crystal is distorted due to the presence of zones of compression and tension in the crystal lattice.
6. The dislocation line is a region of higher energy than the rest of the crystal.
7. The lattice above the dislocation line is in a state of compression, whereas below this line, the lattice is in tension.

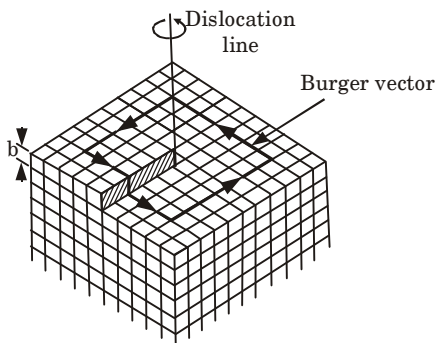


**Fig. 1.14.1.** Edge dislocation with Burger vector.



**b. Screw Dislocation :**

1. The formation of a screw dislocation is shown in (Fig. 1.14.2).
2. The geometry of the screw dislocation has an interesting effect on the solidification process.



**Fig. 1.14.2.** Screw dislocations with Burger vector.

3. A screw dislocation has its displacement or Burger vector parallel to the linear defect but there is a distortion of the plane.
4. In this, the atoms are displaced in two separate planes perpendicular to each other and the distortion follows a helical or screw path.
5. In this type of dislocation, shear stresses are associated with adjacent atoms and extra energy is involved along the dislocation.
6. A screw dislocation does not exhibit climb motion.
7. Three effects of a screw dislocation are of great importance :
  - i. The force required to form and move a screw dislocation is probably somewhat greater than that required to initiate an edge dislocation.
  - ii. Plastic deformation is possible under low stress, without breaking the continuity of the lattice.
  - iii. Screw dislocation causes distortion of the lattice for a considerable distance from the centre of the line and takes the form of spiral distortion of the planes. Dislocations of both types (combinations of edge of screw) are closely associated with crystallization as well as deformation.

**Que 1.15.** Discuss different types of surface and grain boundary defects with neat sketches.

**Answer**

Following are the different types of surface and grain boundaries defects :

**a. Grain Boundaries :**

1. These imperfections separate crystals or grains of different orientation in polycrystalline aggregates during crystallization.

2. In grain boundaries the atomic packing is imperfect and between two adjacent grains, there is a transition zone that is not aligned with either grain (Fig. 1.15.1). As a result boundary atoms in such cases cannot have a perfect complement of surrounding atoms.
3. The mismatch with orientation of the adjacent grain produces a less efficient packing of atoms along the boundary. Thus, atoms along the boundary have higher energy than those within the grains.
4. The higher energy of the boundary atoms is also important for the nucleation of polymorphic phase changes.



Fig. 1.15.1.

5. The lower atomic packing along the boundary favours atomic diffusion.
6. When the orientation difference between neighbouring grains is more than  $10^\circ - 14^\circ$ , boundaries are called high-angle grain boundaries.
7. Grain boundaries can be observed under a microscope if the metal has been etched.

#### b. Tilt Boundaries :

1. Another type of surface defect is the tilt boundary. It is called a small-angle boundary as the two neighbouring crystals have an aligned dislocation less than  $10^\circ$ .
2. This type of boundary is associated with relatively little energy and is composed of edge dislocation lying one above the other in the boundary.
3. (Fig. 1.15.2) shows a tilt boundary.

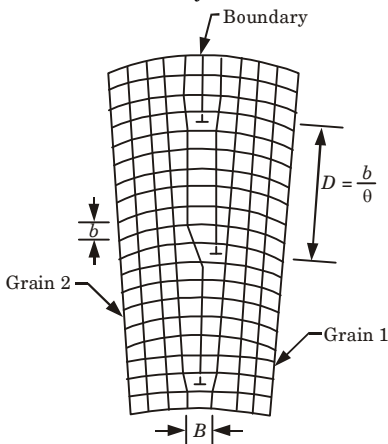
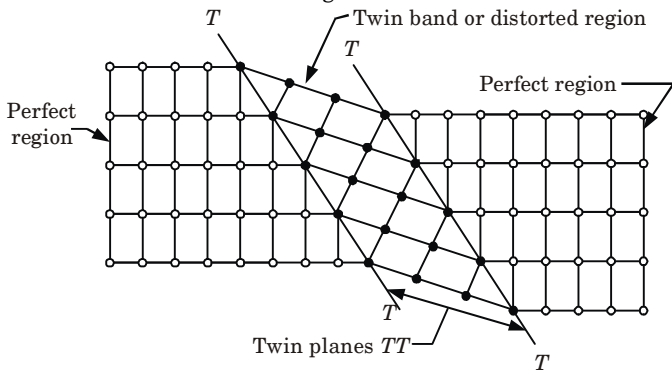


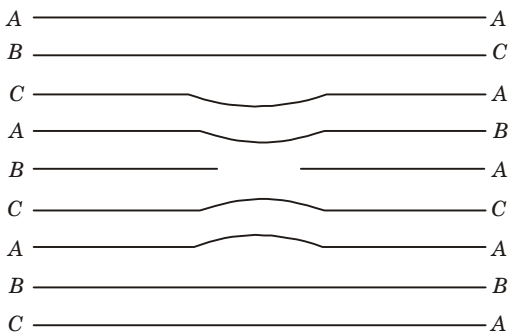
Fig. 1.15.2. Tilt boundary representing a low-angle grain boundary.

**c. Twin Boundaries :**

1. Space imperfections which separate two like orientations and look like mirror images of each other are called twin boundaries.
2. Twinning may result during crystal growth or deformation of materials.
3. In the process of mechanical working (recrystallization) or as a result of annealing after plastic deformation, the twins formed are known as mechanical twins and annealing twins.

**Fig. 1.15.3. Twin boundaries.****d. Stacking Faults :**

1. This type of imperfection may arise where there is only a small dissimilarity between the stacking sequences of close-packed planes in FCC and HCP metals.
2. It is possible for one atom layer to be out of sequence relative to the atoms of the layers above and below, giving a fault.
3. For example, the stacking sequence of an ideal FCC crystal may be described as  $ABC\ ABC\ \dots$  but the stacking fault may change the sequence to  $ABC\ ACAB$  (Fig. 1.15.4).

**Fig. 1.15.4. Stacking fault in FCC crystal.**

**Que 1.16. Write short note on volume defects.**

**Answer**

1. Volume or three-dimensional defects form when a cluster of point defects join to form a three-dimensional void or a pore. Conversely a cluster of impurity atoms may join to form a three-dimensional precipitate.
2. The size of a volume defect may range from a few nanometers to centimeters or sometimes larger.
3. Such defects have a tremendous effect or influence on the behaviour and performance of the material.

#### **PART-4**

*Dislocation Strengthening Mechanisms and Slip Systems,  
Critically Resolved Shear Stress.*

#### **Questions-Answers**

#### **Long Answer Type and Medium Answer Type Questions**

**Que 1.17. Explain different ways of dislocation strengthening mechanisms.**

**Answer**

Different ways of dislocation strengthening mechanisms are as follows :

**a. Strengthening by Grain Size Reduction :**

1. This is based on the fact that it is difficult for a dislocation to pass into another grain, especially if it is very misaligned.
2. Atomic disorder at the boundary causes discontinuity in slip planes. For high-angle grain boundaries, stress at end of slip plane may trigger new dislocations in adjacent grains. Small angle grain boundaries are not effective in blocking dislocations.
3. The finer the grains, the larger the area of grain boundaries that impedes dislocation motion.
4. Grain-size reduction usually improves toughness as well. Usually, the yield strength varies with grain size  $d$  according to :

$$\sigma_y = \sigma_0 + k_y / d^{1/2}$$

5. Grain size can be controlled by the rate of solidification and by plastic deformation.

**b. Solid Solution Strengthening :**

1. Adding another element that goes into interstitial or substitutional positions in a solution increases strength.
2. The impurity atoms cause lattice strain which can anchor dislocations. This occurs when the strain caused by the alloying element compensates that of the dislocation, thus achieving a state of low potential energy.
3. It costs strain energy for the dislocation to move away from this state.
4. The scarcity of energy at low temperatures is why slip is hindered.
5. Pure metals are almost always softer than their alloys.

**c. Strain Hardening :**

1. Ductile metals become stronger when they are deformed plastically at temperatures well below the melting point (cold working). This is different from hot working as the shaping of materials at high temperatures where large deformation is possible.
2. Strain hardening (work hardening) is the reason for the elastic recovery.
3. The reason for strain hardening is that the dislocation density increases with plastic deformation (cold work) due to multiplication.
4. The average distance between dislocations then decreases and dislocations start blocking the motion of each one.
5. The measure of strain hardening is the percent cold work (% CW), given by the relative reduction of the original area,  $A_0$  to the final value  $A_d$ .

$$\therefore \% \text{ CW} = 100 (A_0 - A_d)/A_0$$

**Que 1.18. What do you understand by slip systems ?**

**Answer**

1. A slip system refers to a metallurgical occurrence when deformation planes are formed on a metal's surface or its intergranular boundaries due to applied forces.
2. It is the primary criteria for plastic deformation in a material, which may make it more susceptible to failure or corrosion.
3. It describes the set of symmetrically identical slip planes and associated family of slip directions for which dislocation motion can easily occur and lead to plastic deformation.

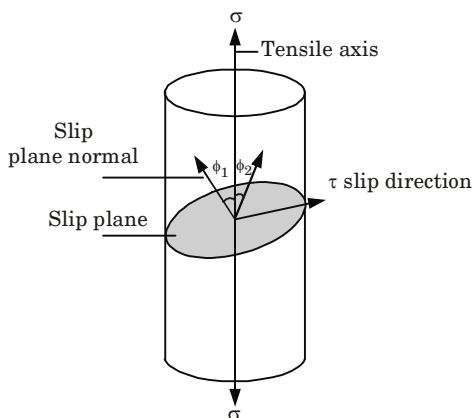
**Que 1.19. What do you understand by critically resolved shear stress ?**

**Answer**

1. The stress at which slip starts in a crystal depends on the relative orientation of the stress axis with respect to the slip plane and the slip direction.

2. When a tensile stress  $\sigma$  is applied to a crystal, (Fig. 1.19.1), the shear stress  $\tau$  resolved on slip plane whose normal makes an angle of  $\phi_1$  with the stress axis, along a slip direction inclined at an angle of  $\phi_2$  to the stress axis is given by

$$\tau = \sigma \cos \phi_1 \cos \phi_2$$



**Fig. 1.19.1.** The resolved shear stress  $\tau$  on a slip plane along a slip direction depends on their orientation with respect to the tensile axis.

3. This resolved shear stress should reach a critical value called the critical resolved shear stress (CRSS) for plastic deformation to start.
4. It is evident that all slip systems in a crystal will not have the same resolved shear stress for a given tensile stress along an axis.
5. As the applied tensile stress is increased from zero, deformation will be initiated first on that slip system for which the resolved shear stress is a maximum and so reaches the critical value first.

## PART-5

*Mechanical Property Measurement :  
Tensile, Compression and Torsion Tests.*

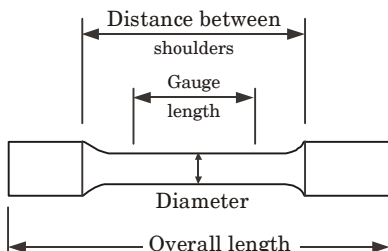
### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 1.20.** Discuss the tensile test in detail.

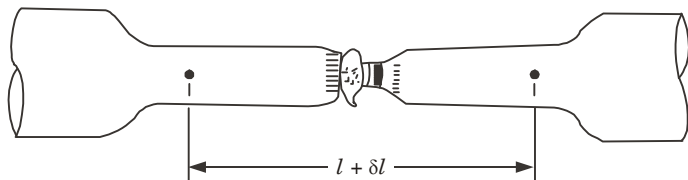
**Answer**

1. Tensile test is one of the most widely used mechanical tests.
2. This test is widely used to indicate the strength, ductility and toughness of a metal.
3. The tensile test on a mild steel test piece is described below :
  - i. The specimen to be tested is in the shape of a circular bar or a flat bar (Fig. 1.20.1).

**Fig. 1.20.1.**

- ii. One end of it is fastened to the frame of the machine by means of grips of clamps, while the other end is similarly fixed to the movable cross-head.
  - iii. The specimen is gradually loaded by the loading unit of the machine.
  - iv. The power to move the cross-head comes from a mechanical or hydraulic drive system.
  - v. The magnitude of the load is measured by the load measuring unit.
  - vi. Elongation is measured by attaching an extensometer or gauge to the specimen.
  - vii. As the load increases the distance between the marked points on the gauge length increases.
  - viii. The test thus gives elongation as a function of load. Stress and strain can be calculated from load elongation data and a graph of stress versus strain can be made for the material.
  - ix. Many testing machines can automatically record stress-strain curves for materials under test.
4. During the tensile test, the different values of load and elongation at different intervals are recorded.
  5. Just before the pointer on the load scale in the load measuring unit of the testing machine stops moving in the forward direction the extensometer should be removed from the gauge length of the specimen. This is done to prevent any damage to the extensometer.
  6. This is the point where the internal structure of the specimen starts yielding.

7. The load is further applied and the maximum travel of the load-scale pointer will indicate the ultimate load.
8. After this the pointer moves in the reverse direction to indicate necking.
9. Finally the pointer stops at a point with a noise to indicate fracture.
10. After fracture the two pieces of the broken specimen are placed (Fig. 1.20.2) as if fixed together and the distance between the two gauge marks is measured as the final length of the specimen.



**Fig. 1.20.2.** Increased length and reduced diameter after fracture.

11. Similarly, the average diameter at the place of fracture and the area of fracture calculated.

**Que 1.21.** Describe compression and torsion test.

**Answer**

**A. Compression Test :**

1. A compression test is conducted in a similar manner to the tensile test, except that the force is compressive and the specimen contracts along the direction of the stress.
2.  $\sigma = \frac{F}{A_0}$  and  $\epsilon = \frac{\Delta L}{l_0} = \frac{l_i - l_0}{l_0}$  are utilized to compute compressive stress and strain, respectively.
3. By convention, a compressive force is taken to be negative, which yields a negative stress.
4. Furthermore, since  $l_0$  is greater than  $l_i$ , compressive strains computed from,  $\epsilon = \frac{\Delta L}{l_0}$  are necessarily negative.
5. Tensile tests are more common because they are easier to perform; also, for most materials used in structural applications, very little additional information is obtained from compressive tests.
6. Compressive tests are used when a material's behaviour under large and permanent (*i.e.*, plastic) strains is desired, as in manufacturing applications, or when the material is brittle in tension.



**B. Torsion Test :**

1. Torsion test involves the twisting of a sample along an axis and is a useful test for acquiring information like torsional shear stress, maximum torque, shear modulus, and breaking angle of a material, etc.
2. In torsion test, a longitudinal sample is placed in a torsion tester and one end of the sample is twisted around the longitudinal axis until failure, during which the force, or in the case of rotation the torque, and the displacement, or in the case of rotation the angular displacement, are recorded.
3. Torsion testing is appropriate for materials that may experience a torsional load like a metallic bone screw, rubber tubing that may become twisted, etc.
4. Torsional test are normally performed on cylindrical solid shafts or tubes.
5. Torsion tests have the following advantages :
  - i. A simple loading condition.
  - ii. A uniform stress state.

**PART-6**

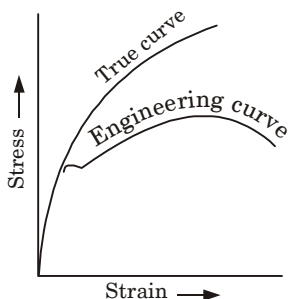
*Young's Modulus, Relations between True and Engineering Stress-Strain Curves, Generalized Hooke's Law.*

**CONCEPT OUTLINE**

**Young's Modulus :** It is defined as the ratio of longitudinal stress to longitudinal strain.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 1.22.** Explain engineering and true stress-strain diagram.



**Fig. 1.22.1.** True and engineering stress-strain curves.

**Answer**

1. In tensile test, as the test progresses, one region of the specimen begins to deform much quicker than the rest.
2. The reduction in area as the test progresses is used for calculating stress.
3. When the stress is calculated on the basis of the original area it is called the engineering or nominal stress.
4. If the original length is used to calculate strain we get the engineering strain.
5. Stress can also be based upon the actual area at any instant of the load. It is then called true stress.

$$\therefore \sigma_f = \text{True stress} = \frac{\text{Instantaneous load}}{\text{Instantaneous cross-sectional area}} \\ = \frac{P}{A_i}$$

$$6. \text{ Similarly, } \epsilon_l = \text{True strain} = \int_{l_0}^{l_i} \frac{dl}{l} = \ln \frac{l_i}{l_0}$$

Where,  $dl$  is the infinitesimal elongation.

7. The true stress-strain curve always has a continually rising characteristic as would be expected when consideration is given to the mechanism of work hardening which is the interaction of mobile dislocation with each other.
8. The ultimate strength of the engineering curve corresponds to the beginning of necking. The rapid area reduction that accompanies necking causes the curve to fall. This does not happen with the true stress-strain curves.
9. As strain is not homogeneous after necking begins, when one part of the specimen is elongating more than the rest, it is not meaningful to use the entire specimen length for finding deformation.
10. True strain can be expressed in terms of area by substituting in the equation :

$$\epsilon_{\text{True}} = \ln \frac{A_0}{A_i} = \frac{\text{Original area}}{\text{Instantaneous area}}$$

11. Most of the diagrams used for practical purpose are based on engineering stress versus engineering strain, while true stress-true strain diagram are required occasionally.

**Que 1.23. State the generalized Hooke's law.**

**Answer**

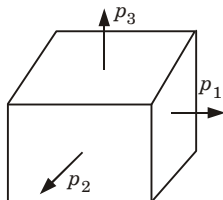
1. The generalized Hooke's law can be used to predict the deformation caused in a given material by an arbitrary combination of stresses.
2. Since any direct stress produces a strain in its own direction and an opposite kind of strain in every direction at right angle to this we have,

$$\text{Longitudinal strain, } \varepsilon_1 = \frac{p_1}{E} - \frac{p_2}{mE} - \frac{p_3}{mE} = \frac{p_1}{E} - \frac{p_2 + p_3}{mE} \quad \dots(1.23.1)$$

$$\text{Similarly, } \varepsilon_2 = \frac{p_2}{E} - \frac{p_3}{mE} - \frac{p_1}{mE} = \frac{p_2}{E} - \frac{p_3 + p_1}{mE} \quad \dots(1.23.2)$$

$$\text{and } \varepsilon_3 = \frac{p_3}{E} - \frac{p_1}{mE} - \frac{p_2}{mE} = \frac{p_3}{E} - \frac{p_1 + p_2}{mE} \quad \dots(1.23.3)$$

Above three equations are known as general equations of Hooke's law or generalized Hooke's law.



**Fig. 1.23.1.**

3. Hooke's law is the constitutive law for linear elastic material.
4. It can be given a precise expression in terms of stress and strain by stating, in the most general form, that, if  $\tau_{ij} \neq \tau_{ji}$ .

$$\sigma_x = f_1(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\sigma_y = f_2(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\sigma_z = f_3(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{xy} = f_4(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{yz} = f_5(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{zx} = f_6(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{yx} = f_7(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{zy} = f_8(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

$$\tau_{xz} = f_9(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx}, \gamma_{yx}, \gamma_{zy}, \gamma_{xz})$$

These functions could be linear or non-linear.

5. For a small deformation an elastic material can be considered to be linearly elastic and in that case the functions become linear. Hence, we can write in tensor form,

$$\sigma_{ij} = C^{ijkl} \varepsilon_{kl}$$

This is the Cauchy's formulation for generalized Hooke's law.

**PART-7**

*Yielding and Yield Strength, Ductility, Resilience, Toughness and Elastic Recovery.*

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 1.24.** Write short note on the following :

- i. Yield strength,
- ii. Ductility,
- iii. Ultimate tensile strength,
- iv. Resilience,
- v. Toughness,
- vi. Elastic recovery, and
- vii. Yielding.

**OR**

Write short notes on the following :

- i. Yield strength,
- ii. Ductility, and
- iii. Ultimate tensile strength.

**AKTU 2017-18, Marks 10**

**Answer**

**i. Yield strength :**

1. Yield strength is defined as the stress at which a material begins to deform plastically.
2. The plastic deformation begins at a point known as yield point.
3. The yield point determines the limits of performance for mechanical components, since it represents the upper limit to forces that can be applied without permanent deformation.

**ii. Ductility :**

1. Ductility is a property that measures the degree of plastic deformation that has been sustained at fracture.
2. A material that experiences very little or no plastic deformation upon fracture is termed brittle.
3. Ductility may be expressed quantitatively as either percent elongation or percent reduction in area. The percent elongation (% EL) is the percentage of plastic strain at fracture and is given as,

$$\% \text{ EL} = \left( \frac{l_f - l_0}{l_0} \right) \times 100$$

Where,

$l_f$  = Fracture length, and

$l_0$  = Original gauge length.

### iii. Ultimate Tensile Strength :

1. The stress at which the load bearing ability reaches at its maximum is known as the ultimate tensile strength.
2. As plastic deformation progresses, the additional increments of strength decreases in magnitude, and a point is reached where the decrease in area cancels the increase in strength.
3. When this occurs, the load bearing ability peaks, and the force required to continue straining the specimen begins to decrease.

### iv. Resilience :

1. It is the capacity of a material to absorb energy when it is deformed elastically and then, upon unloading, to have this energy recovered.
2. The associated property is the modulus of resilience  $U_r$ , which is the strain energy per unit volume required to stress a material from an unloaded state up to the point of yielding.
3. Computationally, the modulus of resilience for a specimen subjected to a uniaxial tension test is just the area under the engineering stress-strain curve taken to yielding and is given as,

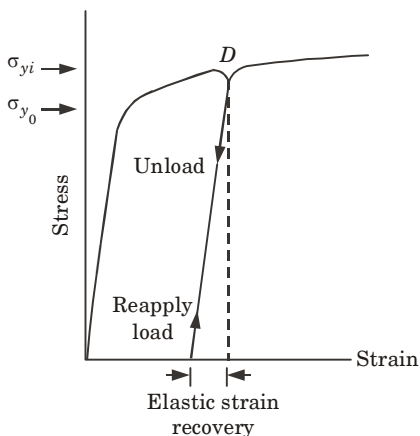
$$U_r = \int_0^{\epsilon_y} \sigma d\epsilon$$

### v. Toughness :

1. The term toughness is defined as the property of metals by virtue of which it can absorb maximum energy before fracture takes place.
2. Tenacity and hardness of a metal are the measures of its toughness.
3. It has been found that the value of toughness fall with the rise in temperature.
4. Toughness of material is indicated by the total area under the material tensile stress-strain curve upto the point of fracture.

### vi. Elastic Recovery :

1. Elastic recovery is the property of a material by which it tends to recover its original size and shape after deformation.
2. If a material is taken beyond the yield point and the stress is then released, the material ends up with a permanent strain.
3. If the stress is reapplied, the material again responds elastically at the beginning upto a new yield point.
4. The amount of elastic strain that it will take before reaching yield point is called elastic strain energy (Fig. 1.24.1).



**Fig. 1.24.1.** Schematic tensile stress-strain diagram showing the phenomena of elastic strain recovery.

- vii. Yielding :** When external force is applied on a component, it started to deform and reached to a point at which plastic deformation takes place. That point is known as yielding point and the phenomenon is known as yielding.

## PART-8

*Hardness : Rockwell, Brinell and Vickers and their Relation to Strength.*

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 1.25.** Define hardness. Discuss in detail about Brinell hardness test.

#### Answer

#### A. Hardness :

1. The term hardness is defined as the property of metal by virtue of which it is able to resist abrasion, indentation (or penetration) and scratching by harder bodies.
2. It is measured by the resistance of the metal which it offers.

**B. Brinell Hardness Test :**

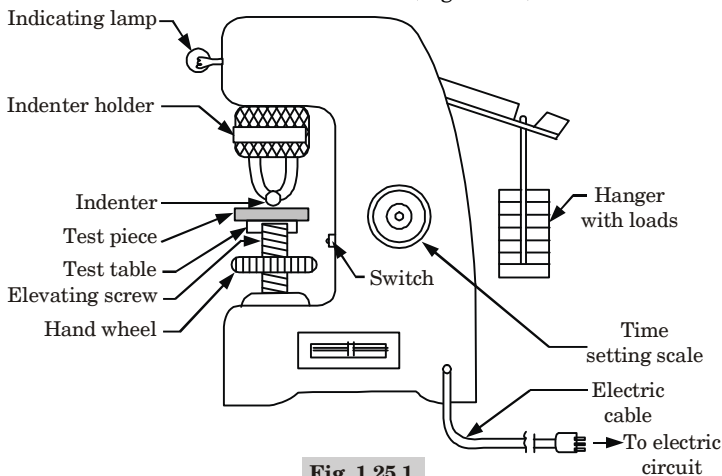
1. In this test a standard hardened steel ball of diameter  $D$  is pressed into the surface of the specimen by a gradually applied load  $P$  which is maintained on the specimen for a definite period of time.
2. The impression of the steel ball (indenter) so obtained is measured by a microscope and the Brinell hardness number (BHN) is found by the following relations,

$$\text{BHN} = \frac{\text{Load in kg}}{\text{Area of impression or indentation of steel ball in m}^2}$$

$$= \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \quad \dots(1.25.1)$$

Where,  $P$  = Applied load,  $D$  = Diameter of steel ball, and  $d$  = Diameter of the impression, measured with a microscope.

3. A Brinell hardness tester is shown in (Fig. 1.25.1).



**Fig. 1.25.1.**

4. In this test, the test sample is placed on the top of the test table which can be raised by the elevating screw so that test sample just touches the ball.
5. The desired load is applied either mechanically or by oil pressure.
6. During this period the steel ball moves to the position of the sample and makes an impression or indentation.
7. The indentation diameter is measured at two places, either on the screen provided with the machine or by coinciding the two points of a reading microscope.
8. The Brinell hardness is determined from the eq. (1.25.1) after substituting the values of  $P$ ,  $D$  and  $d$ .

**Que 1.26.** Discuss in detail about Rockwell and Vickers hardness test.

**Answer**

**A. Rockwell Test :**

1. The Rockwell hardness test is widely used because of its speed and freedom from personal errors.
2. This test requires much smaller penetrators (steel balls as well as cone-shaped diamond penetrators) and loads that used on Brinell hardness tester.
3. There are two scales on a Rockwell testing machine, *B*-scale and *C*-scale.
4. While performing the Rockwell hardness test the following procedure is used :
  - i. The test piece is placed on the machine's test table.
  - ii. The test piece is raised by turning the hand wheel, till it just touches the indenter and the needle on the machine dial reads zero. This indicates that a minor load of 10 kg has been applied on the test sample by the machine and ensures that the specimen is seated properly.
  - iii. After that a major load of 100 kg (for *B*-scale) or 150 kg (for *C*-scale) is applied by pressing the crank provided for this purpose.
  - iv. The depth of the indentation is recorded automatically by means of a dial scale. The reading is correlated with arbitrary hardness numbers.

**B. Vickers Hardness Test :**

1. In this method of hardness testing a square based diamond pyramid is used as indenter.
2. The drawback of the flattening of the steel ball in testing harder materials is eliminated.
3. This method uses the indentation produced by the indenter (diamond pyramid). The indenter gives geometrically similar impressions under different loads from 5 to 120 kg.
4. The value of Vickers hardness can be obtained by the following expression :

$$VPN = DPN = \frac{2 P \sin \theta / 2}{d^2}$$

Where,

VPN = Vickers Pyramid Number,

DPN = Diamond Pyramid Number,



$P$  = Load,

$\theta = 136^\circ$  = Angle between opposite face of diamond pyramid, and

$d$  = Average length of two diagonals, (mm).

5. This method is used to determine the hardness of very thin and very hard materials. It also facilitates the ease of measurement of a diagonal of the indentation area, as compared to circular dimensions which are difficult to measure exactly.
6. The values of Brinell and Vickers hardness are practically the same upto 300. Vickers test can be carried out accurately on polished surfaces but does not give accurate results when used for rough surfaces.

### VERY IMPORTANT QUESTIONS

*Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.*

**Q. 1. With the help of neat sketch explain different types of crystal structure.**

**Ans.** Refer Q. 1.1, Unit-1.

**Q. 2. NaCl structure has FCC structure. The density of NaCl is  $2.18 \text{ cm}^3$ . Calculate the distance between two adjacent atoms.**

**Ans.** Refer Q. 1.5, Unit-1.

**Q. 3. What are ceramic materials ? What are some common properties and applications of ceramic materials ?**

**Ans.** Refer Q. 1.7, Unit-1.

**Q. 4. Describe the various mechanical properties of ceramics. What are the various electrical properties of ceramics ?**

**Ans.** Refer Q. 1.10, Unit-1.

**Q. 5. What is a dislocation? What are different types of dislocation ? Explain and draw their neat sketches and mark burger vector in each case.**

**Ans.** Refer Q. 1.14, Unit-1.

**Q. 6. Discuss the tensile test in detail.**

**Ans.** Refer Q. 1.20, Unit-1.

**Q. 7. Write short note on the following :**

- i. Yield strength,**
- ii. Ductility,**
- iii. Ultimate tensile strength,**
- iv. Resilience,**
- v. Toughness,**
- vi. Elastic recovery, and**
- vii. Yielding.**

**Ans.** Refer Q. 1.24, Unit-1.



# 2

## UNIT

# Static Failure Theories and Fracture Mechanics

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Destructive Testing (NDT)

**PART-1***Static Failure Theories : Ductile and Brittle Failure Mechanism.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 2.1.** What is meant by fracture ? Explain the characteristics of brittle fracture and ductile fracture.

**Answer****A. Fracture :**

1. Fracture refers to the failure of a material under load by breaking into two or more pieces. Fracture can occur under all service conditions.
2. Materials subjected to alternating or cyclic loading fail due to fatigue. The fracture under such circumstances is called fatigue fracture.
3. Materials used at high temperature can fail due to creep fracture.
4. Any fracture involves two steps :
  - i. Crack formation, and
  - ii. Crack propagation.
5. The mode of fracture (ductile or brittle fracture) depends on the mechanism of crack propagation.

**B. Ductile Fracture :** Ductile fractures have the following characteristics :

1. There is considerable plastic deformation in the region of ductile fracture.
2. Ductile fractures are those in which the shear stress exceeds the shear strength before any other mode of fracture can occur. Therefore, the micro-mechanism of fracture is in the shear direction.
3. The surface of a ductile fracture is not necessarily related to the direction of the principal tensile stress, as it is in brittle fracture.
4. The characteristic appearance of the surface of a ductile fracture is dull and fibrous. This is caused by deformation on the fracture surface.
5. Ductile fractures proceed only as long as the material is being strained.
6. Also, once a brittle crack is initiated, it propagates through the material with no possibility of arresting it.

**C. Brittle Fracture :** Following are the characteristics of brittle fracture :

1. It occurs suddenly without any warning.
2. It occurs with little or no plastic deformations.
3. The rate of propagation of the crack is very fast.
4. The fractured surface is shiny and flat.
5. It occurs along the cleavage planes.

**Que 2.2.** Differentiate between brittle and ductile fracture.

**Answer**

S.No.	Brittle Fracture	Ductile Fracture
1.	It occurs with no or little plastic deformation.	It occurs with large plastic deformation.
2.	The rate of propagation of the crack is fast.	The rate of propagation of the crack is slow.
3.	It occurs suddenly without any warning.	It occurs slowly.
4.	The fractured surface is flat.	The fractured surface has rough contour and the shape is similar to cup and cone arrangement.
5.	The fractured surface appears shiny.	The fractured surface is dull when viewed with naked eye and the surface has dimpled appearance when viewed with scanning electron microscope.
6.	It occurs where micro crack is larger.	It occurs in localised region where the deformation is larger.

**Que 2.3.** Discuss the mechanism of ductile fracture.

**Answer**

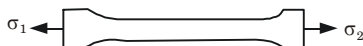
The mechanism involved in ductile fracture is as follows :

- a. Neck Formation :** When load is applied on the specimen, it results in reduced cross-sectional area which leads to formation of neck beyond the ultimate stress.



(a)

Original specimen.



(b)

Final specimen.

**Fig. 2.3.1.** Neck formation.

- b. Crack Nucleation :** In every material, some brittle and natural particles (as cementite in steel and oxide in copper) are present. Due to incompatibility with the surrounding region crack nucleates at these brittle particles.



Fig. 2.3.2. Crack nucleation.

- c. Crack Formation and Growth :** As deformation continues, these micro voids enlarge, come together, and combined to form an elliptical crack, which has its long axis perpendicular to the stress direction.

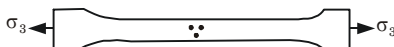


Fig. 2.3.3. Crack formation.

- d. Crack Propagation :** The crack proceeds outward towards the surface in perpendicular direction to the stress direction.



Fig. 2.3.4. Crack propagation.

- e. Cup-cone Fracture :** Fracture occurs as a result of rapid propagation of a crack around the outer perimeter of the neck, by shear deformation at an angle of about  $45^\circ$  with the tensile axis. Sometimes this fracture is called cup-cone fracture because one of the mating surfaces is in the form of a cup, the other like a cone.



Fig. 2.3.5. Cup-cone fracture.

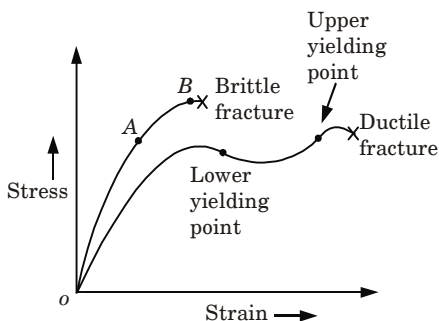
**Que 2.4.**

**Explain brittle and ductile fracture with the help of graph.**

**Answer**

- (Fig. 2.4.1) shows the stress-strain diagram for the ductile and brittle fracture of material.
- From  $o$  to  $A$ , proportional limit is prevailed *i.e.*, material regain its original position if stress is removed.
- At point  $B$ , yield point is reached if stress is applied further and the brittle fracture occurs at this point.
- Ductile materials have more elastic property and they further reached to an upper yielding point on further application of the stressed.

5. If stress is increased above the upper yielding point, the material breaks resulting in ductile fracture.



**Fig. 2.4.1.**

## PART-2

*Tresca, Von-Mises.*

### CONCEPT OUTLINE

**Yield Criterion :** Several yield criteria have been proposed to find out the relation between yield stresses. The most important criteria are :

- i. Tresca's yield criterion, and
- ii. Von-Mises yield criterion.

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 2.5.** State Tresca's and Von-Mises theory. Derive Expression for both.

#### Answer

#### A. Tresca's Theory :

1. Tresca states that failure of a material (or plastic deformation) will occur when the maximum shear stress in a material reaches the value of maximum shear stress at elastic limit.

2. Let principal stresses at a point in the material are  $\sigma_1$ ,  $\sigma_2$  and  $\sigma_3$  ( $\sigma_1 > \sigma_2 > \sigma_3$ ). So maximum shear stress is given by,

$$\frac{\sigma_1 - \sigma_3}{2} = \tau_{\max}$$

3. Plastic deformation occurs when  $\tau_{\max}$  is equal to  $K$  ( $K$  = Maximum shear stress at elastic limit or shear yield stress). So according to Tresca's theory for plastic deformation,

$$\frac{\sigma_1 - \sigma_3}{2} = K \quad \dots(2.5.1)$$

4. For uniaxial tension condition,

$$\begin{aligned} \sigma_1 &= \sigma_y \\ \sigma_2 &= \sigma_3 = 0 \end{aligned} \quad \text{(Tensile yield stress)}$$

5. For uniaxial compression condition,

$$\begin{aligned} \sigma_1 &= \sigma_2 = 0 \\ \sigma_3 &= -\sigma_y \end{aligned} \quad \text{(Compressive yield stress)}$$

6. For uniaxial tension condition, putting the value of  $\sigma_1$  and  $\sigma_3$  in eq. (2.5.1), we get

$$\frac{\sigma_y - (0)}{2} = K$$

$$K = \frac{\sigma_y}{2}$$

7. For uniaxial compression condition, putting the value of  $\sigma_1$  and  $\sigma_3$  in eq. (2.5.1), we get

$$\frac{0 - (-\sigma_y)}{2} = K$$

$$K = \frac{\sigma_y}{2}$$

### B. Von-Mises Theory :

1. Mises states that failure (plastic deformation) of a material will occur when the total shear strain energy per unit volume in strained material reaches a value equal to the shear strain energy per unit volume at the elastic limit.
2. Energy of distortion is given as,

$$U = \frac{1}{12G} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] \quad \dots(2.5.2)$$

Here  $U$  is the shear strain energy per unit volume,  $\sigma_1$ ,  $\sigma_2$  and  $\sigma_3$  are the principal stresses,  $G$  is the shear modulus.

3. So,  $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 12G \times U = C \quad \dots(2.5.3)$   
Where,  $C$  = Constant.

4. For uniaxial tensile loading

$$\sigma_1 = \sigma_y, \sigma_2 = \sigma_3 = 0$$



Putting the value in eq. (2.5.3), we get

$$(\sigma_y - 0)^2 + (0 - 0)^2 + (0 - \sigma_y)^2 = C$$

$$2\sigma_y^2 = C \quad \dots(2.5.4)$$

5. Considering yielding under pure torsion,

For pure shear :  $\sigma_1 = K, \sigma_2 = 0, \sigma_3 = -K$

Putting these values in eq. (2.5.3), we get

$$(K - 0)^2 + (0 - (-K))^2 + (-K - K)^2 = C$$

$$6K^2 = C \quad \dots(2.5.5)$$

6. Equating the eq. (2.5.4) and eq. (2.5.5), we get

$$2\sigma_y^2 = 6K^2$$

$$K = \frac{\sigma_y}{\sqrt{3}}$$

### PART-3

#### Maximum Normal Stress.

#### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 2.6.** Write short note on maximum normal stress theory.

#### Answer

- Maximum normal stress theory states that “the failure of the mechanical component subjected to bi-axial or tri-axial stresses occurs when the maximum normal stress reaches the yield or ultimate strength of the material”.
- If  $\sigma_1, \sigma_2$  and  $\sigma_3$  are the three principal stresses at a point on the component such that,

$$\sigma_1 > \sigma_2 > \sigma_3$$

Then according to this theory, the failure occurs whenever,

$$\sigma_1 = \sigma_{yt}/\text{FOS}$$

or

$$\sigma_1 = \sigma_{ut}/\text{FOS}$$

Whichever is applicable.

- This theory gives good predictions for brittle materials. It is not recommended for ductile materials.

**PART-4***Mohr-Coulomb and Modified Mohr-Coulomb.***Questions-Answers****Long Answer Type and Medium Answer Type Questions****Que 2.7. What is Mohr-Coulomb failure theory ?****Answer**

1. Mohr-Coulomb theory is a mathematical model describing the response of brittle materials such as concrete, or rubble piles, to shear stress as well as normal stress.
2. Generally, this theory applies to materials for which the compressive strength far exceeds the tensile strength.
3. It is used to determine failure load as well as the angle of fracture of a displacement fracture in concrete and similar materials.
4. It can be shown that a material failing according to Coulomb's friction hypothesis will show the displacement introduced at failure forming an angle to the line of fracture equal to the angle of friction.
5. This makes the strength of the material determinable by comparing the external mechanical work introduced by the displacement and the external load with the internal mechanical work introduced by the strain and stress at the line of failure.
6. By conservation of energy the sum of these must be zero and this will make it possible to calculate the failure load of the construction.
7. Coulomb assumed the relation between  $\tau_f$  and  $\sigma$  to be linear and gave the following equation popularly known as Coulomb's equation.

$$s = c + \sigma \tan \phi \quad \dots(2.7.1)$$

Where,  $c$  is the intercept on the strength envelope on the  $\tau$ -axis and  $\tan \phi$  is the slope of the strength envelope,  $c$  is known as cohesion and  $\phi$  is angle of internal friction or more comprehensively angle of shearing resistance.

**Que 2.8. What is modified Mohr-Coulomb theory ?****Answer**

1. We know Mohr-Coulomb's equation is given by,

$$s = c + \sigma \tan \phi \quad \dots(2.8.1)$$

2. The parameters  $c$  and  $\phi$  in eq. (2.8.1) are not necessarily fundamental properties of the soil as was originally assumed by Coulomb.

3. These parameters depend upon a number of factors, such as the water content, drainage conditions, conditions of testing.
4. To consider  $c$  and  $\phi$  as mathematical parameters which represent the failure condition for a particular soil under given conditions. That is the reason why  $c$  and  $\phi$  are now called cohesion intercept and the angle of shearing resistance.
5. These indicate the intercept and the slope of the failure envelope, respectively.
6. Terzaghi established that the normal stresses which control the shear strength of a soil are the effective stresses and not the total stresses.
7. In terms of effective stresses, eq. (2.8.1) is written as

$$s = c' + \bar{\sigma} \tan \phi' \quad \dots(2.8.2)$$

Where  $c'$  and  $\phi'$  are the cohesion intercept and the angle of shearing resistance in terms of the effective stresses.

8. Eq. (2.8.2) is known as the modified Mohr-Coulomb equation.
9. Modified Mohr-Coulomb theory consider the effect of the intermediate principle stress. It approximates the curved failure envelop by a straight line.

### PART-5

*Fracture Mechanism : Introduction to Stress Intensity Factor Approach and Griffith Criterion.*

#### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 2.9.** Discuss the stress intensity factor approach.

#### Answer

1. The stress intensity factor ( $K$ ) is used in the field of fracture mechanics.
2. The magnitude of  $K$  depends on :
  - i. Sample geometry,
  - ii. Size and location of the crack,
  - iii. Magnitude of load, and
  - iv. Distribution of load.
3. The stress intensity factor is a single parameter characterization of the crack tip stress field.

4. The stress intensity factor describes the stress state at a crack tip is related to the rate of crack growth, and is used to establish failure criteria due to fracture.
5. It is a method of calculating the amount of energy available for fracture in terms of the asymptotic stress and displacement fields around a crack front in a linear elastic solid.
6. This asymptotic expression for the stress field in loading is related to the stress intensity factor as given below,

$$\sigma_{ij} = \left( \frac{K_I}{\sqrt{2\pi r}} \right) f_{ij}(\theta)$$

Where,

$\sigma_{ij}$  = Cauchy stresses,

$r$  = Distance from the crack tip,

$\theta$  = Angle with respect to the plane of the crack, and

$f_{ij}$  = Functions that depend on the crack geometry and loading conditions.

**Que 2.10.** Show by graph brittle and ductile fracture of materials.

Explain in brief Griffith's theory of brittle fracture.

**AKTU 2015-16, Marks 15**

**Answer**

**A. Brittle and Ductile Fracture :** Refer Q. 2.4, Page 2-4B, Unit-2.

**B. Griffith's Criterion :**

1. Griffith has postulated a criterion for the propagation of pre-existing cracks in a brittle material.
2. The crack could come from a number of sources such as a collection of dislocations, a flaw which occurred during solidification, or a surface scratch.
3. As the crack becomes longer, the material on both sides of the crack can no longer store elastic energy because tensile stress cannot be transmitted across the crack. Thus, an increase in crack length causes the release of elastic energy.
4. Griffith postulated that when the elastic energy released by extending a crack was equal to the surface energy required for crack extension, the crack would grow.
5. For an elliptical crack (Fig. 2.10.1), the maximum stress at the tips is given by :

$$\sigma_{\max} = 2 \sigma \sqrt{C/R}$$

Where,

$R$  = Radius of curvature at the tip, and

$\sigma$  = Applied stress perpendicular to length  $2C$ .

6. The elastic strain energy for unit volume is given by,

$$U_E = \frac{\sigma^2}{2E} \times \text{Area} \times \text{Width}$$

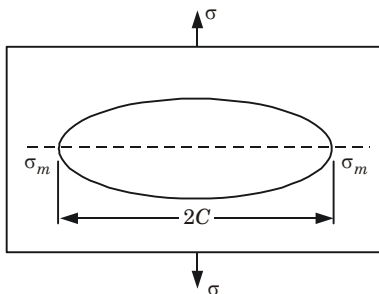
$$= \frac{\sigma^2}{2E} \times \pi 2C \times C = \frac{\sigma^2}{E} \pi C^2$$

7. If the surface energy per unit area is  $\gamma$  then the surface energy for a crack of length  $2C$  and unit width will be,

$$U_S = (2 \gamma C) \times 2 = 4 \gamma C$$

We multiply by 2 because there are two faces.

8. Applying Griffith's criterion, if the crack is to propagate, the change in surface energy with crack length must equal to the change in elastic strain energy.



**Fig. 2.10.1.** Model for Griffith's fracture theory.

$$\frac{dU_E}{dC} = \frac{dU_S}{dC}$$

$$\frac{d}{dC} \left( \frac{\pi C^2 \sigma^2}{E} \right) = \frac{d}{dC} (4 \gamma C)$$

$$\sigma = \sqrt{\left( \frac{4 \gamma E}{\pi C} \right)}$$

9. This result shows that the stress necessary to cause fracture varies inversely as the square root of the crack length and so the tensile stress of a completely brittle material will depend on the length of the largest existing crack in the material.

## PART-6

*Fatigue Failure : High Cycle Fatigue,  
Stress-Life Approach, S-N Curve.*

## CONCEPT OUTLINE

**Fatigue :** The failure of an object due to cyclic loading and unloading is known as fatigue failure.

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

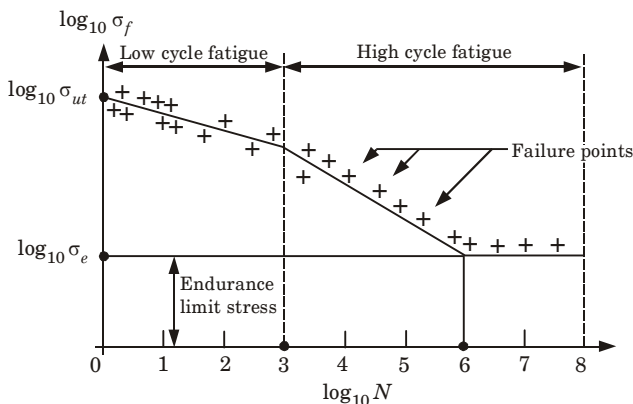
**Que 2.11.** Write short note on the following :

- i. Low cycle fatigue.
- ii. High cycle fatigue.
- iii. Stress-life approach.
- iv.  $S-N$  curve.

#### Answer

**i. Low Cycle Fatigue :**

1. Any fatigue failure when the number of stress cycles are less than 1000 is called low cycle fatigue.
2. Failure of studs on truck wheels, failure of setscrews for locating gears on shafts or failures of short-lived devices such as missiles are the examples of low cycle fatigue.



**Fig. 2.11.1.** Low and high cycle fatigue.

**ii. High Cycle Fatigue :**

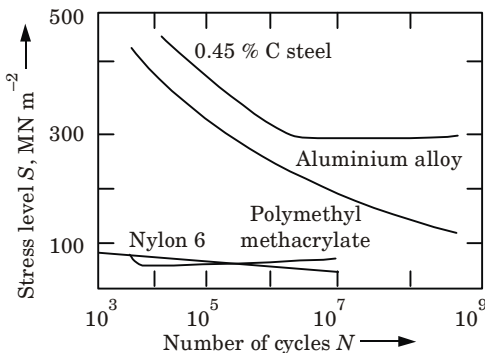
1. Any fatigue failure when the number of stress cycles are more than 1000 is called high cycle fatigue.
2. Failure of machine components such as springs, ball bearings or gears that are subjected to fluctuating stresses, are the example of high cycle fatigue.

**iii. Stress-Life Approach :**

1. The stress life approach estimates total life without distinguishing crack initiation from crack propagation.
2. It usually requires that the test data relate to the geometry of the structure under assessment.
3. Stress life approach is applicable for situation involving the primary elastic deformation.
4. In these conditions component expected to have a long life time.
5. It is based on stress levels only.
6. It is least accurate approach, especially for low cycle applications.

**iv. S-N Curve :**

1. S-N curve represents the dependence of the life of the specimen, in number of cycles to failure  $N$ , on the maximum applied stress  $\sigma$ .
2. S-N curve is the basic method of presenting engineering fatigue data.
3. Typical S-N curves obtained by means of the rotating beam machine are shown in the (Fig. 2.11.2).



**Fig. 2.11.2.** The S-N curves for different materials.

4. (Fig. 2.11.2) shows the number of cycles of stress which a metal can endure before failure increases with decreasing stress.
5. Generally,  $N$  is taken as the number of cycles of stress to cause complete fracture of the specimen. Fatigue tests at low stresses are usually carried out for  $10^7$  cycles and sometimes to  $5 \times 10^8$  cycles for non-ferrous metals.

6. For a few important engineering materials such as steel and titanium, the  $S-N$  curve becomes horizontal at a certain limiting stress. Below this limiting stress, which is called the fatigue limit, or endurance limit, the material can presumably endure an infinite number of cycles without failure.
7. Most non-ferrous metals like aluminium, magnesium and copper alloys have  $S-N$  curve which slopes gradually downward with increasing number of cycles. These materials do not have a true fatigue limit because the  $S-N$  curve never becomes horizontal.
8. The  $S-N$  curve is also known as the Wohler curve.

**PART-7***Endurance or Fatigue Limit.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 2.12.** Write a short note on fatigue or endurance limit.

**Answer**

1. Fatigue limit is also known as endurance limit.
2. The endurance limit of a material is defined as the maximum amplitude of completely reversed stress that the standard specimen can sustain for an unlimited number of cycles without fatigue failure.
3. Since the fatigue test cannot be conducted for unlimited or infinite number of cycles,  $10^6$  cycles is considered as a sufficient number of cycles to define the endurance limit.
4. The endurance limit is affected by factors such as the size of the component, shape of component, the surface finish, temperature and the notch sensitivity of the material.
5. Examples of parts in which fatigue failures are common in transmission shafts, connecting rods, gears, vehicle suspension springs and ball bearings.

**PART-8***Effects of Mean Stress using the Modified Goodman Diagram.*

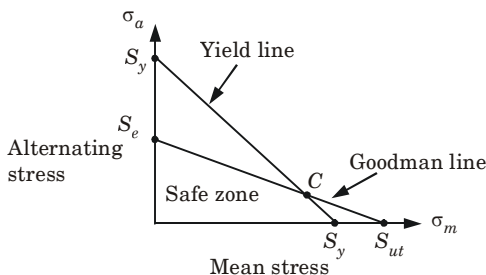


**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 2.13.** Explain effects of mean stress using modified Goodman diagram.

**Answer**

1. Mean stress effects are handled by using a modified Goodman diagram applied to nominal stress  $S$ .
2. This involves crude assumptions of a constant notch factor  $k_{fm}$  applied to the mean nominal stress, with the details again varying drastically among different design books.
3. The overall process of estimating  $S-N$  curves and mean stress effects for notched members is very crude, often highly inaccurate, and has only weak support in experimental data.
4. The mean stress effect should be seriously considered in fatigue analysis.
5. Mean normal stresses are responsible for the opening and closing state of micro-cracks.
6. The Modified Goodman correction is equivalent to the linear mean stress correction in that the reduction of the allowable stress range is linear.
7. (Fig. 2.13.1) shows effect of mean stress on fatigue life using modified Goodman diagram.



**Fig. 2.13.1.**

8. As the mean stress increases, the material breaks at lower alternating stress amplitude.

**PART-9***Fracture with Fatigue .***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 2.14.** What is a fatigue failure ? How is a fatigue test carried out ?

**AKTU 2014-15, Marks 10**

**Answer****A. Fatigue Fracture :**

1. Fatigue fracture results from the presence of fatigue cracks, usually initiated by cyclic stresses, at surface imperfections such as machine markings and slip steps.
2. Although the initial stress concentration associated with these cracks are too low to cause brittle fracture but they may be sufficient to cause slow growth of the cracks into the interior. Eventually the cracks may become sufficiently deep so that the stress concentration exceeds the fracture strength and sudden failure occurs.
3. The extent of the crack propagation process depends upon the brittleness of the material under test.
4. In brittle materials the crack grows to a critical size from which it propagates right through the structure in a fast manner, whereas with ductile materials the crack keeps growing until the remaining area cannot support the load and an almost ductile fracture suddenly occurs.
5. Fatigue failures can be recognized by the appearance of fracture.

**B. Fatigue Tests :**

1. Fatigue tests are performed in the laboratory to determine the capacity of a material to withstand repeated applied stresses.
2. Fatigue testing with respect to the type of load and the manner in which it is applied, is important to find the various fatigue properties of materials.
3. The basic types of loading are simple axial loading, bending, torsion, and a combination of these three.
4. Fig. 2.14.1 shows a constant load machine used for fatigue testing.

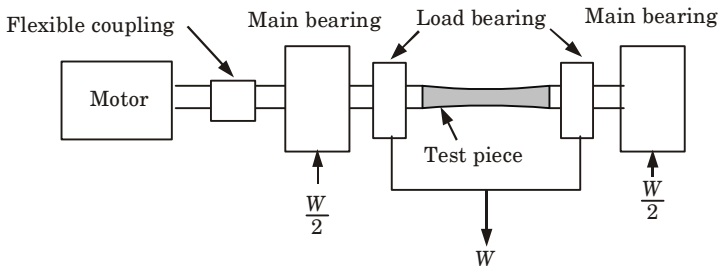


Fig. 2.14.1.

5. The test specimen in the form of cantilever which forms the extension of a shaft is placed in the machine. The shaft is driven by an electric motor.
6. A dead load is applied to the machine by means of ball bearings. The bearing relieves the motor of the large bending moment which is applied to the specimen.
7. While the specimen is rotating, any given position on the surface of the specimen alternates between a state of maximum tensile stress and a state of maximum compressive stress.
8. There is sinusoidal variation of stress as the specimen rotates.
9. The stress is greatest at the surface and zero at the centre.
10. The number of cycles will depend upon the value of the applied stress so that fatigue may occur. The number of cycles will be less where the value of the stress is high.
11. On the other hand, if the applied stress is less, the number of cycles will have to be increased. Ultimately a stress is reached below which failure will not take place within the limits of the standard test. This value of stress is known as the endurance limit.
12. If fracture does not take place within the specified cycles for the material, then it is assumed that fracture will not take place.

**Que 2.15.** Briefly explain mechanism of fatigue with neat sketches.

**Answer**

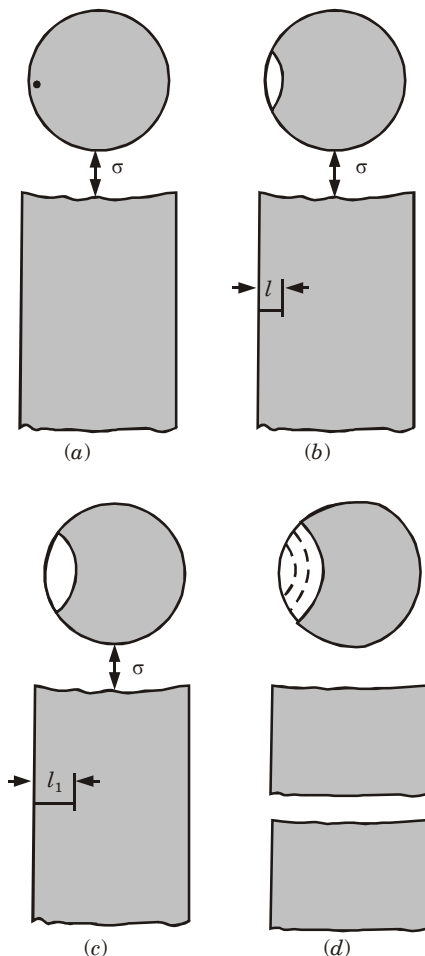
The steps involved in the fatigue fracture are as follows :

**Step 1 : Nucleation of Crack :** Nucleation is caused when maximum stress  $\sigma_{\max}$  fluctuates between tensile to compressive (within the elastic range) (Fig. 2.15.1 (a)).

**Step 2 : Crack Growth :** Crack grows to a microscopic size on continued load cycles. (Fig. 2.15.1 (b))

**Step 3 : Crack Growing to Tiny Size :** Crack becomes visible to the eyes after some times of continued load cycles. (Fig. 2.15.1 (c))

**Step 4 : Fracture :** When crack reaches to some critical size, resulting in reduced effective cross-sectional area of the material, results in fracture. (Fig. 2.15.1 (d))



**Fig. 2.15.1.** Events leading to fatigue fracture.

**Que 2.16.** Give the fatigue properties.

**Answer**

Following are the fatigue properties :

1. Fatigue process begins at the common locations of stress concentration.
2. Fatigue is a process that has a degree of randomness, often showing considerable scatter even in seemingly identical sample in well controlled environments.
3. Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads.
4. The greater is the applied stress range, the shorter is the life.
5. Fatigue life scatter tends to increase for longer fatigue life.
6. Damage is cumulative. Materials do not recover when tested.
7. Fatigue life is influenced by a variety of factors, such as temperature, surface finish, metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses, etc.

**PART-10***Introduction to Non-Destructive Testing (NDT).***CONCEPT OUTLINE**

**Non-Destructive Testing (NDT) :** NDT is aimed at extracting information on the physical, chemical, mechanical or metallurgical state of materials or structures without damaging its intended utility value.

**NDT Methods :** Some common NDT methods are :

- i. Visual inspection,
- ii. Penetrant testing,
- iii. Magnetic particle inspection,
- iv. Eddy current testing,
- v. Radiography testing, and
- vi. Ultrasonic testing.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 2.17.** What is non destructive testing (NDT) ? Explain in detail any two NDT methods.

**AKTU 2018-19, Marks 07****Answer**

**A. NDT :**

1. It refers to a method of detecting internal flaws in engineering materials without breaking them.

2. It can also be defined as, "The use of non-invasive technique to determine the integrity of a material component or structure or quantitatively measuring some characteristics of an object."

**B. NDT Methods :****a. Penetrant Testing :**

1. In this method, test specimen is coated with liquid of fluorescent dye solution. Then excess penetrant is removed very carefully and developers are applied.
2. These developers acts as blotter and draws out the trapped penetrant from defect to open surface.
3. These penetrants are now easily visible because of colour contrast between penetrant and developer with fluorescent dyes.
4. Ultraviolet lights are used which make the bleed out penetrant readily seen.

**b. Magnetic Particle Testing :**

1. This method employs the role of magnetic field which may be produced by any of the magnetizing technique. Then a powdered magnet or liquid magnet called as magnetic ink is spread over the surface to be inspected.
2. Surface or near surface defect cuts the magnetic flux line, which generates a new magnetic pole, at the defect point. This concentrates the iron particles near imperfection or defect giving a clear visualization of defect.

**Que 2.18.** Explain the various non-destructive testing methods.

**Answer**

Various non-destructive testing methods are as follows :

- a. Visual and Optical Testing :** It may be performed manually by an inspector or by special automated techniques like magnifying glasses, mirrors, or borescope to gain access and more closely inspect the component.
- b. Eddy Current Testing :**
  1. An electrical current is generated in a conductive material by inducing an alternating magnetic field.
  2. The electrical currents are called eddy currents because they flow in circles at and just below the surface of the material.
  3. When these eddy currents are interrupted by any defect, an indication is produced for change in dimension or conductivity.
- c. Radiography Testing :**
  1. It involves the use of X-rays or gamma rays for inspection of components.

2. When  $X$ -rays from  $X$ -ray generator are directed through a part and into film or other imaging media, the resulting image or shadow shows the dimensional details of part.
3. This method is same as  $X$ -ray of human body used in medicals.

**d. Ultrasonic Testing :**

1. It uses transmission of high frequency sound waves into a material to detect and locate the defect.
2. It generally uses pulse echo technique, wherein sound is introduced into a test specimen and its reflections or echoes are received by receiver.

**e. Penetrant Testing :** Refer Q. 2.17, Page 2-19B, Unit-2.

**f. Magnetic Particle Testing :** Refer Q. 2.17, Page 2-19B, Unit-2.

**VERY IMPORTANT QUESTIONS**

*Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.*

**Q. 1. What is meant by fracture ? Explain the characteristics of brittle fracture and ductile fracture.**

**Ans.** Refer Q. 2.1, Unit-2.

**Q. 2. State Tresca's and Von-Mises theory. Derive Expression for both.**

**Ans.** Refer Q. 2.5, Unit-2.

**Q. 3. Show by graph brittle and ductile fracture of materials. Explain in brief Griffith's theory of brittle fracture.**

**Ans.** Refer Q. 2.10, Unit-2.

**Q. 4. Write short note on the following :**

- i. Low cycle fatigue.
- ii. High cycle fatigue.
- iii. Stress-life approach.
- iv.  $S-N$  curve.

**Ans.** Refer Q. 2.11, Unit-2.

**Q. 5. What is a fatigue failure ? How is a fatigue test carried out ?**

**Ans.** Refer Q. 2.14, Unit-2.

**Q. 6. Briefly explain mechanism of fatigue and corrosion with neat sketches.**

**Ans.** Refer Q. 2.15, Unit-2.

**Q. 7. What is non destructive testing (NDT) ? Explain in detail any two NDT methods.**

**Ans.** Refer Q. 2.17, Unit-2.





# 3

## UNIT

# Phase Diagram

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**PART-1***Alloys.***Questions-Answers****Long Answer Type and Medium Answer Type Questions****Que 3.1.** Write short note on alloys.**Answer**

1. Alloy is a metallic substance that is composed of two or more elements.
2. Alloys are more widely used in industry than pure metals because their physical and chemical properties can be easily varied to suit the exact individual requirement.
3. This can be achieved by making alloys of different metals.
4. From alloy diagrams it is possible to get an idea of the structure and the physical and chemical properties of any given alloy.
5. In the solid state the alloy may be represent in one or more of the following forms :
  - i. As a solid solution.
  - ii. As an intermediate phase or intermetallic chemical compound.
  - iii. As a finely divided mechanical mixture of the metals.
  - iv. As a finely divided mechanical mixture of solid solution.

**PART-2***Substitutional and Interstitial Solid Solutions.***CONCEPT OUTLINE**

**Solid Solution :** It is a solid state solution of one or more solutes in a solution.

**Types of Solid Solution :** It is of following two types :

- i. Substitutional solid solution
- ii. Interstitial solid solution.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 3.2.**

What do you understand by solid solution ? Explain with neat sketches the substitutional solid solution and interstitial solid solution.

OR

Write short note on solid solution and its types.

AKTU 2018-19, Marks 07

**Answer****A. Solid Solutions :**

1. A solid solution is a solid state solution of one or more solutes in a solvent.
2. Such a mixture is considered as a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes, and when the mixture remains in a single homogeneous phase.

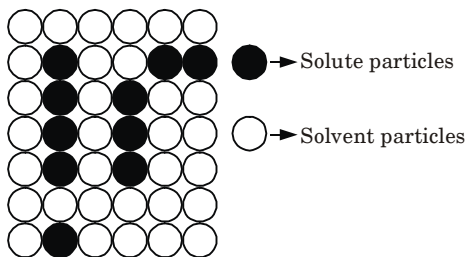


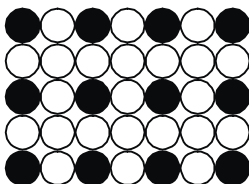
Fig. 3.2.1. Solid solutions.

3. Solid solutions form readily when solvent and solute atoms have similar sizes and electron structures, so that it is chemically homogeneous and the component atoms of the elements cannot be distinguished physically or separated mechanically.
4. There is a homogeneous distribution of two or more constituents in the solid state so as to form a single phase or solid solution.

**B. Types of Solid Solutions :** These are of following two types :**a. Substitutional Solid Solution :**

1. A solute atom may occupy two alternative positions in the lattice of solvent (matrix) metal.
2. If the two atoms are of comparable size, the solute atom will substitute at random for one of the matrix atoms in the crystal lattice. This kind of structure is called a substitutional solid solution.
3. For example, brass is an alloy of copper and zinc which forms solid solutions most readily as the atoms of these elements have similar sizes and electron structure.
4. Substitutional solid solutions are of two types :

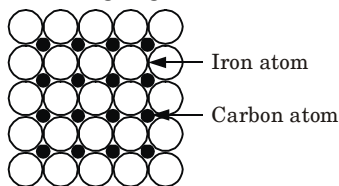
- i. Random substitutional solid solutions, and
- ii. Ordered substitutional solid solutions.



**Fig. 3.2.2.** Substitutional solid solutions.

**b. Interstitial Solid Solutions :**

1. There are few relatively small atoms that can be accommodated in the intersites between solvent atoms to form an interstitial solid solution.
2. Carbon in iron is the example of such a type of solution which is the basis of steel hardening (Fig. 3.2.3).



**Fig. 3.2.3.** Interstitial solid solutions.

3. Interstitial solid solutions normally have very limited solubility and are generally considered of secondary importance.
4. In some alloys, both interstitial and substitutional solid solutions are formed to an appreciable extent.

**Que 3.3.**

**Write short note on Hume-Rothery's rule.**

**Answer**

1. Hume-Rothery has given some criteria in alloy development for substitutional solid solution. These are known as Hume-Rothery's Rules and are described below :
  - a. Chemical Affinity Factor :**
    1. The greater the chemical affinity of two metals the more restricted is their solid solubility.
    2. When their chemical affinity is great, two metals tend to form an intermediate phase rather than a solid solution.
  - b. Relative Valency Factor :**
    1. If the alloying element has a different valence from that of the base metal, the number of valence electrons per atom, called the electron ratio, will be changed by alloying.

2. Crystal structures are more sensitive to a decrease in the electron ratio than to an increase. Therefore, a metal of high valence can dissolve only a small amount of lower valence metal, while the lower valence metal may have good solubility for a higher valence metal.

**c. Relative Size Factor :**

1. If the size of two metallic atoms differs by less than 15 percent, the metals are said to have a favourable size factor for solid solution formation.
2. If the size factor is greater than 15 %, solid solution formation tends to be severely limited and is usually only a fraction of one percent.

**d. Lattice Type Factor :**

1. Only metals that have the same type of lattice can form a complete series of solid solutions.

**PART-3**

*Phase Diagrams.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.4.** What do you mean by phase diagrams ? What are the different types of phase diagrams ?

**Answer**

**A. Phase or Equilibrium Diagrams :**

1. The existence of different phases in an alloy system can be represented by a diagram known as phase diagram.
2. In phase diagrams, graphic representations of changes in state due to variations in concentration and temperature enables the phase content of the alloy to be determined at any temperature and composition.
3. They enable the phase transformations to be followed in heating or cooling the alloy under equilibrium conditions, *i.e.*, when all processes in the given system are reversible.
4. All phase diagrams have temperature as the vertical scale (ordinate) and percentage composition by weight as the horizontal scale (abscissa).
5. A phase diagram permits the control and study of metallurgical processes.

**B. Types of Phase Diagrams :** Phase diagrams are of following three types :

1. Single component or unary phase diagrams,
2. Two component or binary phase diagrams, and
3. Three component or ternary phase diagrams.

**Que 3.5. Discuss Gibbs phase rule.**

**Answer**

1. Gibbs phase rule provides the theoretical foundation for characterizing the chemical state of a system, and predicting the equilibrium relations of the phases present as a function of physical conditions such as pressure and temperature.
2. It is expressed mathematically as follows :
 
$$P + F = C + n$$

$$P + F = C + 2$$

$$\therefore n = \text{number of external factors}$$

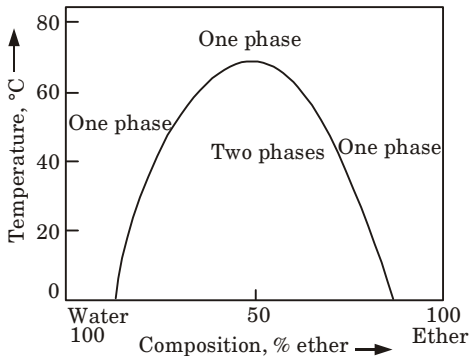
$$= 2 \text{ (temperature and pressure)}$$
3. The number of degrees of freedom is the quantity of independent external or internal variables, like temperature, pressure and concentration, which may be changed without causing the disappearance of a phase or the formation of a new phase in the system.
4. In studying chemical equilibrium, temperature and pressure are considered as external factors determining the state of the system.
5. In applying the phase rule of two metal systems the effect of pressure is neglected, leaving only one variable factor - temperature. The equation will then be :
 
$$F = C + 1 - P$$
6. In equilibrium all factors have definite values, hence the degree of freedom cannot be less than zero
 
$$C - P + 1 \geq 0$$
 then  $P \leq C + 1$   
 which shows that the number of phases in a system cannot exceed the number of components plus one.
7. Therefore, no more than three phases may be in equilibrium in a binary system.

**Que 3.6. Discuss in detail the construction of a simple phase diagram.**

**Answer**

1. Construction of a phase diagram requires that the phase changes taking place at different temperatures and at different compositions to be known.
2. These phase changes are then shown in a chart with temperature as ordinate and compositions as abscissa.

3. Let us first consider a simple case of two liquids and do an experiment on the water-ether system.
4. Take a series of mixtures of water and ether in various proportions and place them in a test tube to settle.
5. We shall observe the following :
  - i. Ether and water are completely soluble in one another upto ten percent of ether in water. There is only one phase present in this test tube.
  - ii. When the percentage of ether exceeds 10 per cent, the two liquids separate into two layers, the upper layer being ether and lower water. Therefore, two phases are present in the test tube.
  - iii. In test tubes containing more than 90 per cent of ether, only one phase is present and water is soluble in ether upto 10 per cent.
  - iv. If the test tubes containing separate layers of water and ether are heated, we shall find that after reaching a particular temperature, the two phases become one regardless of the proportions of ether and water.
6. Now, if we plot the above observations on a graph, with temperature as ordinate and composition as abscissa, we get a curve as shown in (Fig. 3.6.1). This curve is known as phase diagram.



**Fig. 3.6.1.** Schematic representation of the solubilities of ether and water for each other.

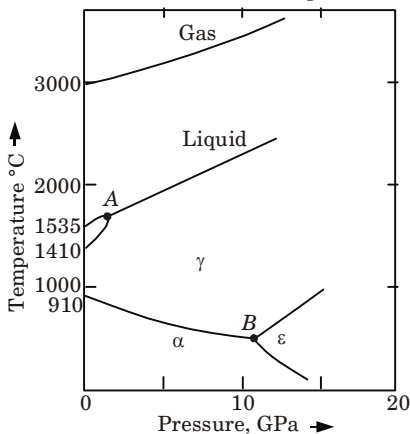
7. The middle portion of the phase diagram where two phases are present is called solubility gap between the two phases.
8. Similarly, the phase changes can be plotted for alloys containing two elements A and B to obtain a binary phase diagram.

**Que 3.7.**

**Discuss the single component systems or unary phase diagram.**

**Answer**

1. In single component systems, there is no composition variable and other variables are temperature and pressure.
2. The phase diagram for iron is shown in (Fig. 3.7.1). Pressure is plotted on the  $x$ -axis and temperature on the  $y$ -axis.
3. Consider first the single phase regions on the diagram such as gas, liquid and several crystal forms of iron.
4. In a single phase region, both temperature and pressure can be varied independently within the limits prescribed by the boundaries of the region.
5. When two phases are in equilibrium that is either temperature or pressure can be varied independently, but not both, two-phase equilibrium exists along the phase boundaries as shown in (Fig. 3.7.1).
6. When we are at a point on the phase boundary if we change the temperature by an arbitrary amount, we need to change the pressure by such an amount that we return to a point on the phase boundary.



**Fig. 3.7.1.** Pressure-temperature diagram for the one-component system of iron.

7. Three-phase equilibrium exists at points on the phase diagram, where three phase boundaries meet. Two such points are shown in (Fig. 3.7.1) point (A and B). Such points are called triple points. At this neither pressure nor temperature can be varied arbitrarily.
8. Three phases will co-exist at only one particular combination of pressure and temperature.
9. The equilibrium crystal form of iron at ambient temperature and pressure is BCC ( $\alpha$ ).



10. On heating to 910 °C,  $\alpha$  changes over to the FCC ( $\gamma$ ) form. On heating to 1410 °C, the  $\gamma$  iron changes over to the BCC ( $\delta$ ) form.
11. As the pressure is increased, the  $\alpha \rightarrow \gamma$  transition temperature is lowered, whereas the  $\gamma \rightarrow \delta$  transition temperature is increased.

**PART-4***Interpretation of Binary Phase Diagrams and  
Microstructure Development.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 3.8.** What do you mean by binary phase diagram ?

**Answer**

1. A graphical representation of a mixture or alloy of two metals instead of pure substance is known as binary phase diagram.
2. Pure copper is a one component system, whereas an alloy of copper and nickel is a two component system. Sometimes a compound in an alloy is also considered as a separate component. For example plain carbon steels containing iron and iron carbide are considered two component systems.
3. In some binary metallic system, the two elements are completely soluble in each other in both the liquid and solid states.
4. In these systems only a single type of crystal structure exists for all compositions of the components and therefore they are called isomorphous system.
5. A phase diagram of copper-nickel system with temperature as the ordinates and chemical composition in weight percent as the abscissa is shown in (Fig. 3.8.1).
6. This diagram has been determined for slow cooling or equilibrium conditions at atmospheric pressure and does not apply to alloys that have been rapidly cooled through the solidification temperature range.

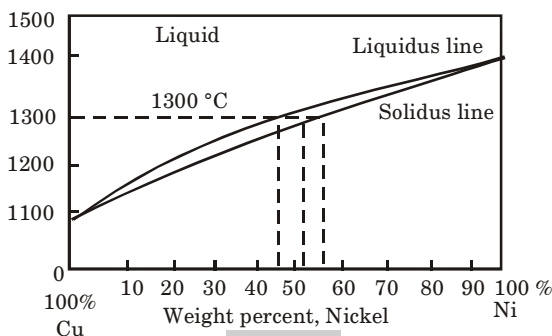


Fig. 3.8.1.

7. The area above the upper line in the diagram called the liquidus, corresponds to the region of the stability of the liquid phase and the area below the lower line or solidus represents the region of stability for the solid phase.
8. The region between the liquidus and solidus represents a two phase region where both the liquid and solid phase co-exists.
9. The amount of each phase present depends on the temperature and chemical composition of the alloy.

**Que 3.9.** What kind of interpretation can be obtained from a binary phase diagram ?

**Answer**

A binary phase diagram is helpful in obtaining the following three type of information :

**a. Phases Present :**

1. The establishment of what phases are present is relatively simple. One just locates the temperature-composition point on the diagram and notes the phase (s) with which the corresponding phase field is labeled.

**b. Determination of Phase Compositions :**

1. The first step in the determination of phase compositions is to locate the temperature-composition point on the phase diagram.
2. If only one phase is present, the composition of this phase is simply the same as the overall composition of the alloy.
3. For an alloy having composition and temperature located in a two-phase region, the situation is more complicated.
4. In all two-phase regions, one may imagine a series of horizontal lines, one at every temperature, each of these is known as a tie line, or sometimes as an isotherm. These tie lines extend across the two-phase region and terminate at the phase boundary lines on either side.

5. To compute the equilibrium concentrations of the two phases, the following procedure is used :
  - i. A tie line is constructed across the two-phase region at the temperature of the alloy.
  - ii. The intersections of the tie line and the phase boundaries on either side are noted.
  - iii. Perpendiculars are dropped from these intersections to the horizontal composition axis, from which the composition of each of the respective phases is read.

**c. Determination of Phase Amounts :**

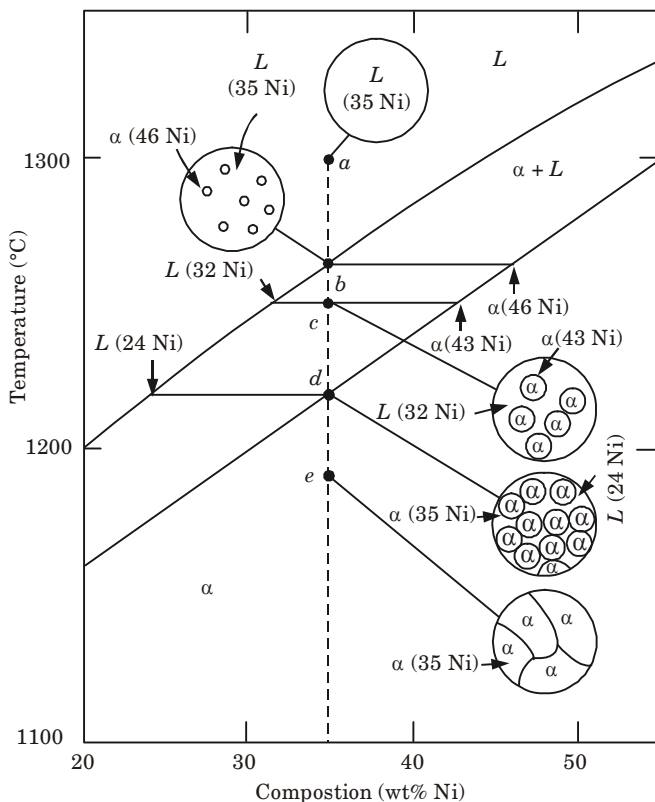
1. The relative amounts of the phases present at equilibrium may also be computed with the aid of phase diagrams.
2. The solution is obvious in the single-phase region: Since only one phase is present, the alloy is composed entirely of that phase *i.e.*, the phase fraction is 1.0 or alternatively, the percentage is 100 %.
3. If the composition and temperature position is located within a two-phase region, things are more complex.
4. The tie line must be utilized in conjunction with a procedure that is often called the lever rule (or the inverse lever rule), which is applied as follows :
  - i. The tie line is constructed across the two-phase region at the temperature of the alloy.
  - ii. The overall alloy composition is located on the tie line.
  - iii. The fraction of one phase is computed by taking the length of tie line from the overall alloy composition to the phase boundary for the other phase, and dividing by the total tie line length.
  - iv. The fraction of the other phase is determined in the same manner.
  - v. If phase percentages are desired, each phase fraction is multiplied by 100.
5. In the employment of the lever rule, tie line segment lengths may be determined either by direct measurement from the phase diagram using a linear scale, preferably graduated in millimeters, or by subtracting compositions as taken from the composition axis.

**Que 3.10. Explain development of microstructure in isomorphous alloys for equilibrium cooling.**

**Answer**

1. Let us consider the copper-nickel system specifically an alloy of composition 35 wt% Ni-65 wt% Cu as it is cooled from 1300 °C.
2. The region of the Cu-Ni phase diagram in the vicinity of this composition is shown in (Fig. 3.10.1).

- Cooling of an alloy of the above composition corresponds to moving down the vertical dashed line.
- At 1300 °C, point *a*, the alloy is completely liquid (of composition 35 wt % Ni-65 wt% Cu) and has the microstructure represented by the circle inset in the figure.
- As cooling begins, no microstructural or compositional changes will be realized until we reach the liquidus line (point *b*. ~1260 °C).
- At this point, the first solid  $\alpha$  begins to form, which has a composition dictated by the tie line drawn at this temperature [*i.e.*, 46 wt% Ni-54 wt% Cu, noted as  $\alpha(46 \text{ Ni})$ ]; the composition of liquid is still approximately 35 wt% Ni-65 wt% Cu [*L*(35 Ni)], which is different from that of the solid  $\alpha$ .



**Fig. 3.10.1.** Development of micro structure during equilibrium solidification of 35 % Ni-65% Cu alloy.

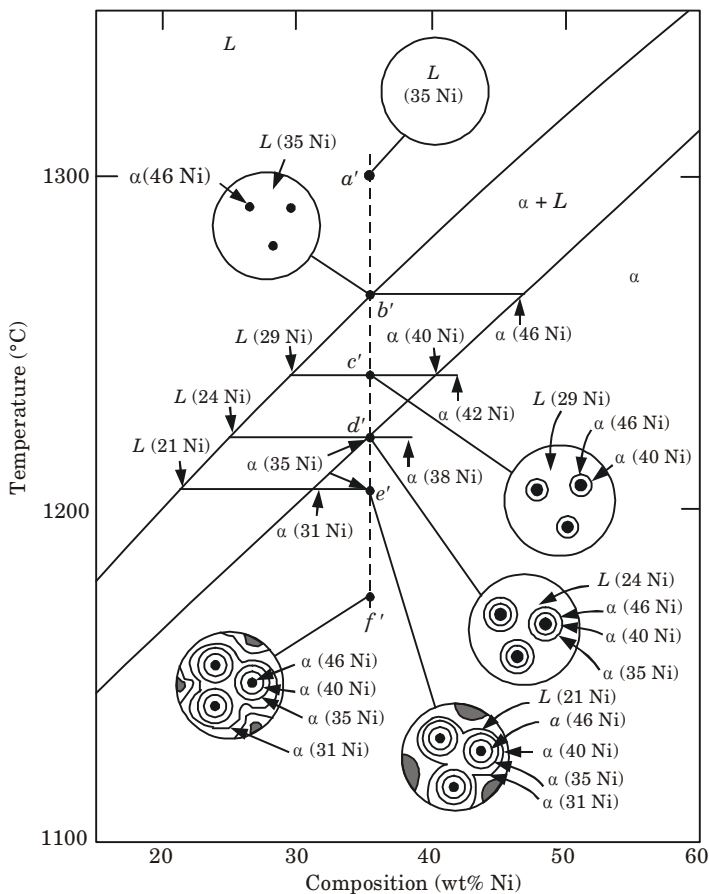
7. With continued cooling, both compositions and relative amounts of each of the phases will change.
8. The compositions of the liquid and  $\alpha$  phases will follow the liquidus and solidus lines, respectively. Furthermore, the fraction of the  $\alpha$  phase will increase with continued cooling.
9. The overall alloy composition (35 wt% Ni-65 wt% Cu) remains unchanged during cooling even though there is a redistribution of copper and nickel between the phases.
10. At 1250 °C, point *c* in (Fig. 3.10.1), the compositions of the liquid and  $\alpha$  phases are 32 wt% Ni-68 wt% Cu [L(32 Ni)] and 43 wt% Ni-57 wt% Cu [ $\alpha$  (43 Ni)], respectively.
11. The solidification process is virtually complete at about 1220 °C, point *d*, the composition of the solid  $\alpha$  is approximately 35 wt% Ni-65 wt% Cu (the overall alloy composition) while that of the last remaining liquid is 24 wt% Ni-76 wt% Cu.
12. Upon crossing the solidus line, this remaining liquid solidifies, the final product then is  $\alpha$  polycrystalline  $\alpha$ -phase solid solution that has a uniform 35 wt% Ni-65 wt% Cu composition, point *e*. (Fig. 3.10.1).

**Que 3.11. Explain development of microstructure in isomorphous alloys for non equilibrium cooling.**

**Answer**

1. Let us begin cooling from a temperature of about 1300 °C, this is indicated by point *a'* in the liquid region.
2. This liquid has a composition of 35 wt% Ni-65 wt% Cu noted as *L*(35 Ni) in (Fig. 3.11.1), and no changes occur while cooling through the liquid phase region (moving down vertically from point *a'*).
3. At point *b'* (approximately 1260 °C),  $\alpha$ -phase particles begin to form, which, from the tie line constructed have a composition of 46 wt% Ni-54 wt% Cu [ $\alpha$ (46 Ni)].
4. Upon further cooling to point *c'* (about 1240 °C), the liquid composition has shifted to 29 wt% Ni-71 wt% Cu; furthermore, at this temperature the composition of the  $\alpha$  phase that solidified is 40 wt% Ni-60 wt% Cu [ $\alpha$ (40 Ni)].
5. However, since diffusion in the solid  $\alpha$  phase is relatively slow, the  $\alpha$  phase that formed at point *b'* has not changed composition appreciably that is, it is still about 46 wt% Ni-and the composition of the  $\alpha$  grains has continuously changed with radial position, from 46 wt% Ni at grain centers to 40 wt% Ni at the outer grain perimeters.
6. Thus, at point *c'*, the average composition of the solid  $\alpha$  grains that have formed would be some volume weighted average composition, lying between 46 and 40 wt% Ni. Take this average composition to be 42 wt% Ni-58 wt% Cu [ $\alpha$ (42 Ni)].

7. Furthermore, we would also find that, on the basis of lever-rule computations, a greater proportion of liquid is present for these non equilibrium conditions than for equilibrium cooling.
8. The implication of this non-equilibrium solidification phenomenon is that the solidus line on the phase diagram has been shifted to higher Ni contents-to the average compositions of the  $\alpha$  phase, (e.g., 42 wt % Ni at 1240 °C)-and is represented by the dashed line in (Fig. 3.11.1).



**Fig. 3.11.1.** Development of micro structure during non equilibrium solidification of 35 % Ni- 65 % Cu alloy.

9. There is no comparable alteration of the liquidus line in as much as it is assumed that equilibrium is maintained in the liquid phase during cooling because of sufficiently rapid diffusion rates.

10. At point  $d'$  ( $\sim 1220^\circ\text{C}$ ) and for equilibrium cooling rates, solidification should be completed. However, for this non equilibrium situation, there is still an appreciable proportion of liquid remaining, and the  $\alpha$  phase that is forming has a composition of 35 wt% Ni [ $\alpha(35\text{ Ni})$ ]; also the average  $\alpha$ -phase composition at this point is 38 wt% Ni [ $\alpha(38\text{ Ni})$ ].
11. Non equilibrium solidification finally reaches completion at point  $e'$  ( $\sim 1205^\circ\text{C}$ ), composition of the last  $\alpha$  phase to solidify at this point is about 31 wt% Ni, the average composition of the  $\alpha$  phase at complete solidification is 35 wt% Ni.
12. The inset at point  $f'$  shows the microstructure of the totally solid material.
13. The degree of displacement of the non-equilibrium solidus curve from the equilibrium one will depend on rate of cooling.
14. The slower the cooling rate, the smaller this displacement, that is, the difference between the equilibrium solidus and average solid composition is lower.

**PART-5**

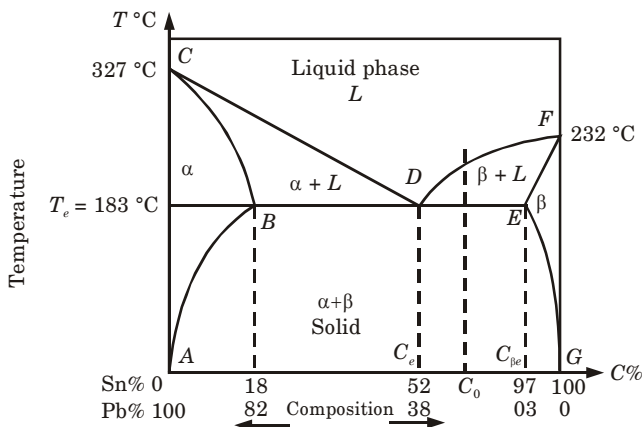
*Eutectic, Peritectic, Peritectoid and Monotectic Reactions.*

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 3.12.** Explain eutectic phase diagram with its reaction.

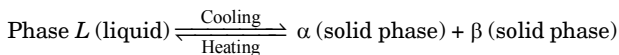
**Answer**

1. When the melting points of the two components are not much different and a partial or negligible solid solubility exists between them, the phase diagram is called eutectic phase diagram.
2. In (Fig. 3.12.1), we choose lead and tin as there is not much difference in their melting points. The two solid phases  $\alpha$  and  $\beta$  are present.
3. In  $\alpha$ -phase very small amount of tin is dissolved in lead and in  $\beta$ -phase very small amount of lead is dissolved in tin.
4. In  $\alpha + \beta$  phase both tin and lead are dissolved in each other sufficiently.
5. BDE line separates the two phase regions of  $\alpha + L$  and  $\alpha + \beta$ ,  $\alpha + \beta$  and  $L$ ,  $\alpha + \beta$  and  $\beta + L$ . This line is called eutectic line and temperature corresponding to this line is called eutectic temperature.



**Fig. 3.12.1.** Binary phase diagram of lead-tin showing phases, eutectic point and eutectic composition.

6. At point  $D$  eutectic reaction occurs as liquid phase is in equilibrium with two solid phases.



7. At point  $D$ ,

$$\text{Degree of freedom, } D = C - P + 1$$

$$C = 2, P = 3$$

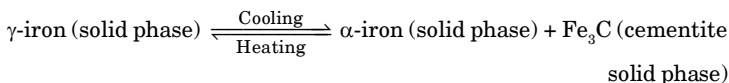
$$\text{So, } D = 2 - 3 + 1 = 0$$

8. At point  $D$ , eutectic temperature and eutectic reaction are called invariant temperature and invariant reaction.

**Que 3.13.** Discuss eutectoid phase diagram.

**Answer**

1. In eutectoid phase diagram, a solid phase transforms into two other solid phases on cooling and on heating the two solid phases transforms into one solid phase means one solid phase is in equilibrium with two other solid phases.
2. A eutectoid reaction can be seen in iron-carbon equilibrium diagram.
3. Between austenite ( $\gamma$ -iron) and two solid phases of iron as ferrite ( $\alpha$ -iron) and cementite ( $\text{Fe}_3\text{C}$ ) an equilibrium occurs which is called eutectoid reaction.





- 
- The diagram is a graph of Temperature (°C) on the y-axis versus % Carbon on the x-axis. The y-axis has labels for 910 °C and 723 °C. The x-axis has a label for 0.83. A horizontal line is drawn at 723 °C. A vertical dashed line is drawn at 0.83 % Carbon. The diagram shows several phase regions:  $\alpha + \gamma$  (labeled with an arrow pointing to the region between the 910 °C and 723 °C lines),  $\gamma + \text{cementite}$  (labeled in the upper right), and  $\alpha + \text{cementite (Fe}_3\text{C)}$  (labeled in the lower right). A point labeled 'D' is located at the intersection of the 723 °C line and the 0.83 % Carbon line. The curve for the  $\gamma + \text{cementite}$  boundary starts at 910 °C and 0.83 % Carbon and curves upwards and to the right. The curve for the  $\alpha + \text{cementite (Fe}_3\text{C)}$  boundary starts at 723 °C and 0.83 % Carbon and curves upwards and to the right.

5. In the (Fig. 3.13.1), point *D* is called eutectoid point. The leftward region is called hypo-eutectoid (carbon percentage less than 0.8 %) and rightward region is called hyper- eutectoid (carbon percentage greater than 0.8 %).

## Answer

- 
- The diagram is a phase diagram for a binary system. The vertical axis is labeled 'Temperature (in °C)' and the horizontal axis is labeled 'Percent composition'. The horizontal axis has two scales: the top scale shows composition from 0 to 100% (A% to 100%), and the bottom scale shows composition from 100% to 0% (B% to 0%). Key points on the horizontal axis are marked at 25, 50, and 75. The phase regions are labeled:  $\alpha$  (leftmost),  $\alpha + L$  (top middle),  $\beta$  (bottom right), and  $\alpha + L$  (middle). A horizontal line represents the liquidus, and a vertical dashed line at 50% composition is labeled  $C_P$ . A tie line connects point A on the liquidus at 25% composition to point C on the liquidus at 75% composition. The region between the liquidus and the tie line is labeled  $\alpha + L$ .

3. Temperature of this point is called as peritectic temperature and composition is called peritectic composition.

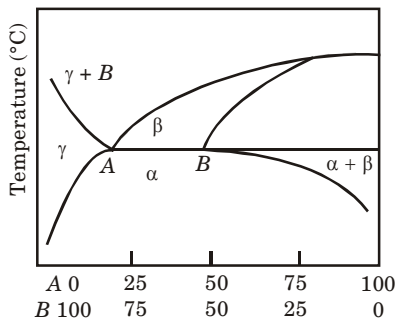
- The degree of freedom is zero at this point. Hence the peritectic reaction is an invariant reaction.
- From (Fig. 3.14.1), two components  $A$  and  $B$  are chosen (such that there is a much difference in their melting point).
- Their phase diagram consists of two solid phase ' $\alpha$ ' and ' $\beta$ ' and a liquid phase ' $L$ '.
- At point  $B$ ,  $\beta$ (solid phase) +  $L$ (liquid phase) is in equilibrium with solid phase.
- This point  $B$  is called peritectic point. The temperature and composition with respect to point  $B$  is called peritectic temperature and peritectic composition respectively.

**Que 3.15.** Write a short note :

- Peritectoid phase diagram.
- Monotectic phase diagram.

**Answer**

- Peritectoid Phase Diagram :**



**Fig. 3.15.1.** Peritectoid phase diagram.

- When two different solid phases change to a single solid phase, phase diagram is called peritectoid phase diagram and temperature and composition with respect to this peritectoid point are called peritectoid temperature and peritectoid composition.
- Let there are two solid phase  $\gamma$  and  $\beta$  which are in equilibrium with a single solid phase  $\alpha$  at point  $A$ . Point  $A$  is called peritectoid point.
- In the given (Fig. 3.15.1), at point  $A$ 

$$\gamma(\text{solid}) + \beta(\text{solid}) \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \alpha(\text{solid})$$

- Monotectic Phase Diagram :**

- Another three phase invariant reaction that occurs in some binary system is monotectic reaction in which a liquid transforms to another liquid and a solid.

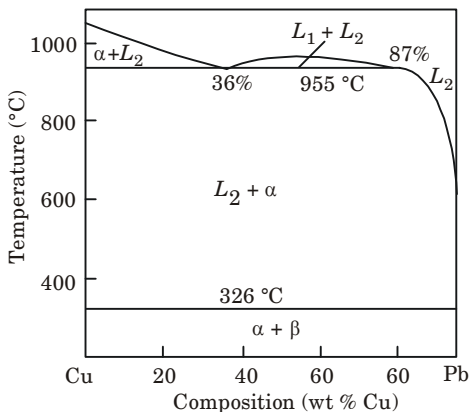


Fig. 3.15.2.

2. Cu-Pb system has a monotectic at 36 % Pb and 955 °C as shown in (Fig 3.15.2).

**Que 3.16.** What do you understand by lever rule ? Determine the mass fraction of the phases present at 184 °C in a sample of lead and tin with 45 % tin in it.

**AKTU 2015-16, 2018-19; Marks 07**

### Answer

#### A. Lever Rule :

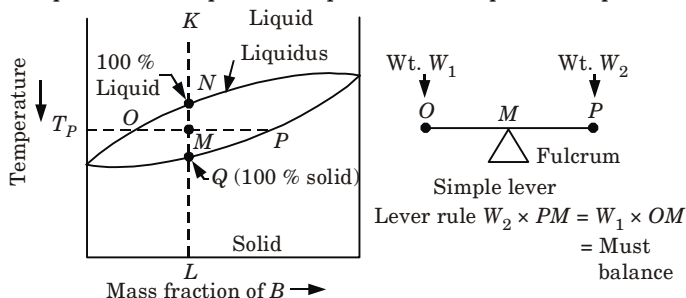
1. The lever rule is a tool used to determine weight percentages of each phase of a binary equilibrium phase diagram.
2. It is used to determine the percent weight of liquid and solid phases for a given binary composition and temperature that is between the liquidus and solidus line.
3. To determine the relative amounts of two phases, an ordinate or vertical line is erected at a point on the composition scale which gives the total composition of the alloy.
4. The intersection of this ordinate with the given isothermal line is the fulcrum of a simple lever system.
5. The ordinate  $KL$  intersects the temperature line at a point  $M$ .
6. The relative lengths of lever arms  $OM$  and  $MP$  multiplied by the amount of phases present must balance.
7. The length  $MP$  shows the amount of liquid, whereas the length  $OM$  indicates the amount of solid. Therefore,

$$\text{The percentage of solid present} = \frac{OM}{OP} \times 100$$

$$\text{The percentage of liquid present} = \frac{MP}{OP} \times 100$$

Where,  $OM + MP = OP = \text{Total composition of alloy between liquidus and solidus, say at } T_p$ .

8. The isothermal (line  $OMP$ ) can be considered a tie line since it joins the composition of two phases in equilibrium at a specific temperature  $T_p$ .



**Fig. 3.16.1.** The phase diagram used for deriving the lever rule.

### B. Numerical :

**Given :** Sn = 45 %,  $T = 184^\circ\text{C}$ .

**To Find :** Mass fraction of phases.

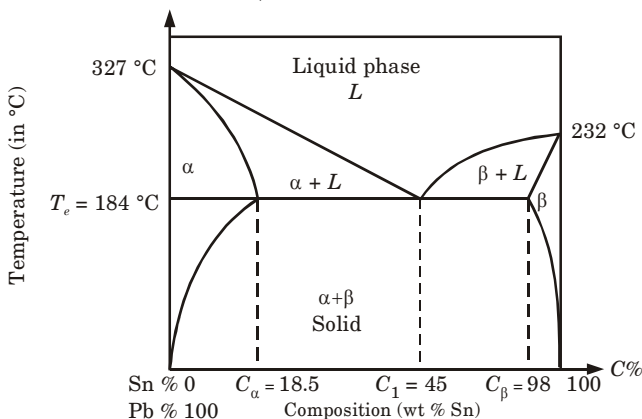
1. From lead-tin phase diagram,

$$C_\alpha = 18.5, C_\beta = 98, C_1 = 45$$

2. Mass fractions in terms of weight percentage tin,

$$W_\alpha = \frac{C_\beta - C_1}{C_\beta - C_\alpha} = \frac{98 - 45}{98 - 18.5} = 0.667$$

$$W_\beta = \frac{C_1 - C_\alpha}{C_\beta - C_\alpha} = \frac{45 - 18.5}{98 - 18.5} = 0.333$$



**Fig. 3.16.2.** The lead-tin phase diagram.

**PART-6***Iron Carbide Phase Diagram.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 3.17.** Draw the iron-carbon equilibrium diagram and explain the features.

**AKTU 2014-15, 2016-17; Marks 10**

**OR**

Draw iron-carbon equilibrium diagram, and show their salient features. Indicate significance of this diagram for heat treatment of steel.

**AKTU 2015-16, Marks 15**

**OR**

Explain about iron-carbon equilibrium diagram with a neat sketch.

**AKTU 2017-18, Marks 10**

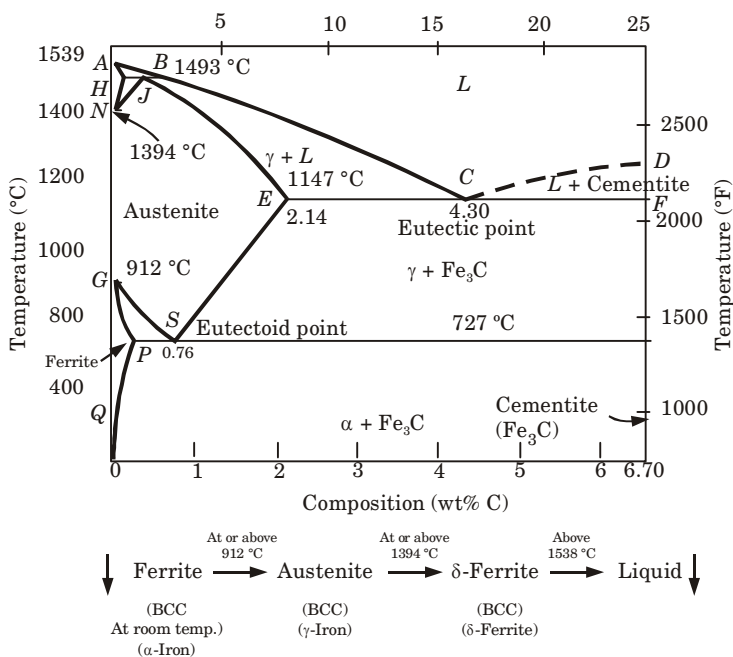
**OR**

What is phase diagram ? Draw a neat sketch of iron-carbon diagram and explain the various phases present in it and the important reactions occurring.

**AKTU 2018-19, Marks 07**

**Answer****A. Iron-carbon Equilibrium Diagram :**

1. In (Fig. 3.17.1), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.
2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature 912 °C, ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature 1394 °C, austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of 1538 °C.
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below 727 °C.
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region 727 °C to 1147 °C.
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.

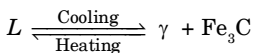


**Fig. 3.17.1. Fe-C phase diagram.**

6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

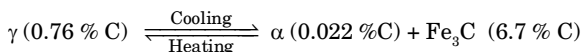
**i. Eutectic Point :**

1. Eutectic point is shown in the phase diagram indicated as point C.
2. At point C, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature = 1147 °C
3. There is an equilibrium state between liquid state (L) and two solid phases (γ phase and cementite).



**ii. Eutectoid Point :**

1. Point S is indicated as eutectoid point.
2. At point S, there is an equilibrium state between solid state and two solid phases (α and cementite).
3. Eutectoid composition = 0.76 % carbon (percent by weight)



**B. Feature of the Fe-C Diagram :** The salient features of the equilibrium diagram (Fig. 3.17.1) are as follows :

1. Iron-carbon equilibrium diagram concerns transformation that occurs in alloys having compositions from pure iron to 6.67 % carbon.
2. Point A is the highest melting point (1539 °C) of pure iron and point D is the melting point (approx. 1550 °C) of the iron carbide ( $\text{Fe}_3\text{C}$  called cementite) having 6.67 % C.
3. The line through points A-B-C-D are liquidus lines and the lines through point A-H-J-E-C-F are the solidus lines. The lowest temperature for solidification is 1130 °C, and it happens along the constant temperature line E-C-F.
4. The upper left hand portion of the diagram represents the allotropic transformations at high temperature. Line H-J-B represents peritectic transformation that is taking place at temperature 1493 °C.
5. When the alloy crosses, the liquidus line A-B-C-D, solidification starts and completes along A-E-C-F. Austenite is precipitated along A-B-C and cementite along C-D.
6. At point C (1130 °C and 4.3 % C) austenite and cementite are simultaneously precipitated from the liquid alloy to form eutectic cast iron called ledeburite. This formation obeys the rules of eutectic transformation.

**C. Significance :**

1. From the iron-carbon diagram we know that the value of  $\gamma$ -iron (austenite) compared with that of  $\alpha$ -iron (ferrite) reflects much greater solubility of carbon in  $\gamma$ -iron, with a maximum value of just over 2 wt % at 1147 °C.
2. This high solubility of carbon in  $\gamma$ -iron is of extreme importance in heat treatment, when solution treatment in the  $\gamma$ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed.

**D. Phase Diagram :** Refer Q. 3.4, Page 3-5B, Unit-3.

## PART-7

*Microstructural Aspects of Ledeburite,  
Austenite, Ferrite and Cementite.*

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 3.18.** Explain microstructural aspects of ledeburite, austenite, ferrite and cementite.

**Answer**

**a. Microstructural Aspects of Cementite :**

1. A fixed amount of carbon and a fixed amount of iron are needed to form cementite. Its chemical formula is  $\text{Fe}_3\text{C}$ . It contains 6.67 percent carbon by weight.
2. It is a hard and brittle interstitial compound of low tensile strength (approximately 5000 psi) but high compressive strength.
3. Its crystal structure is orthorhombic. It is the hardest structure that appears on the iron carbide diagram.

**b. Microstructural Aspects of Austenite :**

1. It is an interstitial solid solution of carbon dissolved in iron having a face centered cubic (FCC) crystal structure.
2. Average properties of austenite are as under :
  - i. Tensile strength : 150,000 psi.
  - ii. Elongation : 10 % in 2 inch gauge length.
  - iii. Hardness : Rockwell C 40.
  - iv. Toughness : High.
3. Austenite is normally unstable at room temperature. Under certain conditions it is possible to obtain austenite at room temperature (as in austenite stainless steels).
4. Austenite is non-magnetic.

**c. Microstructural Aspects of Ledeburite :**

1. It is the eutectic mixture of austenite and cementite. It contains 4.3 percent carbon.
2. It exists when the carbon content is greater than 2 %, which represents the dividing line on the equilibrium diagram between steel and cast iron.
3. Its melting point is 1147 °C.

**d. Microstructural Aspects of Ferrite :**

1. It is an interstitial solid solution of a small amount of carbon dissolved in iron having a body centered cubic (BCC) crystal structure.
2. It exists above 723 °C.
3. It is the softest structure on the iron carbide diagram.
4. Its maximum solubility is 0.022 % at temperature of 727 °C.
5. Average properties of ferrite are as under :
  - i. Tensile Strength: 40,000 psi.



- ii. Elongation: 40 % in 2 inch gauge length.
- iii. Hardness: Less than Rockwell C 0 or less than Rockwell B 90.
- iv. Toughness : Low.

**PART-8***Cast Iron.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 3.19.** Discuss microstructural aspects of cast iron.

**Answer**

1. Cast iron is one of the most complex alloys used in industry because it can solidify with formation of either a stable (austenite-graphite) or a metastable eutectic.
2. The microstructure formation in cast iron during the liquid-solid transformation includes two stages.
3. The first stage is solidification of proeutectic or off-eutectic phases which are austenite ( $\gamma$ ) dendrites in hypoeutectic irons, and graphite crystallization from the liquid in hypereutectic cast irons.
4. The second stage is solidification of stable/metastable eutectics and includes the eutectic austenite and the various shapes of the carbon-rich phases (graphite or carbide).
5. In cast irons, the eutectic solidification involves coupled growth of eutectic phases which is highly dependent on chemical composition and cooling rate.
6. Addition of Si to cast iron is essential because it increases the carbon equivalent and stabilizes the Fe-C phase diagram.
7. The carbon equivalent (CE) is an empirical value, relating the combined effects of different alloying elements (in weight percent) used in the making of cast iron and steels to an equivalent amount of carbon.
8. In order to decrease the risk of a metastable eutectic reaction, cast iron is usually inoculated. The addition of inoculants can be early (in the ladle) or late (during pouring to the mould or in the mould) during the casting process.

**VERY IMPORTANT QUESTIONS**

*Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.*

**Q. 1. What do you understand by solid solution ? Explain with neat sketches the substitutional solid solution and interstitial solid solution.**

**Ans.** Refer Q. 3.2, Unit-3.

**Q. 2. Discuss Gibbs phase rule.**

**Ans.** Refer Q. 3.5, Unit-3.

**Q. 3. What kind of interpretation can be obtained from a binary phase diagram ?**

**Ans.** Refer Q. 3.9, Unit-3.

**Q. 4. Write a short note :**

- i. Peritectoid phase diagram.
- ii. Monotectic phase diagram.

**Ans.** Refer Q. 3.15, Unit-3.

**Q. 5. What do you understand by lever rule, determine the mass fraction of the phases present at 184 °C in a sample of lead and tin with 45 % tin in it.**

**Ans.** Refer Q. 3.16, Unit-3.

**Q. 6. Draw the iron-carbon equilibrium diagram and explain the features.**

**Ans.** Refer Q. 3.17, Unit-3.

**Q. 7. Explain microstructural aspects of ledeburite, austenite, ferrite, cementite.**

**Ans.** Refer Q. 3.18, Unit-3.



# 4

## UNIT

# Heat Treatment of Steel

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<b>Part-10</b>	: Flame and Induction Hardening .....	<b>4-21B to 4-24B</b>
<b>Part-11</b>	: Vacuum and Plasma Hardening .....	<b>4-24B to 4-25B</b>

**PART- 1***Heat Treatment of Steel.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.1.** What do you understand by heat treatment ? What are its purposes ?

**Answer****A. Heat Treatment :**

1. Heat treatment may be defined as an operation involving the heating of solid metals to definite temperatures, followed by cooling at suitable rates in order to obtain certain physical properties which are associated with changes in the nature, form size and distribution of the micro-constituents.
2. Heat treatment is a very important process in the various fabrication and manufacturing operations.

**B. Purposes :** The purpose of heat treatment is to achieve one or more of the following objectives :

1. To relieve internal stresses set up during cold working, casting, welding and hot working operations.
2. To improve machinability.
3. To soften metals for further treatment as wire drawing and cold rolling.
4. To improve mechanical properties.
5. To modify the structure to increase wear, heat and corrosion resistance.
6. To modify magnetic and electrical properties.

**Que 4.2.** Give the classification of various heat treatment processes.

**Answer**

Heat treatment processes are classified as follows :

1. Tempering :
  - i. Austempering, and

- ii. Martempering.
- 2. Annealing :
  - i. Process annealing,
  - ii. Full annealing,
  - iii. Stress-relief annealing, and
  - iv. Spherodise annealing.
- 3. Normalizing
- 4. Spherodizing
- 5. Case hardening (or carburizing) :
  - i. Solid or pack carburizing,
  - ii. Liquid carburizing, and
  - iii. Gaseous carburizing.
- 6. Cyaniding
- 7. Nitriding
- 8. Carbo-nitriding
- 9. Flame hardening
- 10. Induction hardening

**Que 4.3.** Give various types of defects due to heat treatment of steels.

**Answer**

There are so many defects occur during heat treatment which are needed to prevent. These are as follows :

- 1. Overheating problem due to rise in high temperature causes to burn the surface.
- 2. Decarburization due to overheating.
- 3. Black fracture.
- 4. Quenching cracks.
- 5. Excessive or insufficient hardness after tempering process.
- 6. Corrosion and erosion.

**PART-2**

*Annealing.*

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.4.** Define annealing. What are its objectives ?

**Answer****A. Annealing :**

1. Annealing is a heat treatment process that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable.
2. Annealing consists of :
  - i. Heating of steel above the critical temperature by 10 to 25 °C more than the lower critical temperature.
  - ii. Keeping the steel at this temperature for a definite period of time so that complete transformation into austenite takes place.
  - iii. After that slowly furnace cooling is done at the rate of 25 to 15 °C/hour.

**B. Objectives :** The following objectives are achieved with annealing :

1. Softens the metal to ease machinability.
2. Refines and removes structural in homogeneity.
3. Relieves internal stresses.
4. Removes gases trapped during casting of metals.
5. Changes physical and mechanical properties.
6. Prepares the steel for further treatment.

**Que 4.5.** Discuss the following annealing operations in brief :

- a. Full annealing,
- b. Process annealing,
- c. Spheroidize annealing, and
- d. Diffusion annealing.

**Answer****a. Full Annealing :**

1. This removes all structural imperfections by complete recrystallization.

2. The purpose of annealing is to soften the metal, relieve stresses and refine the grain structure. Full annealing consists of :
  - i. Heating the steel to about 50-75 °C above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature for hypereutectoid steels.
  - ii. Holding it at this temperature for a sufficient time depending upon the thickness of work.
  - iii. Slowly cooling it in the furnace.

**b. Process Annealing :**

1. Process annealing is usually carried out to remove the effects of cold working and to soften the steel to make it suitable for further plastic deformation.
2. It is the recrystallization of cold worked steel by heating below the lower critical temperature.
3. The exact temperature depends upon the extent of cold working, grain size, composition and time held at heat.
4. This process is very useful in mild steels and low carbon steels.
5. During recrystallization, the deformed grains are reoriented to increase plasticity and remove internal stresses.

**c. Spheroidize Annealing :**

1. This is a form of annealing in which cementite in the granular (globular) form is produced in the structure of steel.
2. This process causes the agglomeration of all carbides in the steel in the form of small globules or spheroids.
3. This process is usually applied to high carbon steels which are difficult to machine.
4. The process consists of heating the steel slightly above the lower critical point (730 °C - 770 °C), holding at this temperature and then cooling slowly to a temperature of 600 °C.
5. The rate of cooling in the furnace is from 25 to 30 °C per hour.

**d. Diffusion Annealing :**

1. In order to remove the heterogeneity in the composition of heavy castings, diffusion annealing is used.
2. This process homogenizes the austenite grain when heated to above the upper critical point and it is always followed by full annealing for fine grained structure in the castings.

**PART-3***Tempering.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.6.** Discuss tempering in brief.

**Answer**

1. The tempering process provides a method for transforming martensite into ferrite and cementite. How much of the martensite is transformed depends on the temperature and time of the tempering process.
2. Tempering occurs in four stages which are discussed as follows :

**Stage 1 :**

1. Heating a hardened steel upto a temperature of 200 °C causes the martensite to reject some of the interstitial carbon.
2. In doing this, the tetragonal martensite structure comes closer to the equilibrium BCC structure of ferrite.
3. This rejected carbon combines with some martensite to form carbide whose composition ranges from  $\text{Fe}_2\text{C}$  to  $\text{Fe}_3\text{C}$ . This precipitation is called epsilon carbide or hexagonal close packed carbide.
4. Its presence distorts the martensite matrix and results in a slight hardening of the steel.

**Stage 2 :**

1. Further heating to about 300 °C, causes any austenite that was retained by the steel after quenching to decompose into ferrite and cementite. Some softening accompanies this transformation.

**Stage 3 :**

1. Further heating to about 400 °C causes the epsilon carbide to transform to cementite and ferrite.
2. Most of it forms to cementite because the composition of epsilon carbide is close to that of cementite. This portion of the tempering causes significant softening. If the transformation is allowed to progress long enough the final structure will consist of cementite and ferrite.



3. Often the tempering process is stopped at a point where steel contains cementite, ferrite and martensite.

**Stage 4 :**

1. If tempering is done at a temperature just below the lower critical point or the eutectic point, the cementite forms spheres or spheroidized steel.
2. In steels, containing one alloying element in addition, cementite forms first and the alloy diffuses to it.

**PART-4***Normalizing and Spheroidizing.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.7.** Discuss the following :

- a. Normalizing, and
- b. Spheroidizing.

**Answer**

- a. Normalizing :**

1. Normalizing is frequently applied as a final heat treatment process to products which are subjected to relatively high stresses.
2. This process consists of heating steel to a point 40 to 50 °C above its upper critical temperature, holding at that temperature for a short duration and subsequently cooling in still air at room temperature. This is also known as air quenching.
3. This process is suggested for manufacturing operations like hot rolling and forging which are carried out on steels in the austenite range.
4. It is also useful for eliminating coarse grained structure in castings, removing internal stresses that may have been caused by hot or cold working and improving the mechanical properties of the steel by eliminating the carbide network at the grain boundaries of the steels.
5. Normalizing produces microstructures consisting of ferrite and pearlite for hypoeutectoid steels and pearlite and cementite for hypereutectoid steels.

**b. Spherodizing :**

1. This is special type of tempering where the specimen is reheated below the lower critical temperature to transform the shape of carbide into globular shape.
2. Due to this shape steel becomes soft and easy to machine.
3. Globular shape also reduces the problem of stress concentration and improves the ductility but at the same time it lowers the hardness and tensile strength.
4. These spherodizing steels have better ductility than normally annealed steels.

**Que 4.8. Differentiate between normalizing and annealing.**

**Answer**

S. No.	Normalizing	Annealing
1.	It requires high heating range.	It requires low heating range.
2.	Mechanical properties obtained are not as good as in annealing.	Mechanical properties obtained are better.
3.	Heat treatment process is of short duration.	Heat treatment process takes more time than normalizing.
4.	The alloy remains harder after normalizing.	The metals are to be less hard and ductile.
5.	The cooling process is slow and only takes place in air.	The cooling process takes place in air or quenching the metal in water.
6.	Grain size is uniform.	Grain size is not so uniform.

**PART-5**

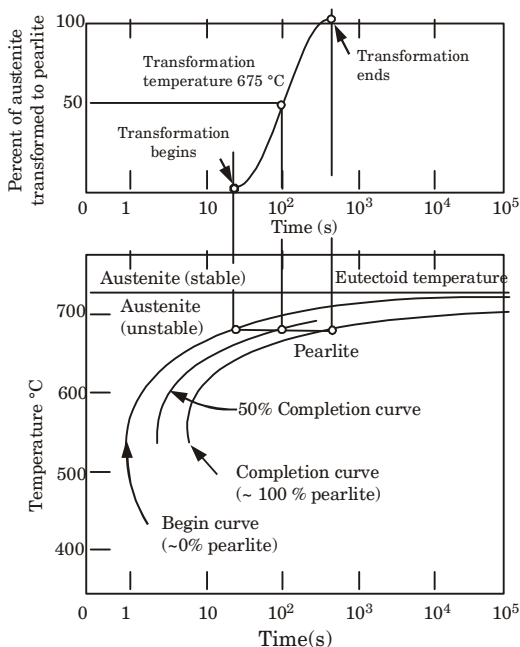
*Isothermal Transformation Diagrams for Fe-C Alloys and Microstructure Development.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

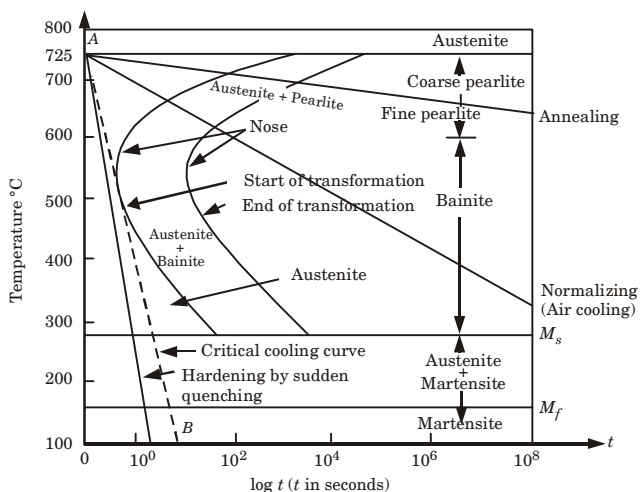
**Que 4.9.****Explain isothermal transformation diagrams for Fe-C alloys.****OR****Draw and explain the TTT diagram for eutectoid steel. Explain important transformations taking place in it on cooling.****AKTU 2018-19, Marks 07****OR****Draw a TTT diagram for eutectoid steel and explain the effect of cooling rate on the transformation products and hardness obtained.****AKTU 2017-18, Marks 10****OR****What is TTT diagram ? Explain briefly with neat sketch stating its importance.****AKTU 2014-15, Marks 10****Answer****A. TTT-Diagram :**

1. Temperature-Time-Transformation diagram represents a relation between starting and ending of the formation of different microstructures.
2. Its shape is same as the English alphabet 'C' so it is known as C-curve.
3. The nose of this curve indicates the least time taken for a particular transformation.
4. The line passes through the nose (or tangent at the nose of C-curve) is known as critical cooling curve and its slope is termed as critical cooling rate.
5. In the (Fig. 4.9.1) transformation of austenite to pearlite is shown. The left most C-curve shows the starting of transformation of austenite into pearlite.
6. At this curve 0 % pearlite, 100 % austenite is present. Then the dashed curve represents that 50 % of austenite transforms into pearlite and the right most C-curve represents (completion curve) 100 % pearlite transformation.
7. These curves are accurate only for transformations in which the temperature of alloy is held constant throughout the duration of the reactions.



**Fig. 4.9.1. TTT diagram.**

8. Thus these plots are also known as isothermal transformation diagrams or TTT diagrams.
9. Depending upon different cooling rate various microstructures can be obtained like pearlite (coarse or fine), bainite, austenite + martensite and martensite.
10. When cooling rate is slow, we get line pearlite which is done by annealing.
11. In normalizing the cooling rate is high by which we get bainite structure.
12. A complete feature of TTT diagram to show its different phase is shown in (Fig. 4.9.2).



**Fig. 4.9.2.** The TTT curve showing temperature and log (time) variation for an eutectoid steel, and its different phases.

### B. Importance of TTT Diagram :

1. It shows the structure that we obtained at different cooling rates.
2. It graphically describes the cooling rate required for the transformation of austenite to pearlite, bainite or martensite.
3. It shows the time required for transformation to various phases.

## PART-6

*Continuous Cooling Curves and Interpretation of Final Microstructures and Properties.*

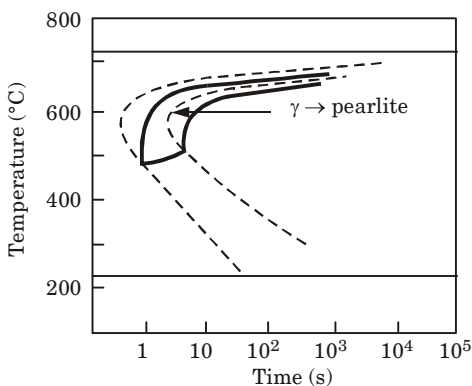
### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 4.10.** Discuss the continuous cooling transformation diagram.

**Answer**

1. In actual practice steel is generally cooled continuously. Continuous-cooling-transformation (CCT) diagrams depict this situation.
2. The CCT curve (dark line) is shifted to the right of the TTT (dashed) curve as continuous cooling transformation occurs at lower temperature and longer time compared with isothermal holding.
3. Bainite generally does not form in steels during continuous cooling and hence the CCT curve ceases just below the nose.
4. The microstructure (fine or coarse) depends on the cooling rate. Higher the cooling rate finer the microstructure is.
5. The critical cooling rate is the one at which the cooling curve just touches the nose of the CCT curve.
6. A cooling rate higher than the critical rate is needed to form martensite.

**Fig. 4.10.1.**

**Que 4.11.** Describe the cooling curves along with their types.

**Answer****A. Cooling Curves :**

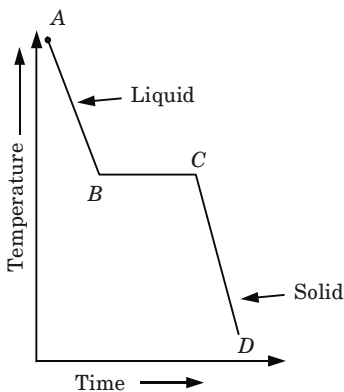
1. A cooling curve is a line graph that represents the change of phase of material.
2. A cooling curve is obtained by recording the temperature of a material versus time as it cools from a temperature at which it is molten through solidification and finally to room temperature.

3. Cooling curves can be used to determine phase transition temperature for both pure metal and alloys.

**B. Types of Cooling Curves :** Following are the three types of cooling curves :

**a. Cooling Curve for Pure Metal :**

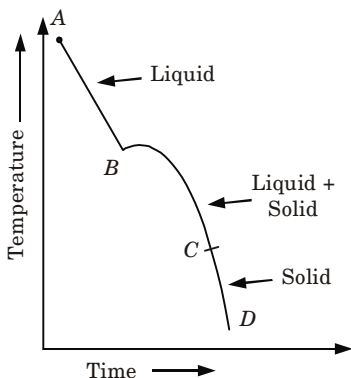
1. Liquid metal cools from *A* to *B*.
2. From *B* to *C* heat is given out and the temperature remains constant.
3. Between *B* and *C* the mass is marshy, on further cooling from *C* to *D*, the metal reaches room temperature.
4. The slopes of *AB* and *CD* lines indicate specific heats of liquid and solid metals, respectively.



**Fig. 4.11.1.** Cooling curve for pure metal.

**b. Cooling Curve of a Binary Solution :**

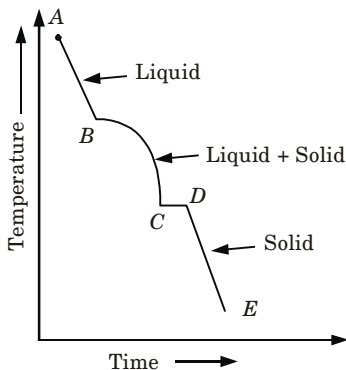
1. Curve *AB* is the same as for pure metals.
2. The freezing line *BC* drops until the whole mass is solid at point *C*. This is due to the fall in temperature recorded during freezing in a binary alloy.
3. The solid further cools along line *CD* to reach room temperature (Fig. 4.11.2).



**Fig. 4.11.2.** Cooling curve for binary alloys.

**c. Cooling Curve of a Multiphase Alloy :**

1. In this system, the two components are completely soluble in the liquid state but entirely insoluble in the solid state.
2. They are liquid along  $AB$  upto point  $B$ . At  $B$  the temperature drops along  $BC$  and crystallization of one component starts.
3. At point  $C$  the components solidify simultaneously at constant temperature, the lowest for a given system, and are called eutectic alloys.
4. A mechanical mixture of two (or more) phases which solidify simultaneously from the liquid alloy is called an eutectic.
5. Cooling from  $D$  to  $E$  is as usual.



**Fig. 4.11.3.** Cooling curve for binary eutectic system.



**Que 4.12.** Briefly explain the final microstructures and their properties obtained from TTT diagram.

**Answer**

Microconstituent	Phases Present	Arrangement of Phases	Mechanical Properties
Spheroidite	$\alpha$ Ferrite + $\text{Fe}_3\text{C}$	Relatively small $\text{Fe}_3\text{C}$ sphere like particles in an $\alpha$ -ferrite matrix	Soft and ductile
Coarse pearlite	$\alpha$ Ferrite + $\text{Fe}_3\text{C}$	Alternating layers of $\alpha$ ferrite and $\text{Fe}_3\text{C}$ that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	$\alpha$ Ferrite + $\text{Fe}_3\text{C}$	Alternating layers of $\alpha$ ferrite and $\text{Fe}_3\text{C}$ that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	$\alpha$ Ferrite + $\text{Fe}_3\text{C}$	Very fine and elongated particles of $\text{Fe}_3\text{C}$ in an $\alpha$ -ferrite matrix	Hardness and strength greater than fine pearlite; hardness less than martensite; ductility greater than martensite
Tempered martensite	$\alpha$ Ferrite + $\text{Fe}_3\text{C}$	Very small $\text{Fe}_3\text{C}$ sphere like particles in an $\alpha$ -ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered tetragonal, single phase	Needle shaped grains	Very hard and very brittle

## PART-7

*Austempering, Martempering.*

### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 4.13.** Describe hardening process in detail.

**Answer**

1. Hardening may be defined as rapid cooling of steel from the austenite phase.
2. The rapid cooling is obtained by immersion of steel in a liquid bath such as water or oil. Sometimes forced air can also be used.

3. The fast cooling of steel from austenite phase results in the formation of a meta-stable phase called martensite.
4. Hardening is also called as quenching, because steel is quenched from a high temperature to a liquid bath at room temperature.
5. The main purpose of hardening of steel is, to increase hardness, strength and wear resistance, and to obtain a suitable microstructure which will have desired mechanical properties after tempering.
6. Successful hardening of steel requires two conditions to be met. Firstly, the formation of homogeneous austenite and secondly rapid cooling of austenite which will result in the transformation to martensite.
7. The formation of homogeneous austenite takes place when steel is heated to the correct austenitizing temperature, and held at this temperature for a sufficient time.
8. After the formation of homogeneous austenite, steel is cooled rapidly by immersion into water or oil baths. This results in the formation of martensite.

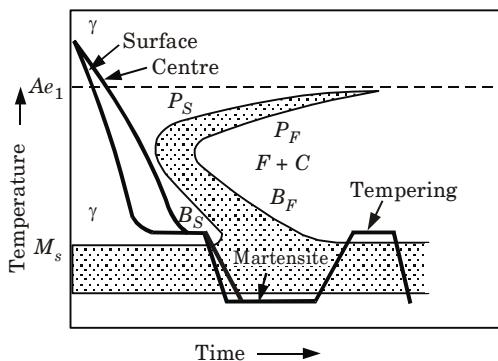
**Que 4.14.** Explain austempering and martempering process with suitable sketch.

**AKTU 2015-16, Marks 10**

**Answer**

**a. Martempering or Stepped Quenching :**

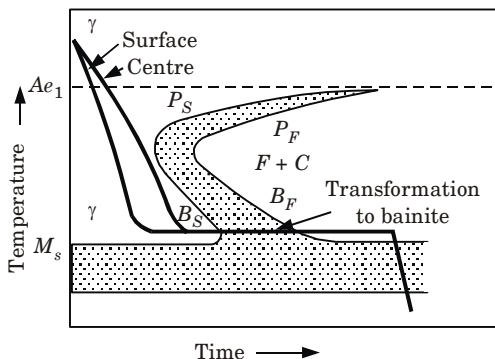
1. This is a hardening method that produces martensite. This method is also known as hardening by interrupted quenching.
2. First the steel is heated to the hardening temperature then quenched in a medium (salt bath) having a temperature slightly above the point where martensite starts to form (usually from 150° to 300 °C).
3. It is held until it reaches the temperature of the medium and then cooled further to room temperature in air or oil.
4. The holding time in quenching medium or bath should be sufficient to enable a uniform temperature to be reached throughout the cross section but not long enough to cause austenite decomposition.
5. Austenite is transformed into martensite during the subsequent period of cooling to room temperature.
6. This treatment provides a structure of martensite and retained austenite in the hardened steel.



**Fig. 4.14.1.** Heat treatment cycle for martempering.

**b. Austempering or Isothermal Quenching :**

1. It is very similar to martempering. Steel is austenitized and then quenched in a salt bath maintained at a constant temperature in the range of  $260^\circ\text{C}$  to  $400^\circ\text{C}$ .
2. The article is held at this temperature for long enough to allow isothermal transformation to be completed.
3. After the complete transformation of austenite to bainite, steel is cooled to room temperature in air. It is also called isothermal quenching.
4. The temperature of quenching lies below the nose of the TTT curve and above the  $M_s$  temperature.
5. Heat treatment cycle for austempering is shown in (Fig. 4.14.2).



**Fig. 4.14.2.** Heat treatment cycle for austempering.

6. The principal purpose of austempering is to obtain high impact strength and increased notch toughness at a given high hardness level.

**PART-8**

*Case Hardening (Carburizing).*

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.15.** What is case hardening (or carburizing) and what are its various types ? Describe briefly.

**AKTU 2017-18, Marks 10**

**Answer****A. Case Hardening (or Carburizing) :**

1. It is a process through which a hard, wear resistant and shock resistant surface is produced on steel having a tough core inside.
2. In this process the steel is heated to red hot and then carbon contents are forced into its surface structure. It is then hardened as usual. For this reason this process is also frequently known as carburizing.
3. Case hardening is done :
  - i. For getting a hard and wear resistant surface.
  - ii. For increasing the machinability of surface.

**B. Types of Carburizing (Case Hardening) Processes :****a. Pack Carburizing :**

1. As name suggests it is a method in which component or specimen is packed in a steel box with carbon rich powder of charcoal or coke in granules form. Then box is heated slowly above the lower critical temperature and soaking is done.
2. The depth of soaking depends on the time of exposure between steel and solid fumes. After soaking, box is then cooled slowly.
3. This method has a disadvantage of scale formation at the surface of metal.

**b. Liquid Carburizing :**

1. In liquid carburizing, liquid carbon is used to impinge upon the heated steel by jets from nozzles. Due to this, carbon gets deposited on the steel.
2. This method does not have a problem of scale formation on the metal surface.

**c. Gas Carburizing :**

1. In this method, heating of steel is done in a carbon rich gaseous (as methane, propane etc.) environment.
2. At high temperature, hydrocarbon gets decompose into carbon and hydrogen. This decomposed carbon gets deposited on the metal surface.
3. The thickness of hardened case can be controlled by rate of gas flow.

**PART-9**

*Nitriding, Cyaniding, Carbo-Nitriding.*

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 4.16.** Explain the process of nitriding with its merits and demerits.

**OR**

**What do you mean by heat treatment process ? Name various types of hardening processes and explain in detail nitriding process with its merits and demerits.**

**AKTU 2018-19, Marks 07**

**Answer**

**A. Heat Treatment Process :** Refer Q. 4.1, Page 4-2B, Unit-4.

**B. Various Types of Hardening Process :** Refer Q. 4.14, Page 4-16B, Unit-4.

**C. Nitriding :**

1. This process is used to form a hard surface of nitride on the surface of metal (or steel). This is also, surface hardening process like carburizing.
2. This process consists of :
  - i. Heating of specimen below the lower critical temperature approximately up to 600 °C.

- ii. Soaking is done in the atmosphere of ammonia ( $\text{NH}_3$ ). The nitrogen from  $\text{NH}_3$  penetrates into the surface of steel to form very hard nitride surface.
3. Nitriding improves corrosion resistance and provides hard surface after this process, there is no need of any heat treatment process.

**a. Merits :**

1. Fatigue strength is increased during nitriding by 30 to 100 %.
2. Resistance against abrasive and adhesive wear is good.
3. Surface is hard and tough combined with good wear resistance.

**b. Demerits :**

1. Skilled personnel are required.
2. Relatively high equipment cost.
3. Oxidation due to prolonged heating time.

**Que 4.17. Explain the process of cyaniding stating its advantages and disadvantages.**

**Answer**

**A. Cyaniding :**

1. In cyaniding, carbon and nitrogen are added to the surface layer of the steel to increase its hardness, wear resistance and fatigue limit.
2. We dipped the component in a bath of sodium cyanide ( $\text{NaCN}$ ) at a temperature  $400^\circ\text{C}$ . Soaking process is completed in the sodium cyanide bath.
3. After completion of soaking, metal or steel is quenched in oil (or water) to harden the surface.
4. The case contains about 4 to 4.5 % carbon and 0.5 to 3 % nitrogen.
5. Cyaniding process is used to increase the fatigue strength of steel. It is less time consuming process but a costly process.

**B. Advantages :**

1. Bright finish of parts can be retained.
2. Cracks and distortions can be minimized by uniform heating maintained by the salt.
3. Most suitable for parts subjected to high loads.

**C. Disadvantages :**

1. Risk of splintering of poisonous salts.

2. Unhealthy fumes formed, requiring careful handling operation.
3. Liquid carburizing can produce better surface hardness.

**Que 4.18. Write a short note on carbo-nitriding.**

**Answer**

1. Carbo-nitriding is the process of heating parts in an atmosphere of natural gas and ammonia in 3 : 1 proportion at the critical temperature, followed by quenching and tempering.
2. In carbo-nitriding, both carbon and nitrogen simultaneously saturate the surface of the steel but the process is slower.
3. At low temperature of about 550 °C, this process is applied to high-speed steel tools. Complex machine parts are heated at 800 °C, followed by subsequent tempering. This produces distortion-free heat treatment.
4. To save time, temperatures as high as 950 °C can be used, as in gas carburizing. This increases wear resistance of the steel.
5. It is a highly progressive method of heat treatment of structural steels. The lower temperature of the process increases the service life of the furnace and its accessories and also reduces fuel consumption.

## PART-10

### *Flame and Induction Hardening.*

#### Questions-Answers

#### Long Answer Type and Medium Answer Type Questions

**Que 4.19. Describe surface hardening in detail.**

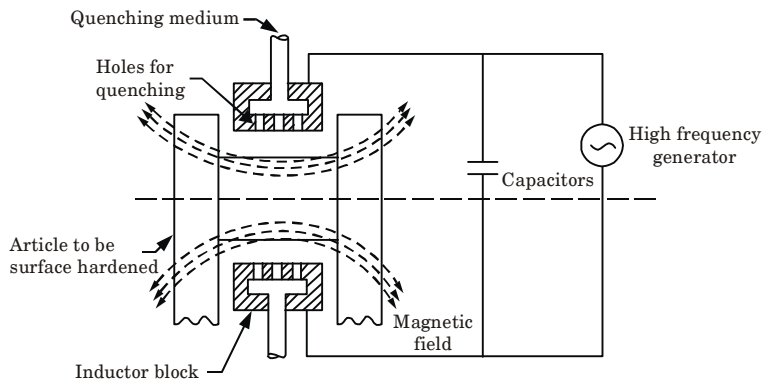
**Answer**

1. Surface hardening is also a method of heat treatment in which the surface layers of a metal are hardened to a certain depth while the core is maintained relatively soft.
2. It differs from case hardening in that the chemical composition of the surface is changed. Secondly, heating and quenching of the metal is rapid and thus the core of the metal remains unaffected.

3. There are two methods of heat treatment in surface hardening :

**a. Induction Hardening :**

1. It is a process of surface hardening in which the surface to be hardened is surrounded by a copper inductor through which a high frequency current of about 2000 cycles per second is passed.
2. The inductor acts as a primary coil of a transformer.
3. The work to be hardened is placed in the inductor in such a way that it does not touch the inductor as shown in (Fig. 4.19.1).



**Fig. 4.19.1.** Arrangement for high-frequency induction heating.

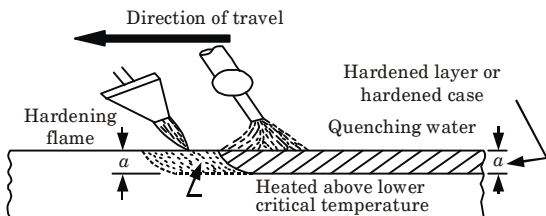
4. The inductor block has a number of holes to spray water for quenching. The heating effect in the work is produced by the induced eddy currents and hysteresis loss in the surface of the work.
5. Steels containing 0.35-0.55 % carbon are most frequently induction hardened. The hardening temperature is above  $768^{\circ}\text{C}$  (Curie point) in order to increase the depth of current penetration.
6. The heated areas are quenched immediately by water sprays directed from the inductor.
7. Induction hardening is extensively used in many industrial plants e.g., camshafts, gears, axles etc.

**b. Flame Hardening :**

1. This process is based on rapid heating and quenching in order to produce a hard surface and soft core in the work.
2. An oxy-acetylene flame is used to heat the work above its critical temperature and quenching is done by means of a spray of water directed on the surface.



3. The torch for heating the work may be stationary or may move progressively over the work which may or may not spin as shown in (Fig. 4.19.2).
4. This method is applied for hardening cast gears, mill rolls or worms.



**Fig. 4.19.2. Flame hardening.**

**Que 4.20.** Write down the advantages and disadvantages of induction hardening.

**Answer**

**a. Advantages :**

1. Heating times are extremely short.
2. No scaling or surface oxidation.
3. Deformation due to heat treatment is considerably reduced.
4. Permits automation of heat treatment processes.
5. Induction hardened steels have high hardness, higher wear resistance, higher impact strength and higher fatigue limit in comparison with ordinary, hardened steels.

**b. Disadvantages :**

1. Not economical for mass production.
2. Cost of equipment is high.
3. Restricted to medium-carbon and low-alloy steels only.

**Que 4.21.** Differentiate between flame and induction hardening.

**Answer**

S. No.	Flame Hardening	Induction Hardening
1.	Basic, cheap, relatively easy set up.	Relatively expensive and complex set up.
2.	Process not very accurate and gives relatively thick hardened cases.	Process can be very accurate.
3.	Process relies on heat conduction from component surface.	Process does not solely rely on heat conduction, but from internally generated heat from induced electrical currents.
4.	Relatively slow process.	Fast heating even for thick case hardening.

**PART- 1 1***Vacuum and Plasma Hardening.***Questions-Answers****Long Answer Type and Medium Answer Type Questions****Que 4.22. Write short note on :**

- i. Vacuum hardening.
- ii. Plasma case hardening (plasma nitriding).

**Answer****i. Vacuum Hardening :**

1. Vacuum hardening is an indispensable part of a modern quality hardening shop.
2. It is economic and environment friendly hardening process.
3. Vacuum technology meets the highest demands for surface quality and mechanical properties of components. Changes in shape and dimensions (warping) are reduced to a minimum.

4. Vacuum technology is therefore particularly well suited for both premium precision tools and for demanding machine components with low machining allowances.
5. The continuous heat treatment in the vacuum creates finish qualities.
6. It is scale free and metallurgically pure surface process.

**ii. Plasma Nitriding :**

1. Plasma nitriding also known as ion nitriding is a form of case hardening process.
2. It is an extension of conventional nitriding process, utilizing plasma discharge physics to diffuse nitrogen into the surface of a ferrous alloy.
3. Plasma nitriding can be further branched out into plasma nitro carburizing.
4. In this process, carbon together with nitrogen was introduced into the metal surface.
5. The hardened case, which is the nitriding layer is commonly known as diffused case or diffusion zone.

**Que 4.23. Explain different types of heat treatment processes in**

**brief.**

**AKTU 2017-18, Marks 10**

**Answer**

Different types of heat treatment processes are given below :

- i. Annealing :** Refer Q. 4.4, Page 4-4B, Unit-4.
- ii. Tempering :** Refer Q. 4.6, Page 4-6B, Unit-4.
- iii. Normalizing and Spheroidizing :** Refer Q. 4.7, Page 4-7B, Unit-4.
- iv. Hardening :** Refer Q. 4.13, Page 4-15B, Unit-4.
- v. Austempering and Martempering :** Refer Q. 4.14, Page 4-16B, Unit-4.
- vi. Case Hardening :** Refer Q. 4.15, Page 4-18B, Unit-4.

**VERY IMPORTANT QUESTIONS**

*Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.*

**Q. 1. Give the classification of various heat treatment processes.**

**Ans.** Refer Q. 4.2, Unit-4.

**Q. 2. Discuss the following annealing operations in brief :**

- a. Full annealing,
- b. Process annealing,
- c. Spheroidize annealing, and
- d. Diffusion annealing.

**Ans.** Refer Q. 4.5, Unit-4.

**Q. 3. Explain isothermal transformation diagrams for Fe-C alloys.**

**Ans.** Refer Q. 4.9, Unit-4.

**Q. 4. Explain austempering and martempering process with suitable sketch.**

**Ans.** Refer Q. 4.14, Unit-4.

**Q. 5. What do you mean by heat treatment process ? Name various types of hardening processes and explain in detail nitriding process with its merits and demerits.**

**Ans.** Refer Q. 4.16, Unit-4.

**Q. 6. Describe surface hardening in detail.**

**Ans.** Refer Q. 4.19, Unit-4.

**Q. 7. Explain different types of heat treatment processes in brief.**

**Ans.** Refer Q. 4.23, Unit-4.



# 5

## UNIT

# Metals and their Alloys

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**PART-1***Alloying of Steel.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.1.** Discuss about the microstructure of ferrous, non-ferrous metals and alloys.

**Answer****A. Microstructure of Ferrous Metals :**

1. In ferrous metals iron is the chief constituent.
2. In addition to iron, the ferrous metals contain carbon, nickel, phosphorus and manganese.
3. Following are the some common ferrous metals used in engineering are as follows :

**a. Microstructure of Mild Steel :**

1. In mild steel, carbon presents up to 0.2 % in ferrite form ( $\text{Fe}_3\text{C}$ ).
2. Ferrite has a flaked type structure and grain sizes are different and irregular in shape.
3. The percentage of iron upto 98 % is present in the mild steel.

**b. Microstructure of Cast Iron :**

1. The carbon percentage varies from 2 to 4.3 % in cast iron.
2. The structure of cast iron contains graphite flakes in ferrite/pearlite matrix.
3. The graphite flakes are about 0.05 to 0.1 mm length. These flakes occupy 10 % of the metal volume.

**B. Microstructure of Non-Ferrous Metals and Alloys :**

1. Non-ferrous metals are those which do not contain iron.
2. Most of the non-ferrous metals have high electrical conductivity, low density and high strength to weight ratio.
3. Some important non-ferrous and alloys are as follows :

**a. Microstructure of Copper :**

1. It is a reddish brown metal.

2. It has crystalline (FCC) structure.
3. It is soft, malleable and good conductor of electricity.

**b. Microstructure of Aluminium :**

1. It is a white lustrous metal.
2. It is highly malleable and ductile.
3. It is a good conductor of heat and electricity.
4. Pure aluminium is highly resistant to corrosion and is easily cast to the required shape.
5. It has good machinability and cold and hot working.

**Que 5.2.** What are the purposes of alloying elements of steel ?

**Answer**

Purposes of alloying elements of steel are as follows :

1. To impart a fine grain size to steel.
2. To improve case hardening properties.
3. To improve elasticity.
4. To improve corrosion, fatigue resistance.
5. To improve hardness, toughness and tensile strength.
6. To improve machinability.
7. To improve high or low temperature stability.
8. To improve cutting ability.
9. To improve wear resistance.
10. To improve ductility.

**Que 5.3.** Discuss effects of alloying elements on the properties of steel.

**AKTU 2015-16, Marks 10**

**Answer**

1. Steel is the most commonly used alloy of iron. Alloying elements are added to effect changes in the properties of steel.
2. The effects of various alloying elements on steel are given below :

S.No.	Alloying Elements	Effect on the Properties of Steel
1.	<b>Nickel</b>	<ol style="list-style-type: none"> <li>Increases toughness.</li> <li>Improve response to heat treatment especially in large sections.</li> <li>In large amount provides special electrical and magnetic properties.</li> <li>Improves forming properties of stainless steel.</li> </ol>
2.	<b>Chromium</b>	<ol style="list-style-type: none"> <li>Provides stainless property in steel.</li> <li>Increase hardenability.</li> <li>Increase high temperature strength.</li> </ol>
3.	<b>Manganese</b>	<ol style="list-style-type: none"> <li>Counteracts brittleness from sulphur.</li> <li>Increases strength and hardness markedly.</li> <li>Lowers both ductility and malleability if it is present in high percentage with high carbon content in steel.</li> </ol>
4.	<b>Vanadium</b>	<ol style="list-style-type: none"> <li>Improves response to heat treatment.</li> <li>Provides control of structure.</li> <li>Improves fatigue resistance.</li> </ol>
5.	<b>Tungsten</b>	<ol style="list-style-type: none"> <li>Retention of hardness and toughness at high temperature.</li> <li>Enhances the effects of other alloying elements.</li> <li>Improves high temperature strength.</li> </ol>
6.	<b>Silicon</b>	<ol style="list-style-type: none"> <li>High electrical resistance and magnetic permeability.</li> <li>Increases hardenability.</li> <li>Improves toughness.</li> </ol>
7.	<b>Copper</b>	<ol style="list-style-type: none"> <li>In small amount improves atmospheric corrosion resistance.</li> <li>Act as a strengthening agent.</li> </ol>

## PART-2

*Properties of Stainless Steels, Tool Steels and Maraging Steels.*

## CONCEPT OUTLINE

**Steel :** It is an alloy of iron and carbon containing less than two percent carbon.

**Tool Steel :** It refers to a variety of carbon and alloy steel that are particularly well suited to be made into tools.



**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.4.** Give the composition, properties and uses of the following alloy steels :

- High speed steel,
- Heat resisting steel,
- Silicon steel, and
- Stainless steel etc.

**Answer****a. High Speed Steel :**

- High speed steels are widely used for cutting of metals where hardness must be retained at elevated temperatures.
- These steels are obtained by alloying 18 % tungsten, 4 % chromium and 1 % vanadium with a carbon content of 0.6 to 0.7 %. This alloy is termed as 18 : 4 : 1 while an increase of vanadium to 2 % produces 18 : 4 : 2 steels.
- In addition to heat resistance high speed steels have the desirable properties of high hardness, high compressive strength and outstanding wear resistance.

**Uses :** This steel is used for high speed cutting tools.

**b. Heat Resisting Steel :**

- Steels which must be resistance to creep at high temperatures must contain molybdenum. Silicon and chromium impart resistance to oxidation and scaling.
- Steels which are satisfactory upto about 700 °C operating temperature are : C = 0.15 %, Si = 0.5 to 2.0 %, Mn = 0.5 % maximum, Ni = none, Cr = 1.0 to 6 %, Mo = 0.5 %

**Uses :** These are used in valves of internal combustion engines in rolled or in forged condition.

**c. Silicon Steel :**

- Improves the electrical properties of steel.
- Silicon imparts fatigue strength and resistance to steel.
- Steel containing silicon is more ductile than plain carbon steel.
- Steel containing 3 to 5 % silicon has very low magnetic hysteresis.

**Uses :**

- i. Steel with Mn = 1 %, Si = 2 %, C = 0.4 to 0.6 % has very high elastic limit and is used for springs.
- ii. With Cr = 5 to 7 %, Si = 2 to 4 %, C = 0.4 to 0.5 % steel retain its hardness and resistance to oxidation even at red heat. Such steels are used for internal combustion engines.
- iii. 13 % silicon content steel has very high corrosion resistance so it is used in chemical industries.

**d. Stainless Steel :**

1. Stainless steel is a metal alloy, made up of steel mixed with elements such as chromium, nickel, molybdenum, silicon, aluminum and carbon.
2. Iron mixed with carbon to produce steel is the main component of stainless steel.
3. Chromium is added to make it resistant to rust. The addition of nickel enhances corrosion resistance properties in case of aggressive usage.

**Uses :** It is used for making kitchen utensils, to manufacture cook ware, surgical instruments and also used in food processing plants.

**Que 5.5.** Describe the types of carbon steel and also give their applications.

**Answer**

Various types of carbon steel are as follows :

**a. Low Carbon Steel :**

1. Low carbon steel generally contains less than 0.25 wt % C and are non-responding to heat treatments intended to form martensite.
2. The strengthening is accomplished by cold work.
3. Microstructures consist of ferrite and pearlite constituents. As a consequence, these steels are relatively soft and weak.
4. They have outstanding ductility and toughness.
5. They are machinable, weldable and least expensive to produce.

**i. Applications :**

1. Automobile body components.
2. Structural shapes such as I-beams, channels and angle irons, etc.
3. Mild steel sheets that are used in pipelines, buildings, bridges etc.
4. Tin cans etc.

**b. Medium Carbon Steel :**

1. The medium carbon steels have carbon concentrations between 0.25 and 0.60 wt %.

2. They can be tempered to improve their mechanical properties.
3. The plain medium carbon steels have low hardenability and can be heat treated only in the form of very thin sections by very rapid quenching rates.
4. Additions of chromium, nickel and molybdenum improve the capacity of these alloys to be heat treated, giving rise to a variety of strength ductility combinations.
5. These heat treated alloys are stronger than the low carbon steels.

**i. Applications :**

1. Railway wheels and tracks.
2. Gears.
3. Crankshafts.
4. Machine parts.
5. High strength structural components.

**c. High Carbon Steel :**

1. The high carbon steels normally have carbon contents between 0.60 and 1.4 wt %.
2. They are hardest, strongest and least ductile of all carbon steels.
3. They are almost always used in a hardened and tempered condition.
4. They are especially wear resistant and capable of holding a sharp cutting edge.
5. The tool and die steels are high carbon alloys, usually containing chromium, vanadium, tungsten, and molybdenum.

**i. Applications :**

1. Knives.
2. Razors.
3. Hacksaw blades.
4. Springs.
5. Cutting tools and dies for forming and shaping materials.

**Que 5.6.** Explain the properties and use of types of stainless steels commonly used in industries.

**Answer**

Types of stainless steels used in industries are as follows :

**a. Martensitic Stainless Steel :**

**i. Properties :**

1. Martensitic stainless steel contains 12 to 17 % Cr with sufficient carbon.

2. It is capable of being heat treated in such a way that the martensite is the prime micro-constituent.
  3. It is hardenable and magnetic.
- ii. Applications :** Valves, pumps, surgical instruments, razors, blades, turbine blades, etc.
- b. Ferritic Stainless Steel :**
- i. Properties :**
1. Ferritic stainless steel contains 12 to 30 % Cr with low carbon.
  2. It is mostly composition of a ferrite (BCC) phase.
  3. It is soft, ductile, corrosion resistant and magnetic.
- ii. Applications :** Combustion chamber, lining for petroleum industry, furnace parts, nozzles, gas burners, vessels in chemical industry, etc.
- c. Austenitic Stainless Steel :**
- i. Properties :**
1. Austenitic stainless steel contains 16 to 25 % Cr and 7 to 20 % Ni.
  2. Its crystal structure contains FCC structure. Due to FCC structure it is highly formable.
  3. It is non-magnetic.
- ii. Applications :** Household utensils, steam pipes, boiler tubes, radiant superheater tubes, etc.

**Que 5.7.** Explain maraging steels, its properties and applications.

**Answer**

**A. Maraging Steel :**

1. Maraging steels are carbon free iron-nickel alloys with additions of cobalt, molybdenum, titanium and aluminium.
2. The term maraging is derived from the strengthening mechanism which is transforming the alloy to martensite with subsequent age hardening.

**B. Properties of Maraging Steel :**

1. Ultra high strength at room temperature.
2. Simple heat treatment which results in minimum distortion.
3. Section size is an important factor in the hardening process.
4. It can be easily fabricated.
5. It has good weldability.

**C. Applications of Maraging Steel :**

1. Aerospace, e.g., undercarriage parts and wing fittings.

2. Tooling and machinery, e.g., extrusion press rams and mandrels in tube production, gears.
3. Ordinance components and fasteners.

**PART-3**

*Cast Iron : Grey, White, Malleable and Spheroidal Cast Iron.*

**CONCEPT OUTLINE**

**Cast Iron :** It may be defined as an alloy of iron and carbon containing more than two percent of carbon.

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.8.** Discuss about cast iron, its properties and uses.

**Answer****A. Cast Iron :**

1. Cast iron is very useful engineering material. It contains more carbon percentage (approximately  $2\% < C < 4.5\%$ ).
2. When pig iron is melted with coke and limestone in cupola furnace, it produces cast iron.
3. Coke acts as a fuel and limestone acts as flux.
4. Fluxes are used to separate the impurities from the pig iron (like oxides and fuel ash etc.).

**B. Properties of Cast Iron :**

1. It has good hardness due to presence of high carbon percentage.
2. Its compressive strength is very good.
3. It has good machinability.
4. It has very good rigidity.

**C. Uses of Cast Iron :**

1. The most important use is to make the bed of lathe machines.
2. It is used for making the body structures of tools.
3. To reduce the cost of an IC engine, cylinder head and blocks are made of cast iron.

4. Leaf springs or laminated springs are made of cast iron.
5. Underground pipelines to supply oils and natural gases are made of cast iron.

**Que 5.9.** Give the composition, properties and uses of any three types of cast iron.

**AKTU 2016-17, Marks 10**

**OR**

Give the composition, properties and uses of all types of cast iron.

**Answer**

**a. Grey Cast Iron :**

**i. Composition :**

Element	Percentage (%)
Carbon	2.5 – 4.0 %
Silicon	1.0 – 3.0 %
Manganese	0.25 – 1.0 %
Sulphur	0.02 – 0.25 %
Phosphorus	0.05 – 1.0 %

**ii. Properties :**

1. Tensile strength varies between 1500 and 4000 kg/cm<sup>2</sup>.
2. Hardness lies between 155 and 320 BHN.
3. Compressive strength is 3-4 times the tensile strength.

**iii. Uses :**

1. Engine cylinder block.
2. Flywheel, gear box cases etc.

**b. Malleable Cast Iron :**

**i. Composition :**

Element	Percentage (%)
Carbon	2.00 – 2.60 %
Silicon	1.10–1.60 %
Manganese	0.20–1.00 %
Sulphur	0.04–0.18 %
Phosphorus	0.18 % (max.)

**ii. Properties :**

1. It is the ductile iron.

2. Exhibits better toughness fracture properties in low temperature.
3. Easy castability.

iii. **Uses :** Steering brackets, hubs, crankshafts.

c. **Spheroidal Cast Iron (SG Iron) :**

i. **Composition :**

Element	Percentage (%)
Carbon	3.2 to 4.5 %
Silicon	1.0 to 3.00 %
Manganese	0.1 to 1.00 %
Sulphur	0.3 % (max.)
Phosphorus	0.1 % (max.)

ii. **Properties :**

1. This kind of cast iron has got very high fluidity, castability, strength, toughness, wear resistance, pressure tightness, weldability and machinability.
2. Because of its excellent casting quality, it is suited for both intricate castings as well as big size castings.

iii. **Uses :** Gear, cam shaft and crank shaft.

d. **White Cast Iron :**

i. **Composition :**

Element	Percentage (%)
Carbon	1.8 to 3.6 %
Silicon	0.5 to 1.9 %
Manganese	0.25 to 0.80 %
Sulphur	0.06 to 0.20 %
Phosphorus	0.06 to 0.18 %

ii. **Properties :**

1. Excellent resistance to wear and abrasion.
2. The large amount of iron carbides in their structure is mainly responsible for their wear resistance.

iii. **Uses :** White cast iron serves as the raw material for malleable cast irons.

**Que 5.10. Differentiate between grey cast iron and malleable cast iron.**

**Answer**

S.No.	Grey Cast Iron	Malleable Cast Iron
1.	It contains 2 to 4.5 % carbon.	It contains 0.08 to 0.2 % carbon.
2.	Free carbon occurs in the form of flat or plate like particles.	Free carbon occurs in the form of flat irregular spherical shaped particle.
3.	It is brittle and difficult to machine.	It is ductile and very easily machinable.
4.	It has high damping capacity and corrosion resistant.	It has good shock resistance.
5.	It is less expensive.	It is expensive.
6.	It is used for structural parts such as column, bed plates, pipes, etc.	It is used for complex shapes such as parts of agricultural machinery and implements, automobiles, etc.

**Que 5.11.** State the comparison of cast iron, wrought iron and mild steel.

**AKTU 2014-15, Marks 10**

**Answer**

S.No.	Cast Iron	Wrought Iron	Mild Steel
1.	It contains 2 to 5 % carbon.	Containing 0 to 0.25 % carbon.	Contains 0.08 to 0.35 % carbon.
2.	It has a crystalline, coarse granular structure.	Fibrous structure of bluish colour.	Bright fibrous structure.
3.	Hard and brittle.	Tough and more elastic than cast iron.	Tough and more elastic than wrought iron.
4.	Cannot be magnetised.	Can be temporarily magnetised.	Can be permanently magnetised.
5.	Neither malleable nor ductile.	Very malleable and ductile.	Malleable and ductile.
6.	Cannot absorb shocks.	Can stand sudden and excessive shocks.	Absorbs shocks.



**Que 5.12.** Name the phases that are commonly seen on the micrograph of mild steel specimen and a white cast iron specimen. How will the micrograph look like in grey cast iron ?

**Answer**

**A. Phases on the Micrograph of Mild Steel :**

1. Microstructures of mild steel consist of ferrite and pearlite constituents.
2. As a consequence, these alloys are relatively soft and weak but have outstanding ductility and toughness; in addition, they are machinable, weldable, and, of all steels, are the least expensive to produce.

**B. Phases on the Micrograph of White Cast Iron :**

1. In white cast iron cementite region is surrounded by the pearlite.
2. Heating white iron at temperatures between 800 and 900 °C for a prolonged time period and in a neutral atmosphere causes a decomposition of the cementite, forming graphite, which exists in the form of clusters or rosettes surrounded by a ferrite or pearlite matrix, depending on cooling rate.

**C. Phases on the Micrograph of Grey Cast Iron :**

1. The carbon and silicon contents of grey cast irons vary between 2.5 and 4.0 wt % and 1.0 and 3.0 wt %, respectively.
2. For grey cast iron, the graphite exists in the form of flakes, which are normally surrounded by an  $\alpha$ -ferrite or pearlite matrix.
3. Because of these graphite flakes, a fractured surface takes on a grey appearance.

**PART-4**

*Copper and Copper Alloys : Brass, Bronze and Cupro-Nickel.*

**CONCEPT OUTLINE**

**Copper (Cu) :** Copper is the most widely used non-ferrous metal in industry. It has very good mechanical properties as well as physical properties.

**Cupro-Nickel :** It is an alloy of copper that contains nickel and strengthening elements such as iron and manganese.

## Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 5.13.** Enumerate physical and mechanical properties of copper.

AKTU 2016-17, Marks 07

**OR**

**Explain various properties of copper and give its field of applications.**

#### Answer

**A. Copper (Cu) :**

1. Copper is the most widely used non-ferrous metal in industry.
2. It has very good mechanical properties as well as physical properties.
3. Copper is soft, malleable and good conductor of electricity. Due to formation of copper oxide (CuO) layer, it becomes a highly corrosion resistant material.

**B. Physical Properties :**

Structure	Crystalline (FCC)
Colour	Reddish-brown
Density	$8.96 \times 10^3 \text{ kg/m}^3$
Melting point	1083 °C
Boiling point	2595 °C

**C. Mechanical Properties :**

Resistivity	$1.7 \times 10^{-8} \text{ ohm-m}$
Temperature coefficient	0.0043 per kelvin
Young's modulus	124 GPa
Tensile strength	210 MN/m <sup>2</sup> (or MPa)

**D. Fields of Application :**

1. It is used in making electric wires and cables.
2. It is used for winding purposes in making of motors and coils etc.
3. It is used in electrotyping, electroplating industries.
4. It is widely used for making coins and household utensils.
5. It is used for brazing purposes.

**Que 5.14.** What are bronzes ? How are they classified ? Give the composition, microstructure, properties and applications of any three of them.

**Answer****A. Bronze (Copper-Tin Alloy) :**

1. Bronzes are the alloys of copper and tin. The composition of bronzes generally 75 to 95 % copper and 5 to 25 % tin.
2. Bronzes are hard and resistant to surface wear. Corrosion resistant properties of bronzes are comparatively better than brasses.

**B. Classification :** They are classified on the basis of constituent in its alloying element. For example :

Family	Principal Alloying Element
Phosphor bronze	Phosphorous (P)
Aluminium bronze	Aluminium (Al)
Silicon bronze	Silicon (Si)

**a. Phosphor Bronze :****i. Properties :**

1. Bronzes containing phosphorus are called phosphor bronze.
2. Due to presence of phosphorus its strength and ductility increases.
3. There is a very large change occur in the strength as it changes from 280 MPa to 2300 MPa during rolling or drawing operation.
4. It has good wearing quality and corrosion resistant property to salt water.

**ii. Application :** It is specially used for bearings, worm wheels and gears. Its other uses are in making of nuts, linings and springs etc.

**iii. Microstructure Composition :**

1. Its composition is 87-90 % Cu, 9-10 % Sn and 1-3 % P.

**b. Silicon Bronze :****i. Properties :**

1. Silicon Bronze is a high strength engineering alloy.
2. It can be easily cast, rolled, forged, stamped and pressed in both hot and cold working processes.

**ii. Application :** It is used for making boilers, tanks, stoves etc.

**iii. Microstructure Composition :**

1. Its composition is 96 % Cu, 3 % Si and 1 % Mg or Zn.

**c. Beryllium Bronze :****i. Properties :**

1. It has high wear resistance property (approximate 5 times that of phosphor bronze) so it may be used as a bearing metal.
2. It also has lubricating property which improves its quality as bearing metal. It has high fatigue limit and good yield strength.

3. It has excellent corrosion resistant property towards hot and cold environment.
- ii. **Application :** It is suitable for making of springs, heavy duty electrical switches, cams and bushings etc.
- iii. **Microstructure Composition :**
1. Its composition is 97.7 % Cu and 2.3 % beryllium.

**Que 5.15.** Discuss various types of brasses, their composition and uses.

OR

Classify brass and explain any two types stating its composition.

AKTU 2014-15, Marks 10

OR

What are brasses and bronzes ? How are they classified ? Give the composition, properties, microstructure and applications of any two of each.

AKTU 2018-19, Marks 07

**Answer**

**A. Brasses (Cu – Zn Alloys) :**

1. Brass is an alloy of copper and zinc. In brasses Cu and Zn proportions vary and gives rise of various types of brasses and improve its properties.
2. Good property brasses can be achieved by adding a small amount of alloying elements. As addition of lead alloy by 1 to 1.5 % improves its strength and machining property but reduces its thermal and electrical conductivity.
3. The important quality of brass is its corrosion resistant property towards exposure of environment. Thus brasses are used for electroplating of metals. They have good fabrication properties.

**B. Classification :** These alloys are classified on the basis of their alloying elements. For example :

Family	Principal Alloying Element
Yellow brass	Zn
Leaded brass	Pb
Nickel brass	Ni

**C. Various Types of Brasses and their Uses :**

**a. Gliding Metal :** Its composition is 85 % Cu + 15 % Zn.

**Uses :** It is used for making bullet envelopes, drawn container and dress jewellery.

**b. Cartridge Brass :** Its composition is 70 % Cu + 30 % Zn.

**Uses :** It is used for making cold rolled sheets, wire drawing, deep drawing, pressing and tube manufacturing etc.

- c. **63/37 Brass :** Its composition is 63 % Cu + 37 % Zn.

**Uses :** It is used for cold press work.

- d. **Yellow Brass (Muntz Metal) :** Its composition is 60 % Cu + 40 % Zn.

**Uses :** It is used for hot working processes like rolling, extrusion and stamping etc.

- e. **Leaded Brass :** Its composition is 62.5 % Cu + 36 % Zn + 1.5 % Pb.

**Uses :** It is used for making of plates and tubes etc.

- f. **Naval Brass :** Its composition is 59 % Cu + 40 % Zn + 1 % Sn.

**Uses :** It is used in making different plates and tubes etc.

- g. **Nickel Brass (German Silver or Nickel Silver) :** Its composition is 60-45 % Cu + 35-20 % Zn + 5-35 % Ni.

- D. **Bronzes :** Refer Q. 5.14, Page 5-14B, Unit-5.

**Que 5.16. Write a short note on cupro-nickel.**

**Answer**

1. In cupro-nickel alloys, the copper contents typically varies from 60 to 90 percent. Monel metal is a nickel-copper alloy that contains a minimum of 52 percent nickel.
2. Despite its high copper content, cupro-nickel is silver in colour.
3. Cupro-nickel is highly resistant to corrosion by salt water, and is therefore used for piping, heat exchangers and condensers in seawater systems, as well as for marine hardware.
4. It is sometimes used for the propellers, propeller shafts, and hulls of high-quality boats. Other uses include military equipment and chemical, petrochemical, and electrical industries.
5. Cupro-nickel alloys are used for marine applications due to their resistance to sea water corrosion, good fabricability, and their effectiveness in lowering macrofouling levels.

**Que 5.17. What do you understand by bearing materials ? Give their properties and uses. Write down the factors considered in selecting the bearing materials ?**

**Answer**

- A. Bearing Materials (Babbits) :**

1. Bearing materials are the alloy of metals as copper, lead, tin and cadmium.
2. On the basis of metal-alloy widely used bearing metals are named as :

- i. Copper-base alloys (80 % Cu + 10 % Pb + 10 % Si)
- ii. Lead-base alloys (85 % Pb + 10 % Sb + 5 % Sn)
- iii. Tin-base alloys (80 % Sn + 12 % Sb + 8 % Cu)
- iv. Cadmium-base alloys (95 % Cd + 5 % Ag)

3. Lead-base alloys and tin-base alloys are also known as babbit metals (or babbits or white metals).

**B. Properties of Bearing Materials :** Properties of bearing materials are as follows :

1. Low coefficient of friction.
2. Good wearing properties.
3. Ability to withstand at higher pressure.
4. Good lubricating property.
5. High thermal conductivity (to maintain its temperature low).
6. Non-corrosive property.
7. Good casting property.
8. Should be low in cost.
9. High melting point (to sustain high temperature).

**C. Uses :**

1. Copper base alloys are used for bearings which are working at high pressures or for heavy duty bearing.
2. Cadmium base alloys are used for medium loaded bearings subjected to high temperature.
3. Tin-based, lead-based and silver-based alloys are used as bush bearings to support the rotating shafts.
4. Babbits are mostly used for high speed and fluctuating load conditions.
5. Silver base alloys (or bearing metal) (95% Ag + 4% Pb + 1% Sn) is used for antifricion bearings.

**D. Selection of Bearing Materials :** Factors considered in selecting the bearing materials are as follows :

1. Working condition (low pressure, medium pressure or high pressure and temperature of environment).
2. Bearing pressure.
3. Rotation or rubbing speed.
4. Lubrication property.
5. Cost (very important factor).

**PART-5***Aluminium and Al-Cu Alloys.***CONCEPT OUTLINE****Types of Aluminum-Copper Alloys :**

1. Alloys containing copper and aluminum (known as aluminum bronze) and
2. Alloys containing copper, aluminum and zinc (known as aluminum brass).

**Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.18.** What are the various properties of aluminium and what is its field of applications ?

**Answer****A. Aluminium (Al) :**

1. Aluminium is produced by electrical processes from its ore alumina which is prepared from its mineral bauxite.
2. It has very good mechanical and physical properties.
3. Aluminium has good electrical conductivity and it is highly resistant to corrosion and non-toxic in nature. It has low density and weight.

**B. Physical Properties :**

Structure	Crystalline (FCC)
Colour	White metal
Density	$2.7 \times 10^3 \text{ kg/m}^3$
Melting point	$660^\circ\text{C}$
Boiling point	$2450^\circ\text{C}$

**C. Mechanical Properties :**

Resistivity	$2.8 \times 10^{-8} \text{ ohm-m}$
Temperature coefficient	0.0042 per kelvin
Young's modulus	71 GPa
Tensile strength	Varies from 90 to 150 MPa

**D. Fields of Application :**

1. It is used for making overhead cables.
2. It is used for making kitchen cookware or utensils.
3. Due to its light weight it is used in aircraft engineering.
4. It is also used for wrapping food items.
5. It is used for making automobile parts.

**Que 5.19. Why aluminium alloys are so important in modern engineering practices ? Justify your answer with suitable example.**

**AKTU 2016-17, Marks 08**

**Answer**

1. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc.
2. Aluminium alloys with a wide range of properties are used in engineering.
3. The important factors in selecting aluminium (Al) and its alloy in modern engineering practices are their high strength to weight ratio, their resistance to corrosion by many chemicals, their high thermal and electrical conductivity, their non-toxicity, reflectivity, and appearance, and their ease of formability and of machinability, they are also non-magnetic.
4. The principal uses of aluminium and its alloys are in containers and packaging, in buildings and construction, in transportation, in electrical applications, in consumer durables and in portable tools.
5. Examples :
  - i. Aluminium alloys are widely used in automotive engines, particularly in cylinder blocks and crankcases.
  - ii. Since aluminium alloys are susceptible to warping at elevated temperatures, the cooling system of such engines is critical.

**Que 5.20. Discuss about some aluminium alloys and their compositions.**

**Answer**

Some of aluminium alloys are as follows :

**a. Duralumin :**



1. It is also known as wrought alloy of aluminium. Heat treatment and case hardening improve its tensile strength upto 400 MPa.
2. It contains 3.5 % Cu, 0.5 % Mn, 0.5 % Mg and 95.5 % Al.

**i. Uses :**

1. It is mostly used for forgings, stampings, sheets, tubes and rivets because it can sustain a working temperature upto 500 °C.
2. Due to high strength and low weight it is mostly used in automobile and aircraft parts making.
3. It is also used for manufacturing of connecting rods, bars, rivets and pulleys etc.

**b. Y-alloys :**

1. It is an alloy of copper-aluminum. Copper increases its strength and machinability property.
2. A very small quantity upto 0.6 % each of Si, Mg and Fe is also present in Y-alloy. Y-alloys have better strength than duralumin at high temperature.

**i. Uses :**

1. It is mostly used for casting but it may also be used in forged components.
2. Due to better strength at high temperature, it is used for manufacturing of cylinder heads and pistons for aircraft engines.

**c. Magnalium :**

1. Magnalium is produced by melting the aluminium with 2 to 10 % of magnesium in absence of air (or in vacuum) followed by cooling in vacuum or under a pressure between 100 to 200 atm.
2. It also contains a very small amount of copper (approximate 1.75 %).

**i. Uses :** Due to light weight and good mechanical properties, it is mainly used for manufacturing of aircraft and automobile components.

**d. Hindalium :**

1. Hindalium is an aluminium alloy which is produced by Hindustan Aluminum Corporation Ltd., Renukoot.
2. It is an alloy of aluminium and magnesium and a very small quantity of chromium. Chromium improves its non-corrosive nature.
3. It is produced as a rolled product.

**i. Uses :** Due to non-corrosive nature, it is used in manufacturing of utensils.

**PART-6***Mg Alloys.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.21.** What are types of magnesium alloys ? Also give their applications.

**Answer**

Types of magnesium alloys are as follows :

**a. Wrought Alloys :**

1. It is in the form of sheet, plate, extrusions and forging.
2. Aluminium and zinc are commonly alloyed with magnesium to form wrought magnesium alloys.
3. Aluminium and zinc both increase the strength of magnesium by solid solution strengthening.
4. Aluminium also combines with magnesium to form the precipitate  $\text{Mg}_{17}\text{Al}_{12}$ , which can be used to age-harden Mg-Al alloys.

**i. Applications :**

1. Air borne cargo equipment.
2. Highly stressed aerospace uses.

**b. Casting alloys :**

1. Magnesium casting alloys are made with aluminium and zinc because these elements contribute to solid solution strengthening.
2. Alloying magnesium with rare earth metals, mainly cerium produces a rigid grain boundary network.
3. It dominates 85-90 % of all magnesium alloy products, with Mg-Al-Zn system.

**i. Applications :**

1. Sand casting.
2. Permanent mould casting.

**PART-7***Nickel Based Superalloys.***Questions-Answers****Long Answer Type and Medium Answer Type Questions**

**Que 5.22.** Write down the properties of nickel. Also explain its alloys.

**Answer****A. Properties of Nickel :**

1. It has FCC structure. It has good ductility and malleability.
2. It exhibits good resistance to corrosion and oxidation.
3. It has fairly good electrical conductivity.
4. It has better formability.
5. It is chemically inert hence used for electroplating.

**B. Nickel Based Alloys :****i. Monel Metal :**

1. It is an important alloy of nickel and copper. It contains 68 % nickel, 29 % copper and 3 % other constituents like iron, manganese, silicon and carbon.
2. It is superior to brass and bronze in corrosion resisting properties.
3. It is used for making propellers, pump fittings, condenser tubes, steam turbine blades.

**ii. Inconel :**

1. It consists of 80 % nickel, 14 % chromium and 6 % iron.
2. This alloy has excellent mechanical properties at ordinary and elevated temperatures. It can be cast, rolled and cold drawn.
3. It is used for making springs which have to withstand high temperatures and are exposed to corrosive active. It is also used for exhaust manifolds of aircraft engines.

**iii. Nichrome :**

1. It consists of 65 % nickel, 15 % chromium and 20 % iron. It has high heat and oxidation resistance.
2. It is used in making electrical resistance wire for electric furnaces and heating elements.

**iv. Nimonic :**

1. It consists of 80 % nickel and 20 % chromium. It has high strength and ability to operate under intermittent heating and cooling conditions.
2. It is widely used in gas turbine engines.

**Que 5.23. Write a short note on nickel based superalloys.**

1. Nickel based superalloys have been developed primarily for gas turbine parts that must be able to withstand high temperatures and high oxidizing conditions and be creep-resistance.
2. Most wrought nickel based superalloys consist of about 50 to 60 percent nickel, 15 to 20 percent chromium, and 15 to 20 percent cobalt.
3. Small amounts of aluminium (1 to 4 percent) and titanium (2 to 4 percent) are added for precipitation strengthening.
4. The nickel based superalloys consist essentially of three main phases :
  - i. A matrix of gamma austenite,
  - ii. A precipitate phase of  $\text{Ni}_3\text{Al}$  and  $\text{Ni}_3\text{Ti}$  called gamma prime, and
  - iii. Carbide particles (due to the addition of about 0.01 to 0.04 percent C).
5. The gamma prime provides high temperature strength and stability to these alloys and the carbides stabilize the grain boundaries at high temperatures.

**PART-8***Titanium Alloys.***Questions-Answers****Long Answer Type and Medium Answer Type Questions****Que 5.24. Explain titanium and its alloys.****Answer****A. Titanium :**

1. Titanium is a light, strong, lustrous, corrosion resistant transition non-ferrous metal.
2. It can be easily alloyed with other elements/metals including iron, aluminum, vanadium, molybdenum and others, for producing strong light weight alloys for aerospace and other demanding applications.

**B. Titanium Alloys :**

**a. Alpha Alloys ( $\alpha$ ) :**

1. Alpha alloys commonly have creep resistance.
2. Alpha alloys are suitable for somewhat elevated temperature applications.
3. They are also sometimes used for cryogenic applications.
4. Alpha alloys have adequate strength, toughness, and weldability for various applications.
5. Alpha alloys cannot be strengthened by heat treatment.

**b. Alpha-Beta Alloys ( $\alpha - \beta$ ) :**

1. Alpha-beta alloys have chemical compositions that result in a mixture of alpha and beta phases.
2. The beta phase is normally in the range of 10 to 50 % at room temperature.
3. Alloys with beta contents less than 20 % are weldable.
4. The most commonly used titanium alloy is Ti-6Al-4V, an alpha + beta alloy.
5. While Ti-6Al-4V is fairly difficult to form other alpha + beta alloys normally have better formability.

**c. Beta Alloys ( $\beta$ ) :**

1. Beta alloys have good forging capability. Beta alloy sheet is cold formable when in the solution treated condition.
2. Beta alloys are prone to a ductile to brittle transition temperature.
3. Beta alloys can be strengthened by heat treatment.
4. Typically beta alloys are solution followed by aging to form finely dispersed particles in a beta phase matrix.

**Que 5.25. Write a short note on following topics :**

- a. Gun metal,
- b. Lead,
- c. Tin, and
- d. Solder.

**Answer****a. Gun metal :**

1. Gun metal is an alloy of copper, tin and zinc. This is also known as admiralty gun metal.
2. The composition of gun metal is 88 % Cu + 10 % Sn + 2 % Zn.

3. A small quantity of zinc is added :
  - i. To clean the metal and
  - ii. To increase its fluidity.
4. It is not suitable for work at low temperature but forging process can easily be done at 600 °C.
5. This is very strong resistant to corrosion by water and moist atmosphere. It has very good strength.
6. It is extensively used for casting boiler fittings, bushes, bearings, glands and casting of guns etc.

**b. Lead :**

1. Lead has bluish grey color metal. Its specific gravity is 11.36 and melting point is 326 °C.
2. It is very soft in nature so that it can be easily cut by knife.
3. It is mostly used for making solders, water pipes and as coating for electrical cables.
4. An alloy of lead (83 % Pb + 15 % Sb (antimony) + 1.5 % Sn + 0.5 % Cu) is widely used as a bearing material for light service.
5. Lead base alloys are cheaper and good corrosion resistant materials.

**c. Tin :**

1. Tin is brightly shining white metal. It is very soft, ductile and malleable so that it can be easily rolled into very thin sheets.
2. It is used for making important alloy, solder, tin foil (for moisture proof packing) etc.
3. Its layer acts as a protective coating for iron and steel sheets.
4. A tin base alloy (babbitt as 88 % Sn + 8 % Sb + 4 % Cu) acts as a very good quality bearing metal used for manufacturing of bearings subjected to high pressure and loads.
5. Tin base alloy is also used for manufacturing of bearings subjected to high speed engines, *e.g.*, bearings of aero-engines.

**d. Solder :**

1. Solders are the metals which are easily fused to stick two different metals.
2. Some of solders used for engineering purposes are as follows :

**i. Soft Solders :**

1. It contains lead and tin as 2 : 1, but pure tin is used only for special purposes (like resist wires).

2. There is very small amount of tin present in nature and it is too costly. So it is used only upto 5 %.
3. Soft solder melts between 180 °C to 250 °C. It is used for joining Al, Mg etc.

**ii. Brazing Solders :**

1. These are high zinc brasses. They are used for brazing (joining processes of copper and brass is termed as brazing).
2. Its melting point is about 850 °C.
3. It is called spelter when its composition is about 50 % Zn + 45 % Cu + 5 % Sn.
4. It is used to join steel, iron, nickel and copper alloys.

**iii. Silver Solders :**

1. These are alloy of silver with copper and zinc. Its composition is about 45 % Ag + 30 % Cu + 25 % Zn. Its melting point is nearly to 675 °C.
2. Silver solders have high strength comparative to brazing solders. Due to better corrosion resistance property these are widely used in chemical plants.
3. Silver solders are used to join precious electronic devices as it is too costly.
4. A substitute of silver solder for low cost is Cu + P solder.

**VERY IMPORTANT QUESTIONS**

***Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.***

**Q. 1. Discuss effects of alloying elements on the properties of steel.**

**Ans.** Refer Q. 5.3, Unit-5.

**Q. 2. Explain the properties and use of types of stainless steels commonly used in industries.**

**Ans.** Refer Q. 5.6, Unit-5.

**Q. 3. Give the composition, properties and uses of all types of cast iron.**

**Ans.** Refer Q. 5.9, Unit-5.

**Q. 4. State the comparison of cast iron, wrought iron and mild steel.**

**Ans.** Refer Q. 5.11, Unit-5.

**Q. 5. Discuss various types of brasses, their composition and uses.**

**Ans.** Refer Q. 5.15, Unit-5.

**Q. 6. Discuss about some aluminium alloys and their compositions.**

**Ans.** Refer Q. 5.20, Unit-5.

**Q. 7. Write down the properties of nickel. Also explain its alloys.**

**Ans.** Refer Q. 5.22, Unit-5.





**1****UNIT**

# Crystal Structure and Mechanical Property Measurement

## (2 Marks Questions)

**1.1. Define crystal structure.****AKTU 2016-17, Marks 02**

**Ans.** The arrangement of small representative group of atoms or molecules known as unit cell within the solid is known as crystal structure.

**1.2. What do you mean by amorphous materials ?****AKTU 2017-18, Marks 02**

**Ans.** The materials in which there is a random and irregular arrangement of atoms over a relatively large atomic distance are known as amorphous materials.

**1.3. What is a unit cell ?**

**Ans.** Unit cell may be defined as 3-D arrangement of small group of atoms.

**1.4. What is coordination number ?**

**Ans.** The coordination number is defined as the number of nearest and equidistant atoms with respect to any other atom in a unit cell.

**1.5. What is a ceramic material ? Give any two examples.****AKTU 2017-18, Marks 02**

**Ans. Ceramic Material :** Ceramics are the compound of metallic and non-metallic elements for which the interatomic bonding is predominantly ionic. The desirable properties of these materials are normally achieved through a high temperature heat treatment process.

**Examples :** Clay products, abrasives.

**1.6. Write down any four properties of ceramic materials.**

**Ans.** Properties of ceramic materials are as follows :

- They are very hard and brittle in nature.

- ii. They have low electrical and thermal conductivity.
- iii. They are relatively stiff and strong as compared to metals.
- iv. They are more resistant to high temperatures.

**1.7. What are refractory materials ? Give some examples.**

**AKTU 2018-19, Marks 02**

**Ans.** **Refractory Material :** These are the heat resistant material that can withstand high temperatures, possess sufficient mechanical strength, heat resistance and retain a constant volume.  
**Examples :** Graphite, thoria, zirconia, fireclay bricks.

**1.8. What do you mean by imperfect crystal ?**

**Ans.** If any departure or randomness occurs in a perfectly ordered arrangement of atoms, then the crystal is termed as imperfect.

**1.9. Write down the different types of crystal imperfection.**

**Ans.** The crystal imperfection are as follows :

- i. Point imperfection,
- ii. Line imperfection,
- iii. Surface imperfection, and
- iv. Volume imperfection.

**1.10. What are the different types of point imperfections ?**

**Ans.** The point imperfection are as follows :

- i. Vacancy,
- ii. Substitutional impurity,
- iii. Interstitial impurity,
- iv. Frenkel's defect, and
- v. Schottky's defect.

**1.11. Explain the edge dislocation in short.**

**AKTU 2017-18, Marks 02**

**Ans.** Edge dislocation is a defect which is formed by adding an extra partial plane of atoms to the crystal.

**1.12. Differentiate between edge dislocation and screw dislocation.**

**AKTU 2015-16, Marks 02**

**Ans.**

S. No.	Edge Dislocation	Screw Dislocation
1.	Burger vector is perpendicular to dislocation.	Burger vector is parallel to dislocation.
2.	Cross slip is not possible.	Cross slip is possible.

**1.13. What are the different ways of dislocation strengthening ?****Ans.** Following are the three ways of dislocation strengthening :

- i. Strengthening by grain size reduction,
- ii. Solid solution strengthening, and
- iii. Strain hardening.

**1.14. What is Frenkel's defect ?****Ans.** When a cation displaces from its regular position to an interstitial location it forms a defect called Frenkel's defect. This defect does not affect the electrical neutrality of the crystal.**1.15. What is Schottky's defect ?****Ans.** When a pair of cation and anion is removed from an ionic crystal unit cell it forms a defect known as Schottky's defect.**1.16. Define the term Young's modulus.****Ans.** Young's modulus is defined as the ratio of tensile stress and tensile strain or compressive stress and compressive strain.**1.17. What is Hooke's law ?****Ans.** Hooke's law states that when a material is loaded within its elastic limit, the stress is proportional to strain.**1.18. Define the term ductility.****Ans.** Ductility is the characteristic which permits a material to be drawn out longitudinally to a reduced section, under the action of tensile force.**1.19. Differentiate between toughness and resilience. Also define the endurance limit.****AKTU 2018-19, Marks 02****Ans. Difference between Toughness and Resilience :**

S. No.	Toughness	Resilience
1.	It is defined as the ability of the solid material to absorb energy until fracture occurs.	It is defined as the ability of the solid material to absorb energy when it is elastically deformed.
2.	Toughness is important consideration for metal forming processes.	Resilience is important property to consider when high elastic deformation is desired, such as in spring.

**Endurance Limit :** The value of limiting stress below which a load may be applied repeatedly for an indefinitely large number of times.

**1.20. Why yield points occurs in low carbon steel ?**

**AKTU 2015-16, Marks 02**

**Ans.** In case of low carbon steel, the yield point phenomenon occurs due to the presence of interstitial carbon and nitrogen atoms.

**1.21. What are the drawbacks of Brinell hardness test ?**

**Ans.** Drawbacks of Brinell hardness test are as follows :

- i. Sinking effect, and
- ii. Piling-up effect.

**1.22. What do you mean by shore hardness test ?**

**Ans.** Shore hardness test is suitable for determining hardness of very thin and very soft metals and non-metals. Shore tester instrument is called durometer.

**1.23. A hardened steel ball of 0.50 cm diameter is used to indent a steel specimen in Brinell hardness test. Diameter of indentation measured by an optical microscope of magnification 10 X is observed to be 32.5 mm. Calculate Brinell hardness number of the steel specimen.**

**AKTU 2015-16, Marks 02**

**Ans.**

**Given :**  $D = 0.50 \text{ cm} = 5 \text{ mm}$ ,  $d = 32.5 \text{ mm}$

**To Find :** Brinell hardness number of the steel specimen.

1. Load stage for steel specimen =  $30 D^2$   
 $P = 30 D^2 = 30 \times (5)^2 = 750 \text{ kgf}$
2. The hardness is obtained as,

$$\begin{aligned} \text{BHN} &= \frac{P}{\frac{\pi}{2} D [D - \sqrt{D^2 - d^2}]} \quad \left\{ \because d = \frac{32.5}{10} = 3.25 \text{ mm} \right\} \\ &= \frac{750}{\frac{\pi \times 5}{2} [5 - \sqrt{5^2 - 3.25^2}]} = 79.5 \text{ kg/mm}^2 \end{aligned}$$



# 2

## UNIT

# Static Failure Theories and Fracture Mechanics (2 Marks Questions)

**2.1. Why brittle fracture is more dangerous than ductile fracture ?**

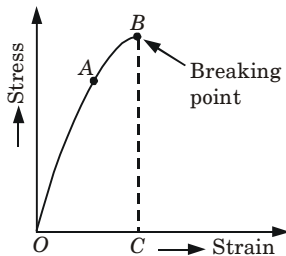
**Ans.** Brittle fracture is more dangerous than ductile fracture because :

- Brittle fracture occurs suddenly without any warning due to rapid crack propagation.
- Brittle fracture requires less strain energy for fracture.

**2.2. Draw the stress strain diagram for brittle materials and explain.**

**AKTU 2017-18, Marks 02**

**Ans.** Fig. 2.2.1 shows the stress-strain diagram for brittle materials, in which the axial strain are plotted along x-axis and corresponding stresses are plotted along y-axis.



**Fig. 2.2.1.**

**2.3. Write important criteria of yielding.**

**Ans.** Most important criteria of yielding are :

- Tresca's yield criteria, and
- Von mises yield criteria.

**2.4. Describe maximum normal stress theory.**

**Ans.** This theory states that the failure of the mechanical component subjected to bi-axial or tri-axial stresses occurs when the maximum normal stress reaches the yield or ultimate strength of the material.

**2.5. Define Mohr-Coulomb failure theory.**

**Ans.** Mohr-Coulomb theory is a mathematical model describing the response of brittle materials such as concrete or rubber piles, to shear stress as well as normal stress.

**2.6. Define fatigue life.**

**Ans.** Fatigue life is defined as the number of stress cycles that the standard specimen can complete during the test before the appearance of the first fatigue crack.

**2.7. What is  $S - N$  curve ?**

**Ans.** The  $S - N$  curve is the graphical representation of stress amplitude ( $S$ ) versus the number of stress cycles ( $N$ ) before the fatigue failure on a log-log graph paper.

**2.8. What is the difference between low cycle fatigue and high cycle fatigue ?**

**Ans.**

S.No.	Low Cycle Fatigue	High Cycle Fatigue
1.	Any fatigue failure when the number of stress cycles is less than 1000, is called low cycle fatigue.	Any fatigue failure when the number of stress cycles is more than 1000, is called high cycle fatigue.
2.	Examples : Failure of studs on truck wheels, failure of setscrews for locating gears on shafts.	Examples : The failure of machine components such as springs, ball bearings or gears that are subjected to fluctuating stresses.

**2.9. What is fatigue phenomenon ?**

**Ans.** Fatigue is a form of failure in which a structure (such as bridges, aircrafts and machine components etc.) is subjected to dynamic and fluctuating stresses.

**2.10. Write down the types of fatigue loading.**

**Ans.** Types of fatigue loading are as follows :

- Zero-to-max-to-zero.
- Varying load superimposed on a constant load.
- Fully-reversing load.

**2.11. Write down some fatigue properties.**

**Ans.** Some fatigue properties are as follows :

- Fatigue life scatter tends to increase the longer fatigue lives.

- ii. Damage is cumulative.

**2.12. What is the need of fatigue testing ?**

**Ans.** Fatigue tests are performed in the laboratory to determine the capacity of a material to withstand repeated applied stress.

**2.13. Define the term strain hardening.**

**AKTU 2018-19, Marks 02**

**Ans.** Strain hardening is defined as the strengthening of a metal or polymer by plastic deformation.

**2.14. Define non-destructive testing.**

**Ans.** Non-destructive testing refers to a method of detecting internal flaws in engineering material without breaking them.

**2.15. Differentiate between destructive and non-destructive testing.**

**Ans.**

S. No.	Destructive Testing	Non-destructive Testing
1.	It includes measuring various mechanical or chemical properties.	It is used to determine the integrity of a material.
2.	It deals in physical testing.	It is mostly deals in modern technologies.
3.	Expensive equipments.	Equipments are less costly.
4.	Equipments are portable.	Equipments are not portable.

**2.16. Write down the advantages of non-destructive testing.**

**Ans.** Advantages of non-destructing testing are as follows :

- Analysis of parts can be done without breaking it.
- Cost saving procedure.
- Improves the quality of production.
- Saves time in product evaluation.

**2.17. Name some of the methods used for non-destructive testing.**

**AKTU 2016-17, Marks 02**

**Ans.** Some methods used for non-destructive testing are as follows :

- Visual inspection,
- Eddy current testing,
- Magnetic particle inspection, and
- Penetrant testing.

**2.18. Write down the factors on which stress intensity factor depends.**

- Ans.** Following are the factors on which stress intensity factor depends :
- Sample geometry,
  - Size and location of the crack,
  - Magnitude of load, and
  - Distribution of load.





# 3

## UNIT

### Phase Diagram (2 Marks Questions)

#### 3.1. What do you mean by solid solution ?

AKTU 2017-18, Marks 02

**Ans.** A solid solution is a solid-state solution of one or more solutes in a solvent.

#### 3.2. What is substitutional solid solution ?

**Ans.** If the two atoms are of comparable size, the solute will substitute at random for one of the matrix atoms in the crystal lattice. This kind of structure is called a substitutional solid solution.

#### 3.3. What are the types of substitutional solid solution ?

**Ans.** Types of substitutional solid solution are as follows :

- Random substitutional solid solution, and
- Ordered substitutional solid solution.

#### 3.4. What is interstitial solid solution ?

**Ans.** Interstitial solid solution forms when few relatively small atoms accommodate in the interstices between solvent atoms.

#### 3.5. What is phase diagram ?

**Ans.** Phase diagram is the graphical representation of phase which is present in a material system at various temperature, pressure and composition.

#### 3.6. Write down the types of phase diagram.

**Ans.** Types of phase diagram are as follows :

- Unary phase diagram,
- Binary phase diagram, and
- Ternary phase diagram.

#### 3.7. What are the informations required for interpretation of phase diagrams ?

**Ans.** Information required for interpretation of phase diagrams are :

- i. Phases present.
- ii. Composition of phases.
- iii. Fraction of phases.

**3.8. What is eutectic phase diagram ?**

**Ans.** When the melting points of the two components are not much different and a partial or negligible solid solubility exists between them, the phase diagram is called eutectic phase diagram.

**3.9. What do you understand by eutectoid reaction ?**

**Ans.** The eutectoid reaction involves transformation of a solid phase into two other solid phases on cooling and vice-versa.

**3.10. What is peritectic phase diagram ?**

**Ans.** Peritectic phase diagram is obtained when the melting points of two components differ too much from each other. The gold-lead system is an example of peritectic phase diagram.

**3.11. What do you understand by monotectic reaction ?**

**Ans.** Monotectic reaction involves transformation of a liquid into another liquid and a solid.

**3.12. What is the use of lever rule ?**

**Ans.** It is used for the estimation of :

- i. The fraction of a proeutectic phase.
- ii. The fraction of the eutectic mixture.
- iii. The fraction of phase that form eutectic mixture.

**3.13. Give the limitation of lever rule.**

**Ans.** Lever rule cannot be applied at eutectic or peritectic temperature.

**3.14. Define the term ledeburite.**

**Ans.** Ledeburite is mixture of 4.3 % of C in iron. It is eutectic mixture of austenite and cementite.

**3.15. Define the term ferrite.**

**Ans.** Ferrite is a solid solution of carbon upto 0.025 % in the solvent  $\alpha$ -iron.  $\gamma$ -phase is converted to ferrite due to slow cooling of the solid alloys. It generally contains no carbon.

**3.16. Define the term cementite.**

**Ans.** Cementite is an intermittent compound consisting of a definite lattice arrangement of iron and carbon atoms, the relative number of each of the atoms present in a ferrite and cementite tend to form a laminated structure called pearlite.

**3.17. Write down the significance of iron-carbon equilibrium diagram.**

**Ans.** The iron-carbon diagram is important to study the behaviour of iron and alloys of iron. It forms the basis of commercial steels and cast irons and it can also influence the behaviour of most complex alloy steels.



# 4

## UNIT

# Heat Treatment of Steel (2 Marks Questions)

### 4.1. What is heat treatment ?

**Ans.** Heat treatment is defined as the heating of the metal followed by cooling under various conditions to control or improve the properties of metal.

### 4.2. What are the purposes of heat treatment ?

**Ans.** Purposes of heat treatment are as follows :

- Produce the surfaces and tough interior portions.
- Modify magnetic and electrical properties.
- Improve machinability.
- Refine the grains.

### 4.3. What are the types of annealing ?

**Ans.** Types of annealing are as follows :

- Process annealing,
- Full annealing,
- Spheroidal annealing,
- Diffusion annealing,
- Recrystallization annealing, and
- Stress relief annealing.

### 4.4. What is stress relief annealing ?

**Ans.** In stress relief annealing, heating of steel is done below the lower critical temperature and keeping at this temperature for some time and then cooled slowly.

### 4.5. Write down the objective of annealing.

**Ans.** Objective of annealing are as follows :

- It softens the steel.
- It improves ductility of steel.
- It enhances machinability.
- It refines the grain structure.

**4.6. Define tempering.**

**Ans.** In tempering process, hardened steel is reheated below its lower critical temperature ( $723^{\circ}\text{C}$ ) and then slow cooling is done.

**4.7. What are the purposes of tempering ?**

**Ans.** Purposes of tempering are as follows :

- i. It reduces brittleness of hardened steel.
- ii. It increases ductility.
- iii. It relieves internal stresses.
- iv. It improves toughness of steel.

**4.8. Define normalizing process.**

**Ans.** Normalizing involves the heating of steel upto  $40-50^{\circ}\text{C}$  above upper critical temperature and keeps it there for certain duration and allowing it to cool in the air. The cooling rate is approximately  $25-30^{\circ}\text{C}/\text{hour}$  which is higher than annealing.

**4.9. Why hardening is followed by tempering ?**

**AKTU 2018-19, Marks 02**

**Ans.** The parts obtained after hardening can not be used directly because of their high stress state which may cause deformation and cracking when placed or used at room temperature, that's why tempering is used after hardening.

**4.10. What is recrystallization temperature ?**

**AKTU 2018-19, Marks 02**

**Ans.** For particular alloy, the minimum temperature at which complete recrystallization will occur within approximately one hour is called recrystallization temperature.

**4.11. What is TTT diagram ?**

**Ans.** Temperature-Time- Transformation diagram represents a relation between starting and ending of the formation of different microstructures.

**4.12. Define 'critical cooling rate' in TTT diagram with neat sketch.**

**AKTU 2018-19, Marks 02**

**Ans.** In TTT diagram, the nose of the curve indicates the least time taken for a particular transformation. The slope of the line passes through this nose (C-curve) is known as critical cooling rate.

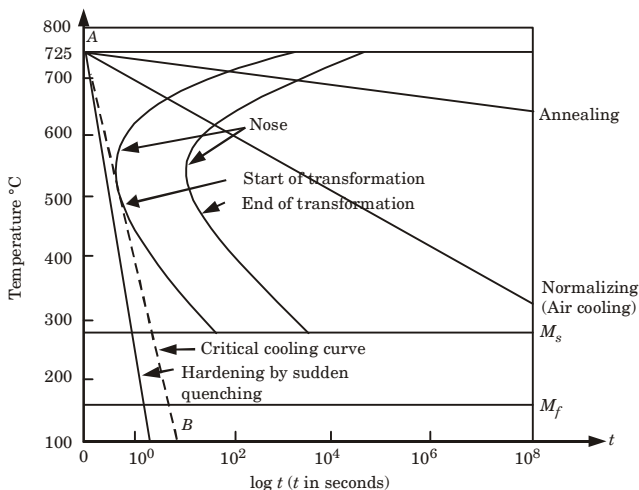


Fig. 4.12.1. TTT diagram.

#### 4.13. What is austempering process ?

AKTU 2017-18, Marks 02

**Ans.** Austempering is a heat treatment process in which steel is austenitized and then quenched in a salt bath maintained at a constant temperature in the range of 260 °C to 400 °C.

#### 4.14. What do you mean by carburizing ?

**Ans.** Carburizing is a process through which a hard, wear resistant and shock resistant surface is produced on steel, having a tough core inside. In this process the steel is heated to red hot and then carbon contents are forced into its surface structure.

#### 4.15. What are the different types of case hardening ?

AKTU 2016-17, Marks 02

**Ans.** Different types of case hardening are as follows :

- Pack carburizing,
- Liquid carburizing, and
- Gas carburizing.

#### 4.16. What is pack carburizing ?

**Ans.** In pack carburizing specimen is packed in a steel box with carbon rich powder. Then box is heated slowly above the lower critical

temperature and soaking is done. After soaking, box is then cooled slowly.

**4.17. What is quenching process ?****AKTU 2017-18, Marks 02**

**Ans.** Quenching is the rapid cooling of a workpiece in water, oil or air to obtain certain material properties. When a piece of heated material is dropped into a quenching medium, the outer surface will cool more rapid than the core.

**4.18. What is liquid carburizing ?**

**Ans.** In liquid carburizing, liquid carbon is used to impinge upon the heated steel by jet from nozzles. Due to this, carbon deposits on the steel.

**4.19. What do you mean by cyaniding ?**

**Ans.** In cyaniding, we dipped the component in a bath of sodium cyanide (NaCN) at a temperature of 400 °C. Soaking process is completed in the sodium cyanide bath. After completion of soaking, metal or steel is quenched in oil to harden the surface.

**4.20. Write down the disadvantages of nitriding.**

**Ans.** Disadvantages of nitriding are as follows :

- High cost, and
- More time consumption to complete the process.

**4.21. Define age hardening.**

**Ans.** Age hardening is the strengthening process of an alloy by precipitating finely dispersed phase from a supersaturated solid solution.

**4.22. What do you understand by flame hardening ?**

**Ans.** In flame hardening, heating and quenching both are simultaneously processed. The component is heated above the critical temperature by oxy-acetylene flame and water is being sprayed under pressure on the surface of metal.

**4.23. What is induction hardening ?**

**Ans.** In induction hardening, heating of the specimen is done by placing it in a strong magnetic field. Due to magnetic field and change of flux, an alternating current induces and produces heating effect to the specimen's surface. A simultaneous quenching process is done by spraying the cold water.

**4.24. Write down the advantages of induction hardening.**

**Ans.** Advantages of induction hardening are as follows :

- i. Heating times are extremely short.
- ii. No surface oxidation.
- iii. Deformation due to heat treatment is considerably reduced.
- iv. Permits automation of heat treatment processes.





# 5

## UNIT

# Metals and their Alloys (2 Marks Questions)

### 5.1. Define an alloy.

AKTU 2016-17, Marks 02

**Ans.** Alloy is a metallic substance that is composed of two or more elements.

### 5.2. Why do we use alloy in steels ?

**Ans.** Alloy in steels are used :

- To form martensite without cracking of steel.
- To enhance hardenability.
- To impart toughness.
- To increase ductility etc.

### 5.3. Why chromium is added into the alloys ?

**Ans.** Chromium is added into the alloys because of following reasons :

- It increases hardenability.
- It increases high temperature strength.

### 5.4. What are the applications of low carbon steel ?

**Ans.** Following are the applications of low carbon steel :

- Automobile body components,
- Structural shapes such as *I*-beam, channels etc.,
- Pipelines, buildings, bridges, and
- Tin cans.

### 5.5. Where do we use medium carbon steels ?

**Ans.** Medium carbon steels are used in :

- Railway wheels and tracks,
- Gears,
- Crankshafts,
- Machine parts, and
- High strength structural components.

### 5.6. What are the applications of high carbon steels ?

**Ans.** Application of high carbon steels are as follows :

- i. Cutting tools and dies for forming and shaping materials,
- ii. Hacksaw blades, and
- iii. Springs.

**5.7. What are basic types of cast iron ?**

**Ans.** Types of cast iron are as follows :

- i. Grey cast iron,
- ii. White cast iron,
- iii. Ductile cast iron, and
- iv. Malleable cast iron.

**5.8. Write the properties of cast iron.**

**Ans.** Properties of cast iron are as follows :

- i. Cast iron is very cheap engineering material.
- ii. It has good hardness due to presence of carbon percentage.
- iii. It can be machine easily due to good machinability.
- iv. It has very good rigidity.

**5.9. How is cast iron produced ?****AKTU 2016-17, Marks 02**

**Ans.** Cast iron is produced when pig iron is melted with coke and limestone in cupola furnace where coke is used as fuel and limestone as a flux.

**5.10. Write the properties of aluminium.**

**Ans.** Properties of aluminium are as follows :

- i. Light weight,
- ii. Corrosion resistance,
- iii. Reflectivity, and
- iv. Ductility.

**5.11. What is duralumin ? Give the composition and their applications.****AKTU 2015-16, Marks 02**

**Ans. Duralumin :** It is also known as wrought alloy of aluminium. Heat treatment and age hardening improve its tensile strength upto 400 MPa.

**Composition :** 3.5 % Cu, 0.5 % Mn, 0.5 % Mg and 95.5 % Al.

**Uses :** It is mostly used for casting but it may also be used in forged components.

**5.12. Write the properties of magnesium.**

**Ans.** Magnesium is a shiny, silver or grey coloured metal that is light in weight and strong.

**5.13. Write effect of nickel on property of steel.**

**Ans.** Effects of nickel on property of steel are as follows :

- i. It increases toughness.
- ii. It improves forming properties of stainless steel.

**5.14. Write the properties of titanium.**

**Ans.** Properties of titanium are as follows :

- i. High strength,
- ii. Stiffness,
- iii. Toughness,
- iv. Low density, and
- v. Good corrosion resistance.

**5.15. What are the different types of stainless steel ?**

**Ans.** Following are the three types of stainless steel :

- i. Martensitic stainless steel,
- ii. Ferritic stainless steel, and
- iii. Austenitic stainless steel.

**5.16. Write down the properties of maraging steel.**

**Ans.** Properties of maraging steel are as follows :

- i. Ultra high strength at room temperature.
- ii. It can be easily fabricated.
- iii. It has good weldability.

**5.17. Name the different types of bronze ?**

**Ans.** Different types of bronze are as follows :

- i. Phosphor bronze,
- ii. Silicon bronze, and
- iii. Aluminium bronze.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2014-15**  
**MATERIAL SCIENCE**

**Time : 3 Hours****Max. Marks : 100**

1. Attempt any **four** parts of the following : (5 × 4 = 20)
  - a. What are some of the typical characteristics of ceramic materials ?
  - b. Name some applications where ceramics are used.
  - c. What are the special properties of plastics that make them useful engineering materials ?
  - d. What are the factors which determine the mechanical behaviour of plastics ?
  - e. Write short notes on smart material with its application.
  - f. Briefly explain mechanism of fatigue and corrosion with neat sketches.
2. Attempt any **two** parts of the following : (10 × 2 = 20)
  - a. What do you mean by Miller indices ? Explain the procedure for finding Miller indices.
  - b. NaCl structure has FCC structure. The density of NaCl is  $2.18 \text{ cm}^3$ . Calculate the distance between two adjacent atoms.
  - c. Enumerate the various atomic models proposed by scientist over the last few decades.
3. Attempt any **two** parts of the following : (10 × 2 = 20)
  - a. What is a fatigue failure ? How is a fatigue test carried out ?
  - b. What is specimen preparation ? Explain the steps involved in specimen preparation.
  - c. Draw the iron-carbon equilibrium diagram and explain the features.
4. Attempt any **two** parts of the following : (10 × 2 = 20)

- a. State and explain Fick's first and second law.
- b. What is TTT diagram ? Explain briefly with neat sketch stating its importance.
- c. i. State the comparison of cast iron, wrought iron and mild steel.
- ii. Classify brass and explain any two types stating its composition.
5. Attempt any **two** parts of the following : (10 × 2 = 20)
  - a. Explain the following :
    - i. Ferromagnetism
    - ii. Diamagnetism
  - b. Distinguish between intrinsic and extrinsic semiconductor. Discuss why intrinsic semiconductor is not used in semiconductor devices.
  - c. Define superconductivity. Explain Type II superconductor in detail and application of Type II superconductor in detail.



**SOLUTION OF PAPER (2014-15)**

1. Attempt any **four** parts of the following : (5 × 4 = 20)

**a. What are some of the typical characteristics of ceramic materials ?**

**Ans.**

1. Ceramic materials are relatively stiff and strong as compared to the metals.
2. Ceramic materials are very hard and brittle in nature.
3. These are highly susceptible to fracture due to presence of cracks and brittle nature.
4. These have low electrical and thermal conductivity means they act as good insulator and refractories.
5. They are more resistant to high temperature and harsh environments than metals and polymers.
6. Ceramics also exhibit some magnetic behaviour.

**b. Name some applications where ceramics are used.**

**Ans.**

1. In firebricks and fireclay for lining of ovens and furnaces.
2. As artificial limbs, teeth etc., in biomedical/medical field.
3. In insulators (dielectrics) in electrical transmission and distribution.
4. In crockery in domestic uses, sanitary wares etc.
5. As ferrites in memory cores of computers.
6. As radiation shield for nuclear reactor.

**c. What are the special properties of plastics that make them useful engineering materials ?**

**Ans.** This question is out of syllabus from session 2019-20.

**d. What are the factors which determine the mechanical behaviour of plastics ?**

**Ans.** This question is out of syllabus from session 2019-20.

**e. Write short notes on smart material with its application.**

**Ans.** This question is out of syllabus from session 2019-20.

**f. Briefly explain mechanism of fatigue and corrosion with neat sketches.**

**Ans.**

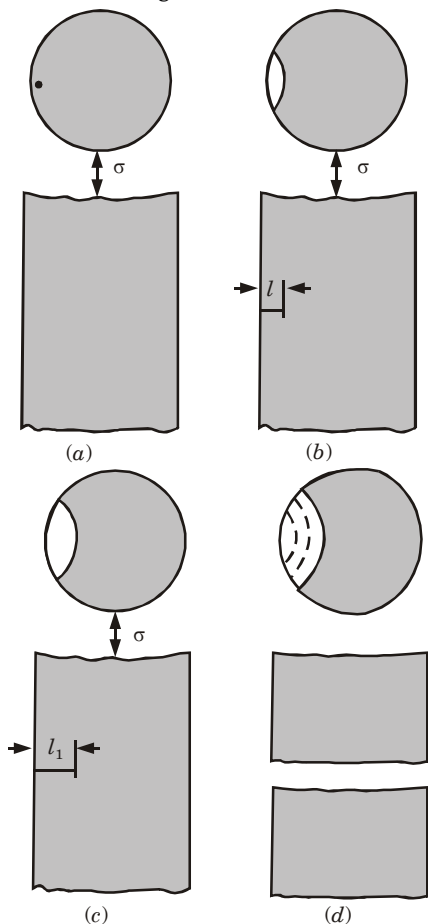
**A. Mechanism of Fatigue :** The steps involved in the fatigue fracture are as follows :

**Step 1 : Nucleation of Crack :** Nucleation is caused when maximum stress  $\sigma_{\max}$  fluctuates between tensile to compressive (within the elastic range) (Fig. 1(a)).

**Step 2 : Crack Growth :** Crack grows to a microscopic size on continued load cycles. (Fig. 1(b))

**Step 3 : Crack Growing to Tiny Size :** Crack becomes visible to the eyes after some times of continued load cycles. (Fig. 1(c))

**Step 4 : Fracture :** When crack reaches to some critical size, resulting in reduced effective cross-sectional area of the material, results in fracture. (Fig. 1(d))



**Fig. 1.** Events leading to fatigue fracture.

**B. Corrosion :** This question is out of syllabus from session 2019-20.

2. Attempt any **two** parts of the following : (10 × 2 = 20)
- a. **What do you mean by Miller indices ? Explain the procedure for finding Miller indices.**

**Ans.** This question is out of syllabus from session 2019-20.

- b. NaCl structure has FCC structure. The density of NaCl is  $2.18 \text{ cm}^3$ . Calculate the distance between two adjacent atoms.**

**Ans.**

**Given :** Density of NaCl =  $2.18 \text{ cm}^3$ .

**To Find :** The distance between two adjacent atoms.

1. Number of effective atoms per unit cell in FCC structure = 4
2. Molecular weight of NaCl = Atomic weight of Na + Atomic weight of Cl

$$= 23 + 35.5 = 58.5 \text{ gm}$$

3. As 58.5 gm of NaCl contains  $6.023 \times 10^{23}$  molecules of NaCl.

$$\therefore \text{Weight of } 6.023 \times 10^{23} \text{ molecules} = 58.5 \text{ gm}$$

$$\text{Therefore weight of 4 molecules} = \frac{58.5 \times 4}{6.023 \times 10^{23}} \text{ gm}$$

This is the weight of unit cell whose volume is  $a^3$ .

4. We know that,  $\rho = \frac{M}{V}$

$$\frac{58.5 \times 4}{6.023 \times 10^{23} \times a^3} = 2.18 \text{ gm/cm}^3$$

$$\therefore a^3 = \frac{58.5 \times 4}{6.023 \times 10^{23} \times 2.18}$$

$$a = 5.63 \times 10^{-8} \text{ cm} \quad (\because 1 \text{ \AA} = 10^{-8} \text{ cm})$$

$$\text{or, } a = 5.63 \text{ \AA}$$

5. The lattice constant ' $a$ ' is the unit cell dimension. In crystals of NaCl, it is twice the distance between adjacent atoms.

$$\therefore \text{Distance between two adjacent atoms} = \frac{5.63}{2} = 2.82 \text{ \AA}$$

- c. Enumerate the various atomic models proposed by scientist over the last few decades.**

**Ans.** This question is out of syllabus from session 2019-20.

3. Attempt any **two** parts of the following : (10 × 2 = 20)
- a. **What is a fatigue failure ? How is a fatigue test carried out ?**

**Ans.**

**A. Fatigue Fracture :**

1. Fatigue fracture results from the presence of fatigue cracks, usually initiated by cyclic stresses, at surface imperfections such as machine markings and slip steps.
2. Although the initial stress concentration associated with these cracks are too low to cause brittle fracture but they may be sufficient



to cause slow growth of the cracks into the interior. Eventually the cracks may become sufficiently deep so that the stress concentration exceeds the fracture strength and sudden failure occurs.

3. The extent of the crack propagation process depends upon the brittleness of the material under test.
4. In brittle materials the crack grows to a critical size from which it propagates right through the structure in a fast manner, whereas with ductile materials the crack keeps growing until the remaining area cannot support the load and an almost ductile fracture suddenly occurs.
5. Fatigue failures can be recognized by the appearance of fracture.

### B. Fatigue Tests :

1. Fatigue tests are performed in the laboratory to determine the capacity of a material to withstand repeated applied stresses.
2. Fatigue testing with respect to the type of load and the manner in which it is applied, is important to find the various fatigue properties of materials.
3. The basic types of loading are simple axial loading, bending, torsion, and a combination of these three.
4. Fig. 2 shows a constant load machine used for fatigue testing.

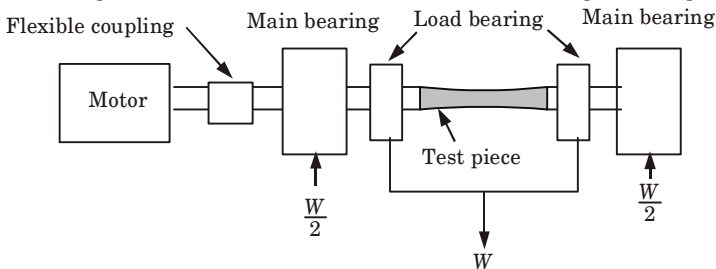


Fig. 2.

5. The test specimen in the form of cantilever which forms the extension of a shaft is placed in the machine. The shaft is driven by an electric motor.
6. A dead load is applied to the machine by means of ball bearings. The bearing relieves the motor of the large bending moment which is applied to the specimen.
7. While the specimen is rotating, any given position on the surface of the specimen alternates between a state of maximum tensile stress and a state of maximum compressive stress.
8. There is sinusoidal variation of stress as the specimen rotates.
9. The stress is greatest at the surface and zero at the centre.
10. The number of cycles will depend upon the value of the applied stress so that fatigue may occur. The number of cycles will be less where the value of the stress is high.
11. On the other hand, if the applied stress is less, the number of cycles will have to be increased. Ultimately a stress is reached below

which failure will not take place within the limits of the standard test. This value of stress is known as the endurance limit.

12. If fracture does not take place within the specified cycles for the material, then it is assumed that fracture will not take place.

**b. What is specimen preparation ? Explain the steps involved in specimen preparation.**

**Ans.** This question is out of syllabus from session 2019-20.

**c. Draw the iron-carbon equilibrium diagram and explain the features.**

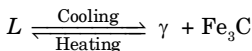
**Ans.**

**A. Iron-carbon Equilibrium Diagram :**

1. In (Fig. 3), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.
2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature 912 °C, ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature 1394 °C, austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of 1538 °C.
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below 727 °C.
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region 727 °C to 1147 °C.
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.
6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

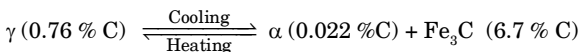
**i. Eutectic Point :**

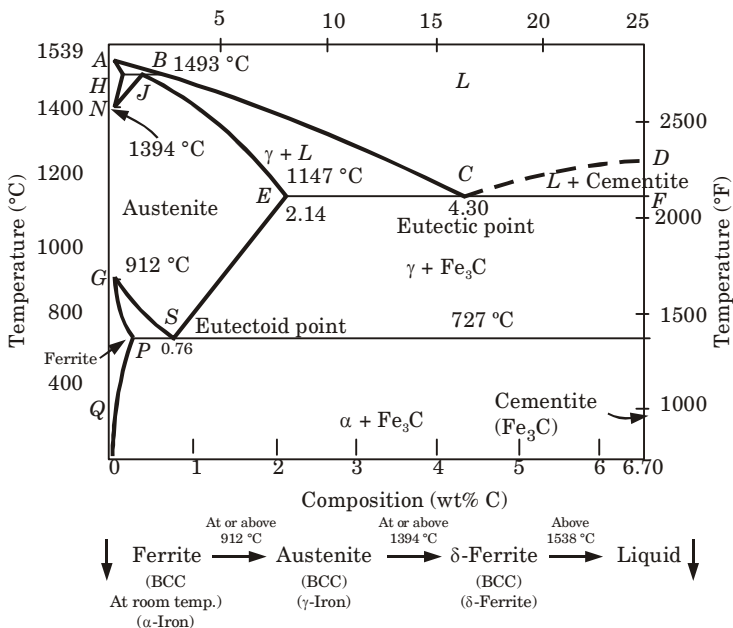
1. Eutectic point is shown in the phase diagram indicated as point C.
2. At point C, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature = 1147 °C
3. There is an equilibrium state between liquid state (L) and two solid phases ( $\gamma$  phase and cementite).



**ii. Eutectoid Point :**

1. Point S is indicated as eutectoid point.
2. At point S, there is an equilibrium state between solid state and two solid phases ( $\alpha$  and cementite).
3. Eutectoid composition = 0.76 % carbon (percent by weight)





**Fig. 3.** Fe-C phase diagram.

**B. Feature of the Fe-C Diagram :** The salient features of the equilibrium diagram (Fig. 3) are as follows :

1. Iron-carbon equilibrium diagram concerns transformation that occurs in alloys having compositions from pure iron to 6.67 % carbon.
2. Point A is the highest melting point (1539 °C) of pure iron and point D is the melting point (approx. 1550 °C) of the iron carbide (Fe<sub>3</sub>C called cementite) having 6.67 % C.
3. The line through points A–B–C–D are liquidus lines and the lines through point A–H–J–E–C–F are the solidus lines. The lowest temperature for solidification is 1130 °C, and it happens along the constant temperature line E–C–F.
4. The upper left hand portion of the diagram represents the allotropic transformations at high temperature. Line H–J–B represents peritectic transformation that is taking place at temperature 1493 °C.
5. When the alloy crosses, the liquidus line A–B–C–D, solidification starts and completes along A–E–C–F. Austenite is precipitated along A–B–C and cementite along C–D.
6. At point C (1130 °C and 4.3 % C) austenite and cementite are simultaneously precipitated from the liquid alloy to form eutectic cast iron called ledeburite. This formation obeys the rules of eutectic transformation.

4. Attempt any **two** parts of the following : (10 × 2 = 20)

a. **State and explain Fick's first and second law.**

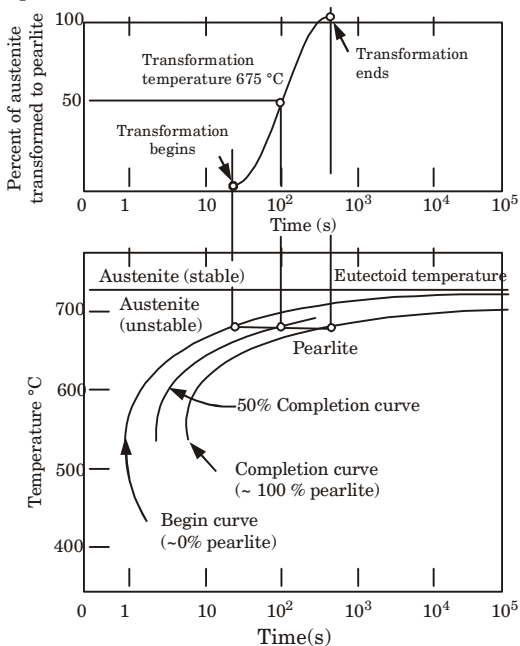
**Ans.** This question is out of syllabus from session 2019-20.

b. **What is TTT diagram ? Explain briefly with neat sketch stating its importance.**

**Ans.**

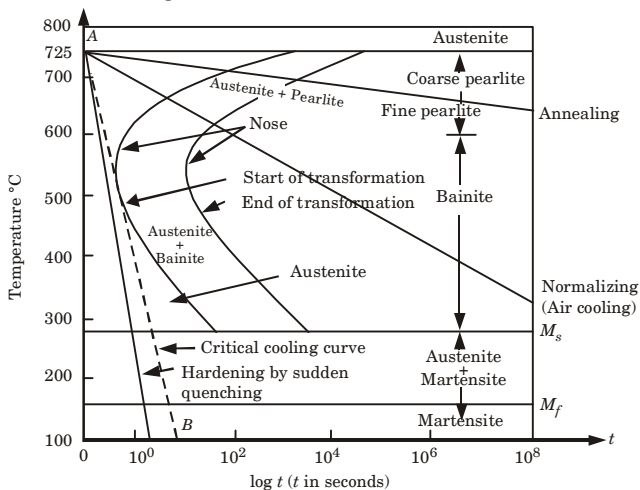
**A. TTT-Diagram :**

1. Temperature-Time-Transformation diagram represents a relation between starting and ending of the formation of different microstructures.
2. Its shape is same as the English alphabet 'C' so it is known as C-curve.
3. The nose of this curve indicates the least time taken for a particular transformation.
4. The line passes through the nose (or tangent at the nose of C-curve) is known as critical cooling curve and its slope is termed as critical cooling rate.
5. In the (Fig. 4) transformation of austenite to pearlite is shown. The left most C-curve shows the starting of transformation of austenite into pearlite.



**Fig. 4. TTT diagram.**

- At this curve 0 % pearlite, 100 % austenite is present. Then the dashed curve represents that 50 % of austenite transforms into pearlite and the right most C-curve represents (completion curve) 100 % pearlite transformation.
- These curves are accurate only for transformations in which the temperature of alloy is held constant throughout the duration of the reactions.
- Thus these plots are also known as isothermal transformation diagrams or TTT diagrams.
- Depending upon different cooling rate various microstructures can be obtained like pearlite (coarse or fine), bainite, austenite + martensite and martensite.
- When cooling rate is slow, we get line pearlite which is done by annealing.
- In normalizing the cooling rate is high by which we get bainite structure.
- A complete feature of TTT diagram to show its different phase is shown in (Fig. 5).



**Fig. 5.** The TTT curve showing temperature and log (time) variation for an eutectoid steel, and its different phases.

### **B. Importance of TTT Diagram :**

- It shows the structure that we obtained at different cooling rates.
- It graphically describes the cooling rate required for the transformation of austenite to pearlite, bainite or martensite.
- It shows the time required for transformation to various phases.

**c. i. State the comparison of cast iron, wrought iron and mild steel.**

**Ans.**

S.No.	Cast Iron	Wrought Iron	Mild Steel
1.	It contains 2 to 5 % carbon.	Containing 0 to 0.25 % carbon.	Contains 0.08 to 0.35 % carbon.
2.	It has a crystalline, coarse granular structure.	Fibrous structure of bluish colour.	Bright fibrous structure.
3.	Hard and brittle.	Tough and more elastic than cast iron.	Tough and more elastic than wrought iron.
4.	Cannot be magnetised.	Can be temporarily magnetised.	Can be permanently magnetised.
5.	Neither malleable nor ductile.	Very malleable and ductile.	Malleable and ductile.
6.	Cannot absorb shocks.	Can stand sudden and excessive shocks.	Absorbs shocks.

**ii. Classify brass and explain any two types stating its composition.**

**Ans.**

**A. Classification :** Brasses are classified on the basis of their alloying elements. For example :

Family	Principal Alloying Element
Yellow brass	Zn
Leaded brass	Pb
Nickel brass	Ni

**B. Types of brasses and their composition :**

**a. Yellow Brass (Muntz Metal) :**

**i. Properties :**

1. It has high fatigue limit and good yield strength.
2. It has excellent machinability.

**ii. Application :** It is used for hot working processes like rolling, extrusion and stamping etc.

**iii : Microstructure Composition :** Its composition is 60 % Cu + 40 % Zn.

**b. Leaded Brass :**

**i. Properties :**

1. It has excellent corrosion resistant property.
2. It has good strength.

**ii. Application :** It is used for making of plates and tubes etc.

**iii. Microstructure Composition :** Its composition is 62.5 % Cu + 36 % Zn + 1.5 % Pb.

**5. Attempt any two parts of the following : (10 × 2 = 20)**

**a. Explain the following :**

**i. Ferromagnetism**

**ii. Diamagnetism**

**Ans.** This question is out of syllabus from session 2019-20.

**b. Distinguish between intrinsic and extrinsic semiconductor. Discuss why intrinsic semiconductor is not used in semiconductor devices.**

**Ans.** This question is out of syllabus from session 2019-20.

**c. Define superconductivity. Explain Type II superconductor in detail and application of Type II superconductor in detail.**

**Ans.** This question is out of syllabus from session 2019-20.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2015-16**  
**MATERIAL SCIENCE**

**Time : 3 Hours****Max. Marks : 100**

**Section – A**

1. Attempt **all** parts. All parts carry **equal** marks. Write answer of each part in short : **(2 × 10 = 20)**
- a. **What is the importance of the materials explain briefly ?**
- b. **Why yield points occurs in low carbon steel ?**
- c. **Classify different types of chemical bonds with appropriate examples.**
- d. **Write the name of all atomic models and explain any one of them.**
- e. **Differentiate between edge dislocation and screw dislocation.**
- f. **Why etchant is used after polishing ? Write etchant name for stainless steel.**
- g. **Explain smart materials and its application.**
- h. **What is duralumin ? Give the composition and their applications.**
- i. **Explain the difference between addition polymerization and condensation polymerization.**
- j. **A hardened steel ball of 0.50 cm diameter is used to indent a steel specimen in Brinell hardness test. Diameter of indentation measured by an optical microscope of magnification 10 X is observed to be 32.5 mm. Calculate Brinell hardness number of the steel specimen.**

**Section – B**

Attempt any **five** questions from this section :

**(10 × 5 = 50)**



2. Compare the microstructure of MS, CI and which material will be more corrosion resistance and why ?
3. Explain in brief creep test and what is its importance ?
4. Why does the electrical conductivity of intrinsic silicon and germanium increases with increasing temperature ?
5. Write main difference between thermoplastics and thermosets with example.
6. What do you understand by lever rule ? Determine the mass fraction of the phases present at 184 °C in a sample of lead and tin with 45 % tin in it.
7. Discuss effects of alloying elements on the properties of steel.
8. Explain austempering and martempering process with suitable sketch.
9. What are some method by which processing of ceramic materials is carried out ? What are the applications of ceramic materials ?

### Section – C

Attempt any **two** questions from this section : (15 × 2 = 30)

10. Draw iron-carbon equilibrium diagram and show their salient features. Indicate significance of this diagram for heat treatment of steel.
11. What is super conductivity and super conducting transition temperature ? Explain what is Meissner effect shown by super-conduction material and what are its possible uses ?
12. Shown by graph brittle and ductile fracture of materials. Explain in brief Griffith's theory of brittle fracture.



## SOLUTION OF PAPER (2015-16)

### Section – A

1. Attempt **all** parts. All parts carry **equal** marks. Write answer of each part in short : (2 × 10 = 20)

**a. What is the importance of the materials explain briefly ?**

**Ans.** This question is out of syllabus from session 2019-20.

**b. Why yield points occurs in low carbon steel ?**

**Ans.** In case of low carbon steel, the yield point phenomenon occurs due to the presence of interstitial carbon and nitrogen atoms.

**c. Classify different types of chemical bonds with appropriate examples.**

**Ans.** This question is out of syllabus from session 2019-20.

**d. Write the name of all atomic models and explain any one of them.**

**Ans.** This question is out of syllabus from session 2019-20.

**e. Differentiate between edge dislocation and screw dislocation.**

**Ans.**

S. No.	Edge Dislocation	Screw Dislocation
1.	Burger vector is perpendicular to dislocation.	Burger vector is parallel to dislocation.
2.	Cross slip is not possible.	Cross slip is possible.

**f. Why etchant is used after polishing ? Write etchant name for stainless steel.**

**Ans.** This question is out of syllabus from session 2019-20.

**g. Explain smart materials and its application.**

**Ans.** This question is out of syllabus from session 2019-20.

**h. What is duralumin ? Give the composition and their applications.**

**Ans. Duralumin :** It is also known as wrought alloy of aluminium. Heat treatment and age hardening improve its tensile strength upto 400 MPa.

**Composition :** 3.5 % Cu, 0.5 % Mn, 0.5 % Mg and 95.5 % Al.

**Application :** It is mostly used for casting but it may also be used in forged components.

- i. Explain the difference between addition polymerization and condensation polymerization.

**Ans.** This question is out of syllabus from session 2019-20.

- j. A hardened steel ball of 0.50 cm diameter is used to indent a steel specimen in Brinell hardness test. Diameter of indentation measured by an optical microscope of magnification 10 X is observed to be 32.5 mm. Calculate Brinell hardness number of the steel specimen.

**Ans.**

**Given :**  $D = 0.50 \text{ cm} = 5 \text{ mm}$ ,  $d = 32.5 \text{ mm}$

**To Find :** Brinell hardness number of the steel specimen.

- Load stage for steel specimen =  $30 D^2$   
 $P = 30 D^2 = 30 \times (5)^2 = 750 \text{ kgf}$
- The hardness is obtained as,

$$\begin{aligned} \text{BHN} &= \frac{P}{\frac{\pi}{2} D [D - \sqrt{D^2 - d^2}]} \quad \left\{ \because d = \frac{32.5}{10} = 3.25 \text{ mm} \right\} \\ &= \frac{750}{\frac{\pi \times 5}{2} [5 - \sqrt{5^2 - 3.25^2}]} = 79.5 \text{ kg/mm}^2 \end{aligned}$$

### Section - B

Attempt any **five** questions from this section : (10 × 5 = 50)

2. Compare the microstructure of MS, CI and which material will be more corrosion resistance and why ?

**Ans.** This question is out of syllabus from session 2019-20.

3. Explain in brief creep test and what is its importance ?

**Ans.** This question is out of syllabus from session 2019-20.

4. Why does the electrical conductivity of intrinsic silicon and germanium increases with increasing temperature ?

**Ans.** This question is out of syllabus from session 2019-20.

5. Write main difference between thermoplastics and thermosets with example.

**Ans.** This question is out of syllabus from session 2019-20.

6. What do you understand by lever rule ? Determine the mass fraction of the phases present at 184 °C in a sample of lead and tin with 45 % tin in it.

**Ans.****A. Lever Rule :**

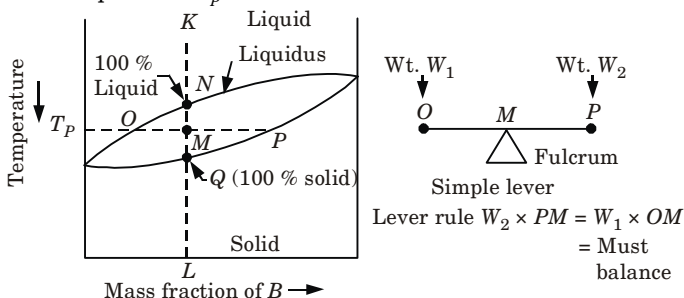
1. The lever rule is a tool used to determine weight percentages of each phase of a binary equilibrium phase diagram.
2. It is used to determine the percent weight of liquid and solid phases for a given binary composition and temperature that is between the liquidus and solidus line.
3. To determine the relative amounts of two phases, an ordinate or vertical line is erected at a point on the composition scale which gives the total composition of the alloy.
4. The intersection of this ordinate with the given isothermal line is the fulcrum of a simple lever system.
5. The ordinate  $KL$  intersects the temperature line at a point  $M$ .
6. The relative lengths of lever arms  $OM$  and  $MP$  multiplied by the amount of phases present must balance.
7. The length  $MP$  shows the amount of liquid, whereas the length  $OM$  indicates the amount of solid. Therefore,

$$\text{The percentage of solid present} = \frac{OM}{OP} \times 100$$

$$\text{The percentage of liquid present} = \frac{MP}{OP} \times 100$$

Where,  $OM + MP = OP = \text{Total composition of alloy between liquidus and solidus, say at } T_p$ .

8. The isothermal (line  $OMP$ ) can be considered a tie line since it joins the composition of two phases in equilibrium at a specific temperature  $T_p$ .



**Fig. 1.** The phase diagram used for deriving the lever rule.

**B. Numerical :**

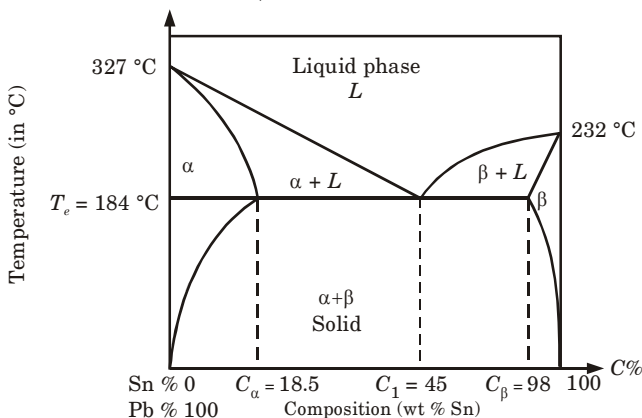
**Given :** Sn = 45 %,  $T = 184^\circ\text{C}$ .

**To Find :** Mass fraction of phases.

1. From lead-tin phase diagram,  
 $C_\alpha = 18.5$ ,  $C_\beta = 98$ ,  $C_1 = 45$
2. Mass fractions in terms of weight percentage tin,

$$W_{\alpha} = \frac{C_{\beta} - C_1}{C_{\beta} - C_{\alpha}} = \frac{98 - 45}{98 - 18.5} = 0.667$$

$$W_{\beta} = \frac{C_1 - C_{\alpha}}{C_{\beta} - C_{\alpha}} = \frac{45 - 18.5}{98 - 18.5} = 0.333$$



**Fig. 2.** The lead-tin phase diagram.

**7. Discuss effects of alloying elements on the properties of steel.**

**Ans.**

1. Steel is the most commonly used alloy of iron. Alloying elements are added to effect changes in the properties of steel.
2. The effects of various alloying elements on steel are given below :

S. No.	Alloying Elements	Effect on the Properties of Steel
1.	<b>Nickel</b>	<ol style="list-style-type: none"> <li>1. Increases toughness.</li> <li>2. Improve response to heat treatment especially in large sections.</li> <li>3. In large amount provides special electrical and magnetic properties.</li> <li>4. Improves forming properties of stainless steel.</li> </ol>
2.	<b>Chromium</b>	<ol style="list-style-type: none"> <li>1. Provides stainless property in steel.</li> <li>2. Increase hardenability.</li> <li>3. Increase high temperature strength.</li> </ol>
3.	<b>Manganese</b>	<ol style="list-style-type: none"> <li>1. Counteracts brittleness from sulphur.</li> <li>2. Increases strength and hardness markedly.</li> <li>3. Lowers both ductility and malleability if it is present in high percentage with high carbon content in steel.</li> </ol>

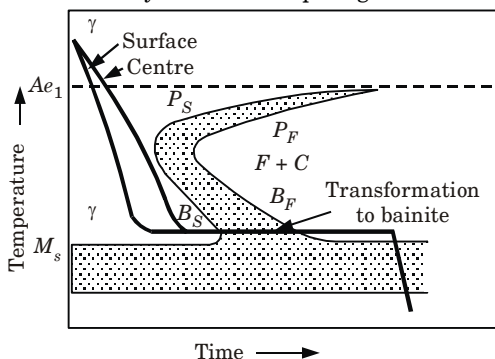
4.	<b>Vanadium</b>	<ol style="list-style-type: none"> <li>1. Improves response to heat treatment.</li> <li>2. Provides control of structure.</li> <li>3. Improves fatigue resistance.</li> </ol>
5.	<b>Tungsten</b>	<ol style="list-style-type: none"> <li>1. Retention of hardness and toughness at high temperature.</li> <li>2. Enhances the effects of other alloying elements.</li> <li>3. Improves high temperature strength.</li> </ol>
6.	<b>Silicon</b>	<ol style="list-style-type: none"> <li>1. High electrical resistance and magnetic permeability.</li> <li>2. Increases hardenability.</li> <li>3. Improves toughness.</li> </ol>
7.	<b>Copper</b>	<ol style="list-style-type: none"> <li>1. In small amount improves atmospheric corrosion resistance.</li> <li>2. Act as a strengthening agent.</li> </ol>

**8. Explain austempering and martempering process with suitable sketch.**

**Ans.**

**i. Austempering or Isothermal Quenching :**

1. It is very similar to martempering. Steel is austenitized and then quenched in a salt bath maintained at a constant temperature in the range of 260 °C to 400 °C.
2. The article is held at this temperature for long enough to allow isothermal transformation to be completed.
3. After the complete transformation of austenite to bainite, steel is cooled to room temperature in air. It is also called isothermal quenching.
4. The temperature of quenching lies below the nose of the TTT curve and above the  $M_s$  temperature.
5. Heat treatment cycle for austempering is shown in (Fig. 3).

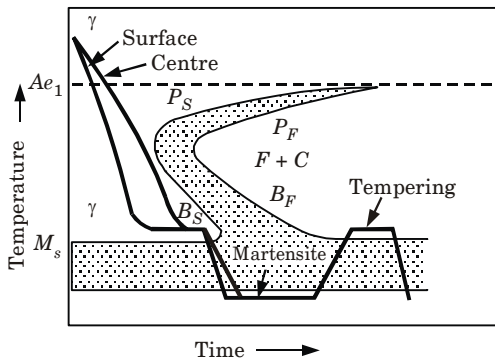


**Fig. 3.** Heat treatment cycle for austempering.

- The principal purpose of austempering is to obtain high impact strength and increased notch toughness at a given high hardness level.

**ii. Martempering or Stepped Quenching :**

- This is a hardening method that produces martensite. This method is also known as hardening by interrupted quenching.
- First the steel is heated to the hardening temperature then quenched in a medium (salt bath) having a temperature slightly above the point where martensite starts to form (usually from 150° to 300 °C).



**Fig. 4.** Heat treatment cycle for martempering.

- It is held until it reaches the temperature of the medium and then cooled further to room temperature in air or oil.
  - The holding time in quenching medium or bath should be sufficient to enable a uniform temperature to be reached throughout the cross section but not long enough to cause austenite decomposition.
  - Austenite is transformed into martensite during the subsequent period of cooling to room temperature.
  - This treatment provides a structure of martensite and retained austenite in the hardened steel.
- 9. What are some method by which processing of ceramic materials is carried out ? What are the applications of ceramic materials ?**

**Ans.**

**A. Various Processing Method used for Ceramics :**

Various processing method which are used to process ceramics are as follows :

- Glass forming processes :
  - Drawing,
  - Pressing,
  - Fibre forming, and
  - Blowing.
- Particulate forming processes :

1. Powder pressing,
  2. Slip casting,
  3. Hydro plastic forming, and
  4. Tape casting.
- iii. Cementation.

### B. Applications of Ceramic Materials :

1. In firebricks and fireclay for lining of ovens and furnaces.
2. As artificial limbs, teeth etc. in biomedical/medical field.
3. In insulators (dielectrics) in electrical transmission and distribution.
4. In crockery in domestic uses, sanitary wares etc.
5. As ferrites in memory cores of computers.
6. As radiation shield for nuclear reactor.

### Section - C

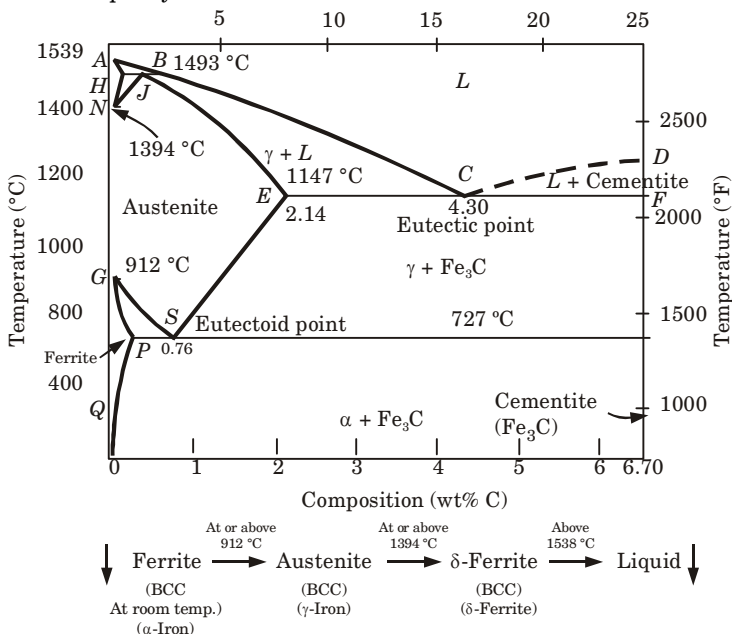
Attempt any **two** questions from this section : (15 × 2 = 30)

10. Draw iron-carbon equilibrium diagram and show their salient features. Indicate significance of this diagram for heat treatment of steel.

**Ans.**

#### A. Iron-carbon Equilibrium Diagram :

1. In (Fig. 5), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.



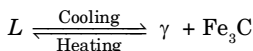
**Fig. 5.** Fe-C phase diagram.



2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature  $912^\circ\text{C}$ , ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature  $1394^\circ\text{C}$ , austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of  $1538^\circ\text{C}$ .
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below  $727^\circ\text{C}$ .
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region  $727^\circ\text{C}$  to  $1147^\circ\text{C}$ .
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.
6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

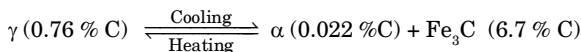
**i. Eutectic Point :**

1. Eutectic point is shown in the phase diagram indicated as point C.
2. At point C, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature =  $1147^\circ\text{C}$
3. There is an equilibrium state between liquid state (L) and two solid phases ( $\gamma$  phase and cementite).



**ii. Eutectoid Point :**

1. Point S is indicated as eutectoid point.
2. At point S, there is an equilibrium state between solid state and two solid phases ( $\alpha$  and cementite).
3. Eutectoid composition = 0.76 % carbon (percent by weight)



**B. Feature of the Fe-C Diagram :** The salient features of the equilibrium diagram (Fig. 3.17.1) are as follows :

1. Iron-carbon equilibrium diagram concerns transformation that occurs in alloys having compositions from pure iron to 6.67 % carbon.
2. Point A is the highest melting point ( $1539^\circ\text{C}$ ) of pure iron and point D is the melting point (approx.  $1550^\circ\text{C}$ ) of the iron carbide ( $\text{Fe}_3\text{C}$  called cementite) having 6.67 % C.
3. The line through points A–B–C–D are liquidus lines and the lines through point A–H–J–E–C–F are the solidus lines. The lowest temperature for solidification is  $1130^\circ\text{C}$ , and it happens along the constant temperature line E–C–F.
4. The upper left hand portion of the diagram represents the allotropic transformations at high temperature. Line H–J–B represents peritectic transformation that is taking place at temperature  $1493^\circ\text{C}$ .

- When the alloy crosses, the liquidus line  $A-B-C-D$ , solidification starts and completes along  $A-E-C-F$ . Austenite is precipitated along  $A-B-C$  and cementite along  $C-D$ .
- At point  $C$  ( $1130^{\circ}\text{C}$  and  $4.3\%$  C) austenite and cementite are simultaneously precipitated from the liquid alloy to form eutectic cast iron called ledeburite. This formation obeys the rules of eutectic transformation.

### C. Significance :

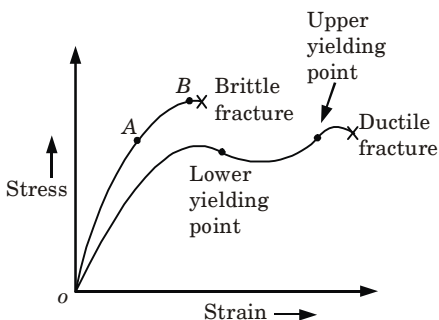
- From the iron-carbon diagram we know that the value of  $\gamma$ -iron (austenite) compared with that of  $\alpha$ -iron (ferrite) reflects much greater solubility of carbon in  $\gamma$ -iron, with a maximum value of just over  $2\text{ wt}\%$  at  $1147^{\circ}\text{C}$ .
  - This high solubility of carbon in  $\gamma$ -iron is of extreme importance in heat treatment, when solution treatment in the  $\gamma$ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed.
- 11. What is super conductivity and super conducting transition temperature ? Explain what is Meissner effect shown by super-conduction material and what are its possible uses ?**
- 12. Shown by graph brittle and ductile fracture of materials. Explain in brief Griffith's theory of brittle fracture.**

**Ans.** This question is out of syllabus from session 2019-20.

**Ans.**

### A. Brittle and Ductile Fracture :

- (Fig. 6) shows the stress-strain diagram for the ductile and brittle fracture of material.
- From  $o$  to  $A$ , proportional limit is prevailed *i.e.*, material regain its original position if stress is removed.
- At point  $B$ , yield point is reached if stress is applied further and the brittle fracture occurs at this point.



**Fig. 6.**

4. Ductile materials have more elastic property and they further reached to an upper yielding point on further application of the stressed.
5. If stress is increased above the upper yielding point, the material breaks resulting in ductile fracture.

### B. Griffith's Criterion :

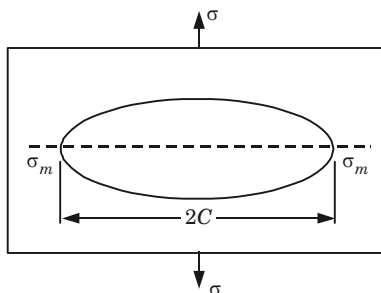
1. Griffith has postulated a criterion for the propagation of pre-existing cracks in a brittle material.
2. The crack could come from a number of sources such as a collection of dislocations, a flaw which occurred during solidification, or a surface scratch.
3. As the crack becomes longer, the material on both sides of the crack can no longer store elastic energy because tensile stress cannot be transmitted across the crack. Thus, an increase in crack length causes the release of elastic energy.
4. Griffith postulated that when the elastic energy released by extending a crack was equal to the surface energy required for crack extension, the crack would grow.
5. For an elliptical crack (Fig. 7), the maximum stress at the tips is given by :

$$\sigma_{\max} = 2 \sigma \sqrt{C/R}$$

Where,

$R$  = Radius of curvature at the tip, and

$\sigma$  = Applied stress perpendicular to length  $2C$ .



**Fig. 7.**

6. The elastic strain energy for unit volume is given by,

$$\begin{aligned} U_E &= \frac{\sigma^2}{2E} \times \text{Area} \times \text{Width} \\ &= \frac{\sigma^2}{2E} \times \pi 2C \times C = \frac{\sigma^2}{E} \pi C^2 \end{aligned}$$

7. If the surface energy per unit area is  $\gamma$  then the surface energy for a crack of length  $2C$  and unit width will be,

$$U_S = (2 \gamma C) \times 2 = 4 \gamma C$$

We multiply by 2 because there are two faces.

8. Applying Griffith's criterion, if the crack is to propagate, the change in surface energy with crack length must equal to the change in elastic strain energy.

$$\frac{dU_E}{dC} = \frac{dU_S}{dC}$$
$$\frac{d}{dC} \left( \frac{\pi C^2 \sigma^2}{E} \right) = \frac{d}{dC} (4\gamma C)$$
$$\sigma = \sqrt{\left( \frac{4\gamma E}{\pi C} \right)}$$

9. This result shows that the stress necessary to cause fracture varies inversely as the square root of the crack length and so the tensile stress of a completely brittle material will depend on the length of the largest existing crack in the material.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2016-17**  
**MATERIAL SCIENCE**

**Time : 3 Hours****Max. Marks : 100**

**Section-A**

1. Attempt **all** parts. All parts carry **equal** marks. Write answer of each part in short. (2 × 10 = 20)
- a. Define crystal structure.
- b. What do you mean by Miller indices ?
- c. Define an alloy.
- d. Name some of the methods used for non-destructive testing.
- e. What are the different types of case hardening ?
- f. How is cast iron produced ?
- g. State some applications of dielectric material.
- h. What is a semiconductor ?
- i. Name any two polymers and state their applications.
- j. State the advantages of nanomaterials.

**Section-B**

**Note :** Attempt any **five** questions from this section. (10 × 5 = 50)

2. With the help of neat sketch explain different types of crystal structure.
3. Enumerate the various atomic models proposed by scientist over the last few decades.
4. Draw the iron-carbon equilibrium diagram and explain the features.

5. Explain the various steps involved in specimen preparation with the help of flow diagram.
6. Give the composition, properties and uses of any three types of cast iron.
7. What is the difference between hard and soft magnetic material ? What are the characteristic and application of soft magnetic material ?
8. Write note on ceramic material.
9. Classify composite material and explain them briefly.

### Section-C

**Note :** Attempt any **two** questions from this section. (15 × 2 = 30)

10. a. Enumerate physical and mechanical properties of copper. (7)
- b. Why aluminium alloys are so important in modern engineering practices ? Justify your answer with suitable example. (8)
11. a. Explain with necessary formulations, the procedure to be adopted in the impact test. (8)
- b. How thermoplastic differ from thermosetting plastics ? (7)
12. Distinguish between intrinsic and extrinsic semiconductor. Explain Type I and Type II superconductors with their application.



**SOLUTION OF PAPER (2016-17)****Section-A**

1. Attempt **all** parts. All parts carry **equal** marks. Write answer of each part in short. **(2 × 10 = 20)**

**a. Define crystal structure.**

**Ans.** The arrangement of small representative group of atoms or molecules known as unit cell within the solid is known as crystal structure.

**b. What do you mean by Miller indices ?**

**Ans.** This question is out of syllabus from session 2020-21.

**c. Define an alloy.**

**Ans.** Alloy is a metallic substance that is composed of two or more elements.

**d. Name some of the methods used for non-destructive testing.**

**Ans.** Some methods used for non-destructive testing are as follows :

- i. Visual inspection,
- ii. Eddy current testing,
- iii. Magnetic particle inspection, and
- iv. Penetrant testing.

**e. What are the different types of case hardening ?**

**Ans.** Different types of case hardening are as follows :

- i. Pack carburizing,
- ii. Liquid carburizing, and
- iii. Gas carburizing.

**f. How is cast iron produced ?**

**Ans.** Cast iron is produced when pig iron is melted with coke and limestone in cupola furnace where coke is used as fuel and limestone as a flux.

**g. State some applications of dielectric material.**

**Ans.** This question is out of syllabus from session 2020-21.

**h. What is a semiconductor ?**

**Ans.** This question is out of syllabus from session 2020-21.

**i. Name any two polymers and state their applications.**

**Ans.** This question is out of syllabus from session 2020-21.

**j. State the advantages of nanomaterials.**

**Ans.** This question is out of syllabus from session 2020-21.

## Section-B

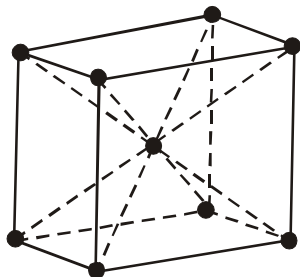
**Note :** Attempt any **five** questions from this section. **(10 × 5 = 50)**

**2. With the help of neat sketch explain different types of crystal structure.**

**Ans.** Following are the different types of crystal structures :

**i. Body Centred Cubic Structure (BCC) :**

1. BCC structure has atoms at its each corner and one atom in its centre.



**Fig. 1. BCC.**

$$\therefore \text{Total atoms in BCC} = \frac{1}{8} \times 8 + 1 = 2 \text{ atoms}$$

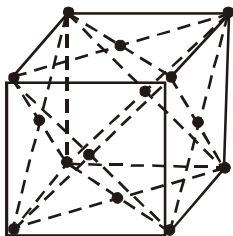
2. The coordination number of BCC arrangement is 8 and packing factor is 0.68.
3. The BCC structure can be generally seen in Lithium, Potassium, Sodium etc.

**ii. Face Centred Cubic Structure (FCC) :**

1. It consists of atoms at its each corner and one atom at centre of each face.

$$\therefore \text{Total atoms in FCC unit cell} = \frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 1 + 3 = 4 \text{ atoms}$$

2. The coordination number is 12 and packing factor is 0.74 for FCC arrangement.
3. The FCC structure can be generally seen in Copper, Gold, Silver and Lead etc.



**Fig. 2. FCC.**

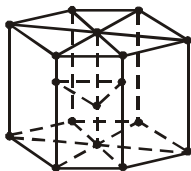


**iii. Hexagonal Close-Packed Structure (HCP) :**

1. The unit cell is like a hexagonal prism in HCP.
2. There are twelve corners and each corner have an atom and one atom at the centre of each of the two hexagonal faces and three atoms in the body of the cell. In total, seventeen atoms take part in formation of a HCP unit cell.

$$\therefore \text{Total atoms in HCP} = 12 \times \frac{1}{6} + 3 + 2 \times \frac{1}{2} = 6 \text{ atoms}$$

3. This is identical to FCC, having coordination number 12 and packing factor 0.74.
4. This HCP structure is generally seen in Zinc, Magnesium and Beryllium etc.

**Fig. 3. HCP**

3. Enumerate the various atomic models proposed by scientist over the last few decades.

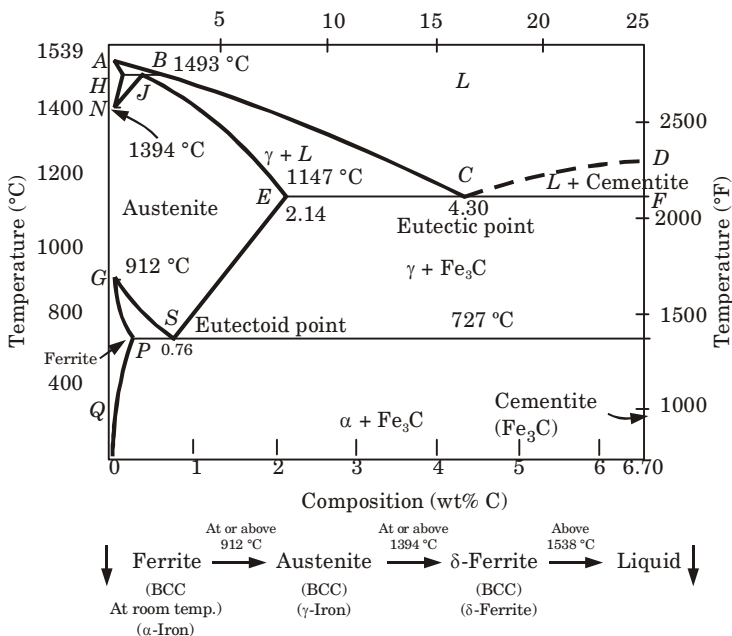
**Ans.** This question is out of syllabus from session 2019-20.

4. Draw the iron-carbon equilibrium diagram and explain the features.

**Ans.**

**A. Iron-carbon Equilibrium Diagram :**

1. In (Fig. 4), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.
2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature  $912^\circ\text{C}$ , ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature  $1394^\circ\text{C}$ , austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of  $1538^\circ\text{C}$ .
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below  $727^\circ\text{C}$ .
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region  $727^\circ\text{C}$  to  $1147^\circ\text{C}$ .
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.

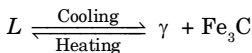


**Fig. 4.** Fe-C phase diagram.

6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

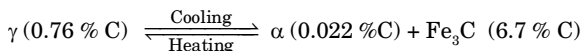
**i. Eutectic Point :**

1. Eutectic point is shown in the phase diagram indicated as point C.
2. At point C, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature = 1147 °C
3. There is an equilibrium state between liquid state (L) and two solid phases (γ phase and cementite).



**ii. Eutectoid Point :**

1. Point S is indicated as eutectoid point.
2. At point S, there is an equilibrium state between solid state and two solid phases (α and cementite).
3. Eutectoid composition = 0.76 % carbon (percent by weight)



**B. Feature of the Fe-C Diagram :** The salient features of the equilibrium diagram (Fig. 4) are as follows :

1. Iron-carbon equilibrium diagram concerns transformation that occurs in alloys having compositions from pure iron to 6.67 % carbon.
2. Point A is the highest melting point (1539 °C) of pure iron and point D is the melting point (approx. 1550 °C) of the iron carbide ( $\text{Fe}_3\text{C}$  called cementite) having 6.67 % C.
3. The line through points  $A-B-C-D$  are liquidus lines and the lines through point  $A-H-J-E-C-F$  are the solidus lines. The lowest temperature for solidification is 1130 °C, and it happens along the constant temperature line  $E-C-F$ .
4. The upper left hand portion of the diagram represents the allotropic transformations at high temperature. Line  $H-J-B$  represents peritectic transformation that is taking place at temperature 1493 °C.
5. When the alloy crosses, the liquidus line  $A-B-C-D$ , solidification starts and completes along  $A-E-C-F$ . Austenite is precipitated along  $A-B-C$  and cementite along  $C-D$ .
6. At point C (1130 °C and 4.3 % C) austenite and cementite are simultaneously precipitated from the liquid alloy to form eutectic cast iron called ledeburite. This formation obeys the rules of eutectic transformation.

**5. Explain the various steps involved in specimen preparation with the help of flow diagram.**

**Ans.** This question is out of syllabus from session 2019-20.

**6. Give the composition, properties and uses of any three types of cast iron.**

**Ans.**

**1. Grey Cast Iron :**

**i. Composition :**

Element	Percentage (%)
Carbon	2.5 – 4.0 %
Silicon	1.0 – 3.0 %
Manganese	0.25 – 1.0 %
Sulphur	0.02 – 0.25 %
Phosphorus	0.05 – 1.0 %

**ii. Properties :**

1. Tensile strength varies between 1500 and 4000 kg/cm<sup>2</sup>.
2. Hardness lies between 155 and 320 BHN.

3. Compressive strength is 3-4 times the tensile strength.

**iii. Uses :**

1. Engine cylinder block.
2. Flywheel, gear box cases etc.

**2. Malleable Cast Iron :**

**i. Composition :**

Element	Percentage (%)
Carbon	2.00 – 2.60 %
Silicon	1.10–1.60 %
Manganese	0.20–1.00 %
Sulphur	0.04–0.18 %
Phosphorus	0.18 % (max.)

**ii. Properties :**

1. It is the ductile iron.
2. Exhibits better toughness fracture properties in low temperature.
3. Easy castability.

**iii. Uses :** Steering brackets, hubs, crankshafts.

**3. Spheroidal Cast Iron (SG Iron) :**

**i. Composition :**

Element	Percentage (%)
Carbon	3.2 to 4.5 %
Silicon	1.0 to 3.00 %
Manganese	0.1 to 1.00 %
Sulphur	0.3 % (max.)
Phosphorus	0.1 % (max.)

**ii. Properties :**

1. This kind of cast iron has got very high fluidity, castability, strength, toughness, wear resistance, pressure tightness, weldability and machinability.
2. Because of its excellent casting quality, it is suited for both intricate castings as well as big size castings.

**iii. Uses :** Gear, cam shaft and crank shaft.

**7. What is the difference between hard and soft magnetic material ? What are the characteristic and application of soft magnetic material ?**

**Ans.** This question is out of syllabus from session 2019-20.

**8. Write note on ceramic material.****Ans.**

1. Ceramics are the compound of metallic and non-metallic elements for which the interatomic bonding is predominantly ionic.
2. The desirable properties of these materials are normally achieved through a high temperature heat treatment process called firing.
3. These are highly susceptible to fracture due to presence of cracks and brittle nature.
4. These have low electrical and thermal conductivity means they act as good insulator and refractories.
5. They are more resistant to high temperature and harsh environments than metals and polymers.
6. In insulators (dielectrics) in electrical transmission and distribution.

**9. Classify composite material and explain them briefly.****Ans.** This question is out of syllabus from session 2019-20.**Section-C****Note :** Attempt any **two** questions from this section. **(15 × 2 = 30)****10. a. Enumerate physical and mechanical properties of copper. (7)****Ans.****A. Copper (Cu) :**

1. Copper is the most widely used non-ferrous metal in industry.
2. It has very good mechanical properties as well as physical properties.
3. Copper is soft, malleable and good conductor of electricity. Due to formation of copper oxide (CuO) layer, it becomes a highly corrosion resistant material.

**B. Physical Properties of Copper :**

Structure	Crystalline (FCC)
Colour	Reddish-brown
Density	$8.96 \times 10^3 \text{ kg/m}^3$
Melting point	1083 °C
Boiling point	2595 °C

**C. Mechanical Properties of Copper :**

Resistivity	$1.7 \times 10^{-8} \text{ ohm-m}$
Temperature	coefficient 0.0043 per kelvin
Young's modulus	124 GPa
Tensile strength	210 MN/m <sup>2</sup> (or MPa)

**b. Why aluminium alloys are so important in modern engineering practices ? Justify your answer with suitable example. (8)**

**Ans.**

1. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc.
  2. Aluminium alloys with a wide range of properties are used in engineering.
  3. The important factors in selecting aluminium (Al) and its alloy in modern engineering practices are their high strength to weight ratio, their resistance to corrosion by many chemicals, their high thermal and electrical conductivity, their non-toxicity, reflectivity, and appearance, and their ease of formability and of machinability, they are also non-magnetic.
  4. The principal uses of aluminium and its alloys are in containers and packaging, in buildings and construction, in transportation, in electrical applications, in consumer durables and in portable tools.
  5. Examples :
    - i. Aluminium alloys are widely used in automotive engines, particularly in cylinder blocks and crankcases.
    - ii. Since aluminium alloys are susceptible to warping at elevated temperatures, the cooling system of such engines is critical.
- 11. a. Explain with necessary formulations, the procedure to be adopted in the impact test. (8)**

**Ans.** This question is out of syllabus from session 2019-20.

- b. How thermoplastic differ from thermosetting plastics ? (7)**

**Ans.** This question is out of syllabus from session 2019-20.

- 12. Distinguish between intrinsic and extrinsic semiconductor. Explain Type I and Type II superconductors with their application.**

**Ans.** This question is out of syllabus from session 2019-20.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2017-18**  
**MATERIAL SCIENCE**

**Time : 3 Hours****Max. Marks : 100**

**Note :** 1. Attempt **all** sections. If require any missing data; then choose suitably.

**Section-A**

1. Attempt **all** questions in brief. (2 × 10 = 20)
- a. What do you mean by amorphous materials ?
  - b. Explain the edge dislocation in short.
  - c. Draw the stress strain diagram for brittle materials and explain.
  - d. What do you mean by solid solution ?
  - e. What is quenching process ?
  - f. Write any two applications of dielectric materials.
  - g. What is a ceramic material ? Give any two examples.
  - h. What is austempering process ?
  - i. Mention difference between hard and soft magnetic materials.
  - j. What is a composite material ? Give any two examples.

**Section-B**

2. Attempt any **three** of the following : (10 × 3 = 30)
- a. What do you mean by Miller indices ? Explain the procedure for finding Miller indices.
  - b. Draw a typical 'creep test' curve, showing different stages of elongation for a long time high temperature creep test.
  - c. Explain different types of heat treatment processes in brief.

- d. What is superconductivity ? Discuss the properties of superconductors.
- e. Describe the various mechanical properties of ceramics. Also explain the various electrical properties of ceramics.

### Section-C

- 3. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Draw a neat sketch of BCC crystal structure and calculate its atomic packing factor and also find out the effective number of atoms.
  - b. Explain different types of bonds commonly found between atoms. How do these atomic bonds effect the properties of materials ?
- 4. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Write short notes on the following :
    - i. Yield strength
    - ii. Ductility
    - iii. Ultimate tensile strength
  - b. Explain about iron carbon equilibrium diagram with a neat sketch.
- 5. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Draw a TTT diagram for eutectoid steel and explain the effect of cooling rate on the transformation products and hardness obtained.
  - b. What is case hardening and what are its various types ? Describe briefly.
- 6. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Distinguish between diamagnetic, paramagnetic and ferromagnetic materials. Explain their properties and applications.
  - b. What do you mean by intrinsic type semiconductors ? Explain in detail.
- 7. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Discuss about various ceramic crystal structures.
  - b. What do you understand by composite materials ? Classify them.





**SOLUTION OF PAPER (2017-18)**

**Note :** 1. Attempt **all** sections. If require any missing data; then choose suitably.

**Section-A**

1. Attempt **all** questions in brief. (2 × 10 = 20)

a. **What do you mean by amorphous materials ?**

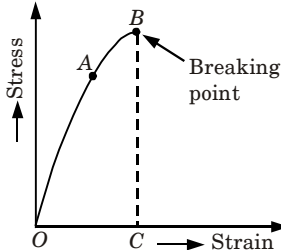
**Ans.** The materials in which there is a random and irregular arrangement of atoms over a relatively large atomic distance are known as amorphous materials.

b. **Explain the edge dislocation in short.**

**Ans.** Edge dislocation is a defect which is formed by adding an extra partial plane of atoms to the crystal.

c. **Draw the stress strain diagram for brittle materials and explain.**

**Ans.** Fig. 1 shows the stress-strain diagram for brittle materials, in which the axial strain are plotted along x-axis and corresponding stresses are plotted along y-axis.



**Fig. 1.**

d. **What do you mean by solid solution ?**

**Ans.** A solid solution is a solid-state solution of one or more solutes in a solvent.

e. **What is quenching process ?**

**Ans.** Quenching is the rapid cooling of a workpiece in water, oil or air to obtain certain material properties. When a piece of heated material is dropped into a quenching medium, the outer surface will cool more rapid than the core.

f. **Write any two applications of dielectric materials.**

**Ans.** This question is out of syllabus from session 2019-20.

**g. What is a ceramic material ? Give any two examples.**

**Ans.** **Ceramic Material :** Ceramics are the compound of metallic and non-metallic elements for which the interatomic bonding is predominantly ionic. The desirable properties of these materials are normally achieved through a high temperature heat treatment process.

**Examples :** Clay products, abrasives.

**h. What is austempering process ?**

**Ans.** Austempering is a heat treatment process in which steel is austenitized and then quenched in a salt bath maintained at a constant temperature in the range of 260 °C to 400 °C.

**i. Mention difference between hard and soft magnetic materials.**

**Ans.** This question is out of syllabus from session 2019-20.

**j. What is a composite material ? Give any two examples.**

**Ans.** This question is out of syllabus from session 2019-20.

### Section-B

**2. Attempt any three of the following : (10 × 3 = 30)**

**a. What do you mean by Miller indices ? Explain the procedure for finding Miller indices.**

**Ans.** This question is out of syllabus from session 2019-20.

**b. Draw a typical 'creep test' curve, showing different stages of elongation for a long time high temperature creep test.**

**Ans.** This question is out of syllabus from session 2019-20.

**c. Explain different types of heat treatment processes in brief.**

**Ans.**

**i. Annealing :**

1. Annealing is a heat treatment process that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable.

2. Annealing consists of :

- Heating of steel above the critical temperature by 10 to 25 °C more than the lower critical temperature.
- Keeping the steel at this temperature for a definite period of time so that complete transformation into austenite takes place.
- After that slowly furnace cooling is done at the rate of 25 to 15 °C/hour.

**ii. Tempering :** The tempering process provides a method for transforming martensite into ferrite and cementite. How much of the martensite is transformed depends on the temperature and time of the tempering process.

**iii. Normalizing :**

1. Normalizing is frequently applied as a final heat treatment process to products which are subjected to relatively high stresses.
2. This process consists of heating steel to a point 40 to 50 °C above its upper critical temperature, holding at that temperature for a short duration and subsequently cooling in still air at room temperature. This is also known as air quenching.
3. This process is suggested for manufacturing operations like hot rolling and forging which are carried out on steels in the austenite range.
4. It is also useful for eliminating coarse grained structure in castings, removing internal stresses that may have been caused by hot or cold working and improving the mechanical properties of the steel by eliminating the carbide network at the grain boundaries of the steels.
5. Normalizing produces microstructures consisting of ferrite and pearlite for hypoeutectoid steels and pearlite and cementite for hypereutectoid steels.

**iv. Spheroidizing :**

1. This is special type of tempering where the specimen is reheated below the lower critical temperature to transform the shape of carbide into globular shape.
2. Due to this shape steel becomes soft and easy to machine.
3. Globular shape also reduces the problem of stress concentration and improves the ductility but at the same time it lowers the hardness and tensile strength.
4. These spheroidizing steels have better ductility than normally annealed steels.

**d. What is superconductivity ? Discuss the properties of superconductors.**

**Ans.** This question is out of syllabus from session 2019-20.

**e. Describe the various mechanical properties of ceramics. Also explain the various electrical properties of ceramics.**

**Ans.**

**A. Mechanical Properties of Ceramics :**

1. Ceramics shows brittle fracture phenomenon at room temperature, as they fracture before any plastic deformation when loaded with a tensile load.
2. Ceramics have greater strength in compression as compared to strength in tension.

- There is porosity present in ceramics which reduces its elastic property as well as strength.
- Ceramics show good hardness and they are used as an abrasive material due to its hardness property.
- Creep phenomenon occurs in ceramics at high temperature.
- Ceramics can withstand at high temperature.
- Ceramics show poor malleability.
- Frenkel and Schottky defects mostly occur in ceramics.

### B. Electrical Properties of Ceramics :

- Ceramics are good thermal and electrical insulators.
- Ceramics have high value of dielectric constant.
- Dielectric strength of ceramic is high.
- Dielectric losses are low.

### Section-C

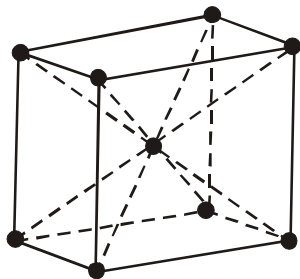
3. Attempt any **one** part of the following : (10 × 1 = 10)

- a. **Draw a neat sketch of BCC crystal structure and calculate its atomic packing factor and also find out the effective number of atoms.**

**Ans.**

#### i. Body Centred Cubic Structure (BCC) :

- BCC structure has atoms at its each corner and one atom in its centre.



**Fig. 2. BCC.**

$$\therefore \text{Total atoms in BCC} = \frac{1}{8} \times 8 + 1 = 2 \text{ atoms}$$

- The BCC structure can be generally seen in Lithium, Potassium, Sodium etc.

#### ii. Packing Factor :

- Packing factor,  $PF = \frac{\text{Volume of all atoms in unit cell}}{\text{Volume of unit cell}} = \frac{v}{V}$

$$= \frac{2 \times \frac{4}{3} \pi r^3}{a^3} = \frac{8\pi r^3}{3a^3} = \frac{8\pi r^3 \cdot 3\sqrt{3}}{3(4r)^3}$$

$$= \frac{\sqrt{3}\pi}{8} = 0.68 \text{ or } 68 \%$$

**iii. Coordination Number (Effective Number of Atoms) :** The centre atom is surrounded by eight corner atoms, so the coordination number is 8.

**b. Explain different types of bonds commonly found between atoms. How do these atomic bonds effect the properties of materials ?**

**Ans.** This question is out of syllabus from session 2019-20.

4. Attempt any **one** part of the following : (10 × 1 = 10)  
**a. Write short notes on the following :**  
 i. Yield strength  
 ii. Ductility  
 iii. Ultimate tensile strength

**Ans.**

**i. Yield strength :**

1. Yield strength is defined as the stress at which a material begins to deform plastically.
2. The plastic deformation begins at a point known as yield point.
3. The yield point determines the limits of performance for mechanical components, since it represents the upper limit to forces that can be applied without permanent deformation.

**ii. Ductility :**

1. Ductility is a property that measures the degree of plastic deformation that has been sustained at fracture.
2. A material that experiences very little or no plastic deformation upon fracture is termed brittle.
3. Ductility may be expressed quantitatively as either percent elongation or percent reduction in area. The percent elongation (% EL) is the percentage of plastic strain at fracture and is given as,

$$\% \text{ EL} = \left( \frac{l_f - l_0}{l_0} \right) \times 100$$

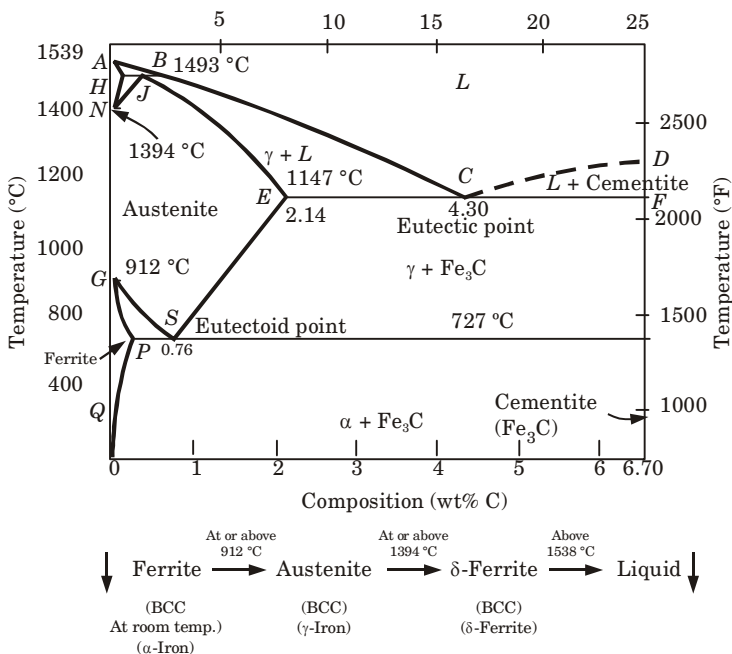
Where,  $l_f$  = Fracture length, and  
 $l_0$  = Original gauge length.

**iii. Ultimate Tensile Strength :**

1. The stress at which the load bearing ability reaches at its maximum is known as the ultimate tensile strength.
2. As plastic deformation progresses, the additional increments of strength decreases in magnitude, and a point is reached where the decrease in area cancels the increase in strength.
3. When this occurs, the load bearing ability peaks, and the force required to continue straining the specimen begins to decrease.

**Ans.**

1. In (Fig. 3), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.
2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature 912 °C, ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature 1394 °C, austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of 1538 °C.
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below 727 °C.
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region 727 °C to 1147 °C.
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.



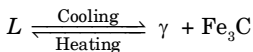
**Fig. 3.** Fe-C phase diagram.

6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

**i. Eutectic Point:**

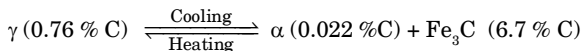
1. Eutectic point is shown in the phase diagram indicated as point C.

- At point *C*, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature = 1147 °C
- There is an equilibrium state between liquid state (*L*) and two solid phases ( $\gamma$  phase and cementite).



## ii. Eutectoid Point :

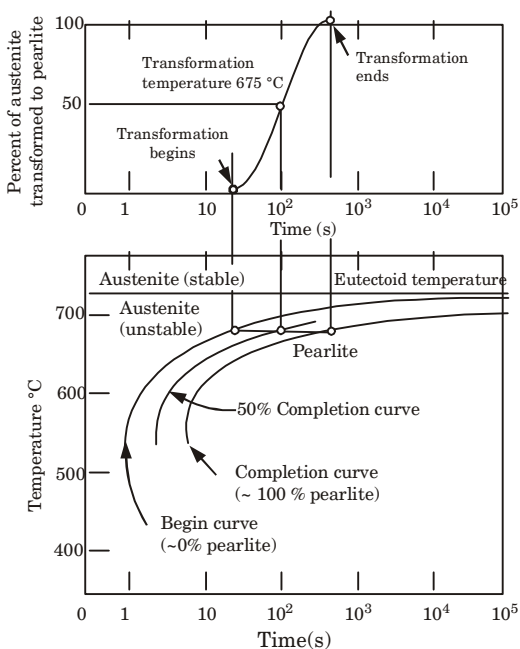
- Point *S* is indicated as eutectoid point.
- At point *S*, there is an equilibrium state between solid state and two solid phases ( $\alpha$  and cementite).
- Eutectoid composition = 0.76 % carbon (percent by weight)



- Attempt any **one** part of the following : (10 × 1 = 10)
- Draw a TTT diagram for eutectoid steel and explain the effect of cooling rate on the transformation products and hardness obtained.**

### Ans.

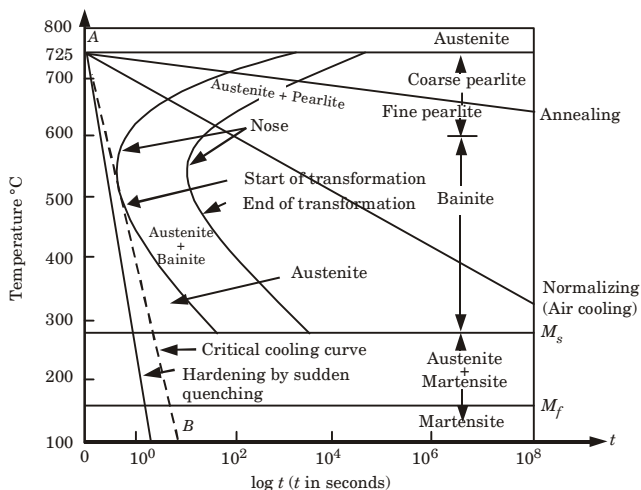
- Temperature-Time-Transformation diagram represents a relation between starting and ending of the formation of different microstructures.
- Its shape is same as the English alphabet 'C' so it is known as C-curve.
- The nose of this curve indicates the least time taken for a particular transformation.
- The line passes through the nose (or tangent at the nose of C-curve) is known as critical cooling curve and its slope is termed as critical cooling rate.
- In the (Fig. 4) transformation of austenite to pearlite is shown. The left most C-curve shows the starting of transformation of austenite into pearlite.
- At this curve 0 % pearlite, 100 % austenite is present. Then the dashed curve represents that 50 % of austenite transforms into pearlite and the right most C-curve represents (completion curve) 100 % pearlite transformation.
- These curves are accurate only for transformations in which the temperature of alloy is held constant throughout the duration of the reactions.



**Fig. 4.** TTT diagram.

8. Thus these plots are also known as isothermal transformation diagrams or TTT diagrams.
9. Depending upon different cooling rate various microstructures can be obtained like pearlite (coarse or fine), bainite, austenite + martensite and martensite.
10. When cooling rate is slow, we get line pearlite which is done by annealing.
11. In normalizing the cooling rate is high by which we get bainite structure.
12. A complete feature of TTT diagram to show its different phase is shown in (Fig. 5).





**Fig. 5.** The TTT curve showing temperature and log (time) variation for an eutectoid steel, and its different phases.

**b. What is case hardening and what are its various types ? Describe briefly.**

**Ans.**

**A. Case Hardening :**

1. It is a process through which a hard, wear resistant and shock resistant surface is produced on steel having a tough core inside.
2. In this process the steel is heated to red hot and then carbon contents are forced into its surface structure. It is then hardened as usual. For this reason this process is also frequently known as carburizing.
3. Case hardening is done :
  - i. For getting a hard and wear resistant surface.
  - ii. For increasing the machinability of surface.

**B. Types of Case Hardening Processes :**

**i. Pack Carburizing :**

1. As name suggests it is a method in which component or specimen is packed in a steel box with carbon rich powder of charcoal or coke in granules form. Then box is heated slowly above the lower critical temperature and soaking is done.
2. The depth of soaking depends on the time of exposure between steel and solid fumes. After soaking, box is then cooled slowly.
3. This method has a disadvantage of scale formation at the surface of metal.

**ii. Liquid Carburizing :**

1. In liquid carburizing, liquid carbon is used to impinge upon the heated steel by jets from nozzles. Due to this, carbon gets deposited on the steel.
2. This method does not have a problem of scale formation on the metal surface.

**iii. Gas Carburizing :**

1. In this method, heating of steel is done in a carbon rich gaseous (as methane, propane etc.) environment.
2. At high temperature, hydrocarbon gets decompose into carbon and hydrogen. This decomposed carbon gets deposited on the metal surface.
3. The thickness of hardened case can be controlled by rate of gas flow.

6. Attempt any **one** part of the following : (10 × 1 = 10)

- a. **Distinguish between diamagnetic, paramagnetic and ferromagnetic materials. Explain their properties and applications.**

**Ans.** This question is out of syllabus from session 2019-20.

- b. **What do you mean by intrinsic type semiconductors ? Explain in detail.**

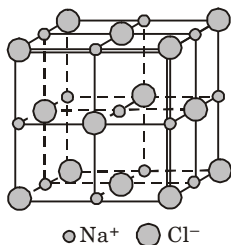
**Ans.** This question is out of syllabus from session 2019-20.

7. Attempt any **one** part of the following : (10 × 1 = 10)

- a. **Discuss about various ceramic crystal structures.**

**Ans.** Some of ceramic crystal structures are as follows :

- i. **Rock Salt Structure :**

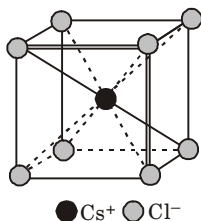


**Fig. 6.** Rock salt structure.

1. (Fig. 6) shows the arrangement of anions and cations.
2. The coordination number for both cations and anions is 6 and cation-anion radius ratio is between 0.414 and 0.732.
3. NaCl, MgO and FeO etc., have this type of structure.

**ii. Cesium Chloride Structure :**

1. (Fig. 7) shows the arrangement of Cs<sup>+</sup> and Cl<sup>-</sup> ions. Both have a coordination number 8.

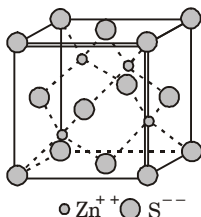


**Fig. 7.** Cesium chloride structure.

2. Approximately they have same cation and anion radius.

**iii. Zinc Blend Structure :**

1. (Fig. 8) shows the arrangement of  $\text{Zn}^{++}$  and  $\text{S}^{--}$  as they are tetrahedrally coordinated.
2. This structure shows that Zn and S both have same coordination number 4.
3. ZnS and SiC etc., shows the same structure.



**Fig. 8.** Zinc blend structure.

- b. What do you understand by composite materials ? Classify them.**

**Ans.** This question is out of syllabus from session 2019-20.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2018-19**  
**MATERIAL SCIENCE**

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**Time : 3 Hours****Max. Marks : 100**

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**Note :** 1. Assume any missing data.

**Section-A**

1. Attempt all questions in brief. (2 × 7 = 14)
- a. Define recrystallization temperature.
  - b. Define 'critical cooling rate' in TTT diagram with neat sketch.
  - c. What are refractory materials ? Give some examples.
  - d. Define the term strain hardening.
  - e. Differentiate between toughness and resilience. Also define the endurance limit.
  - f. Why hardening is followed by tempering ?
  - g. What are Bravais space lattices ?

**Section-B**

2. Attempt any three parts of the following : (7 × 3 = 21)
- a. Define the term diffusion. Explain Fick's law in case of steady state diffusion.
  - b. What is non-destructive testing (NDT) ? Explain in detail any two NDT methods.
  - c. What is phase diagram ? Draw a neat sketch of iron carbon diagram and explain the various phases present in it and the important reactions occurring.

- d. What do you mean by heat treatment process ? Name various types of hardening processes and explain in detail nitriding process with its merits and demerits.
- e. What are ceramics ? What are different types of ceramics ? Also write their properties.

### Section-C

3. Attempt any **one** part of the following : (7 × 1 = 7)
- a. How many atoms per square millimeter are there on the (100) plane of lead ? Lead has FCC structure. Assume the interatomic distance to be 3.499 Å.
- b. NaCl structure has FCC structure. The density of NaCl is 2.18 cm<sup>3</sup>. Calculate the distance between two adjacent atoms.
4. Attempt any **one** part of the following : (7 × 1 = 7)
- a. What is a dislocation? What are different types of dislocation ? Explain and draw their neat sketches and mark burger vector in each case.
- b. Explain the term creep, its mechanism and stages.
5. Attempt any **one** part of the following : (7 × 1 = 7)
- a. Write short note on solid solution and its types.
- b. What do you understand by lever rule ? Determine the mass fraction of the phases present at 184 °C in a sample of lead and tin with 45 % tin in it.
6. Attempt any **one** part of the following : (7 × 1 = 7)
- a. Draw and explain the TTT diagram for eutectoid steel. Explain important transformations taking place in it on cooling.
- b. What are brasses and bronzes ? How are they classified ? Give the composition, properties, microstructure and applications of any two of each.
7. Attempt any **one** part of the following : (7 × 1 = 7)
- a. What are various methods of plastic processing ?
- b. Explain in detail classification and applications of composite materials.



## SOLUTION OF PAPER (2018-19)

**Note :** 1. Assume any missing data.

### Section-A

1. Attempt **all** questions in brief.

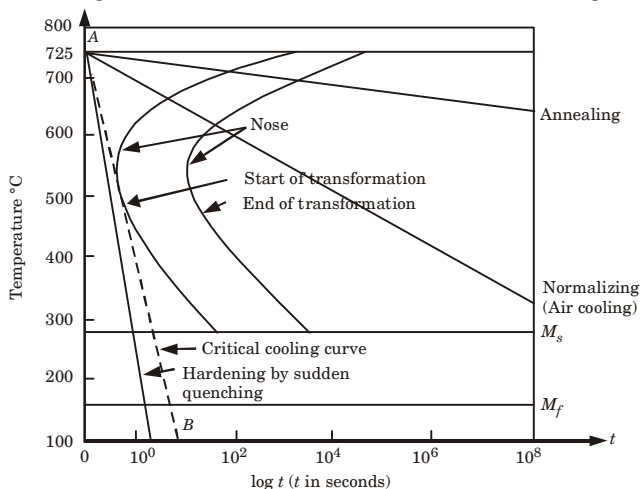
(2 × 7 = 14)

**a. Define recrystallization temperature.**

**Ans.** For particular alloy, the minimum temperature at which complete recrystallization will occur within approximately one hour is called recrystallization temperature.

**b. Define 'critical cooling rate' in TTT diagram with neat sketch.**

**Ans.** In TTT diagram, the nose of the curve indicates the least time taken for a particular transformation. The slope of the line passes through this nose (C-curve) is known as critical cooling rate.



**Fig. 1. TTT diagram.**

**c. What are refractory materials ? Give some examples.**

**Ans. Refractory Material :** These are the heat resistant material that can withstand high temperatures, possess sufficient mechanical strength, heat resistance and retain a constant volume.

**Examples :** Graphite, thoria, zirconia, fireclay bricks.

**d. Define the term strain hardening.**

**Ans.** Strain hardening is defined as the strengthening of a metal or polymer by plastic deformation.

**e Differentiate between toughness and resilience. Also define the endurance limit.**

**Ans.** Difference between Toughness and Resilience :

S. No.	Toughness	Resilience
1.	It is defined as the ability of the solid material to absorb energy until fracture occurs.	It is defined as the ability of the solid material to absorb energy when it is elastically deformed.
2.	Toughness is important consideration for metal forming processes.	Resilience is important property to consider when high elastic deformation is desired, such as in spring.

**Endurance Limit :** The value of limiting stress below which a load may be applied repeatedly for an indefinitely large number of times.

**f. Why hardening is followed by tempering ?**

**Ans.** The parts obtained after hardening can not be used directly because of their high stress state which may cause deformation and cracking when placed or used at room temperature, that's why tempering is used after hardening.

**g. What are Bravais space lattices ?**

**Ans.** This question is out of syllabus from session 2020-21.

### Section-B

2. Attempt any **three** parts of the following : (7 × 3 = 21)

**a. Define the term diffusion. Explain Fick's law in case of steady state diffusion.**

**Ans.** This question is out of syllabus from session 2020-21.

**b. What is non-destructive testing (NDT) ? Explain in detail any two NDT methods.**

**Ans.**

**A. NDT :**

1. It refers to a method of detecting internal flaws in engineering materials without breaking them.
2. It can also be defined as, "The use of non-invasive technique to determine the integrity of a material component or structure or quantitatively measuring some characteristics of an object."

**B. NDT Methods :****i. Penetrant Testing :**

1. In this method, test specimen is coated with liquid of fluorescent dye solution. Then excess penetrant is removed very carefully and developers are applied.
2. These developers acts as blotter and draws out the trapped penetrant from defect to open surface.
3. These penetrants are now easily visible because of colour contrast between penetrant and developer with fluorescent dyes.
4. Ultraviolet lights are used which make the bleed out penetrant readily seen.

**ii. Magnetic Particle Testing :**

1. This method employs the role of magnetic field which may be produced by any of the magnetizing technique. Then a powdered magnet or liquid magnet called as magnetic ink is spread over the surface to be inspected.
2. Surface or near surface defect cuts the magnetic flux line, which generates a new magnetic pole, at the defect point. This concentrates the iron particles near imperfection or defect giving a clear visualization of defect.

**c. What is phase diagram ? Draw a neat sketch of iron carbon diagram and explain the various phases present in it and the important reactions occurring.****Ans.****A. Phase or Equilibrium Diagrams :**

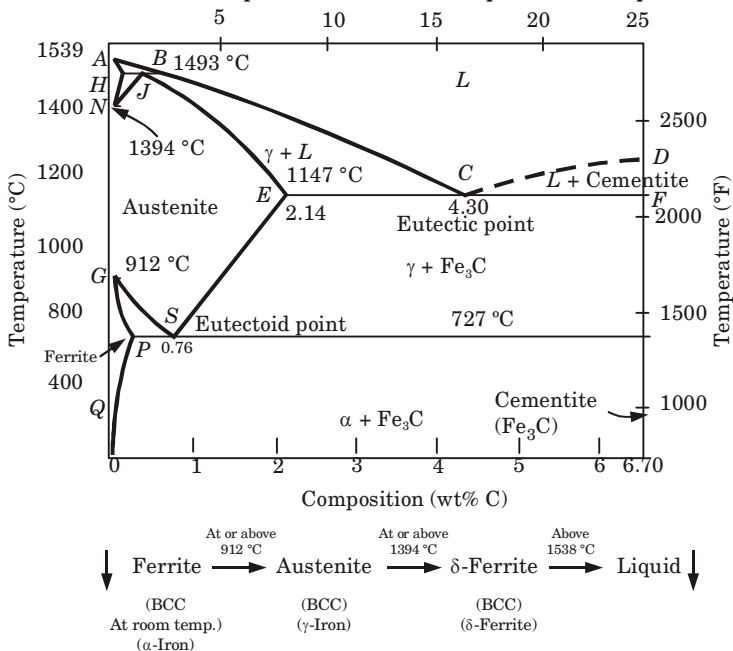
1. The existence of different phases in an alloy system can be represented by a diagram known as phase diagram.
2. In phase diagrams, graphic representations of changes in state due to variations in concentration and temperature enables the phase content of the alloy to be determined at any temperature and composition.
3. They enable the phase transformations to be followed in heating or cooling the alloy under equilibrium conditions, *i.e.*, when all processes in the given system are reversible.
4. All phase diagrams have temperature as the vertical scale (ordinate) and percentage composition by weight as the horizontal scale (abscissa).
5. A phase diagram permits the control and study of metallurgical processes.

**B. Iron-carbon Equilibrium Diagram :**

1. In (Fig. 2), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.
2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.



- At temperature 912 °C, ferrite transforms to austenite ( $\gamma$ -iron).
  - Above the temperature 1394 °C, austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of 1538 °C.
- Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below 727 °C.
  - $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region 727 °C to 1147 °C.
  - Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.

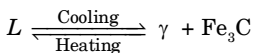


**Fig. 2.** Fe-C phase diagram.

- Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :

**i. Eutectic Point :**

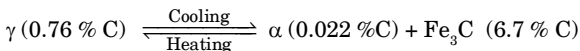
- Eutectic point is shown in the phase diagram indicated as point C.
- At point C, Eutectic composition = 4.3 % carbon (percent by weight)  
Eutectic temperature = 1147 °C
- There is an equilibrium state between liquid state (L) and two solid phases ( $\gamma$  phase and cementite).



**ii. Eutectoid Point :**

- Point S is indicated as eutectoid point.
- At point S, there is an equilibrium state between solid state and two solid phases ( $\alpha$  and cementite).

3. Eutectoid composition = 0.76 % carbon (percent by weight)



- d. What do you mean by heat treatment process ? Name various types of hardening processes and explain in detail nitriding process with its merits and demerits.

**Ans.**

**A. Heat Treatment Process :**

1. Heat treatment may be defined as an operation involving the heating of solid metals to definite temperatures, followed by cooling at suitable rates in order to obtain certain physical properties which are associated with changes in the nature, form size and distribution of the micro-constituents.
2. Heat treatment is a very important process in the various fabrication and manufacturing operations.

**B. Types of Hardening Process :** Types of hardening process are as follows :

1. Martempering or Stepped Quenching.
2. Austempering or Isothermal Quenching.

**C. Nitriding :**

1. This process is used to form a hard surface of nitride on the surface of metal (or steel). This is also, surface hardening process like carburizing.
2. This process consists of :
  - i. Heating of specimen below the lower critical temperature approximately up to 600 °C.
  - ii. Soaking is done in the atmosphere of ammonia (NH<sub>3</sub>). The nitrogen from NH<sub>3</sub> penetrates into the surface of steel to form very hard nitride surface.
3. Nitriding improves corrosion resistance and provides hard surface after this process, there is no need of any heat treatment process.

**i. Merits :**

1. Fatigue strength is increased during nitriding by 30 to 100 %.
2. Resistance against abrasive and adhesive wear is good.
3. Surface is hard and tough combined with good wear resistance.

**ii. Demerits :**

1. Skilled personnel are required.
2. Relatively high equipment cost.
3. Oxidation due to prolonged heating time.

- e. What are ceramics ? What are different types of ceramics ? Also write their properties.

**Ans.**

**A. Ceramics :**

1. Ceramics are the compound of metallic and non-metallic elements for which the interatomic bonding is predominantly ionic.

2. The desirable properties of these materials are normally achieved through a high temperature heat treatment process called firing.
- B. Types of Ceramics with their Properties :** Table 1 shows the ceramics with their properties.

**Table 1.**

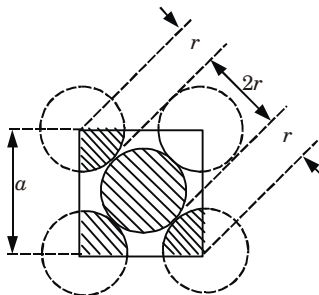
S. No.	Ceramics	Properties
1.	Cement	Chemically active, non-organic, non-metallic
2.	Lime	A kind of ceramic, non-organic, non-metallic
3.	Mud	Clay mixed with water
4.	Gravel	Obtained by crushing the stone
5.	Terracotta	Baked earthenware
6.	Asbestos and glass wool	Non-metals
7.	Porcelain	Acid proof
8.	Plaster of Paris (POP)	Non-metal, ceramic non-organic

**Section-C**

3. Attempt any **one** part of the following : (7 × 1 = 7)
- a. **How many atoms per square millimeter are there on the (100) plane of lead ? Lead has FCC structure. Assume the interatomic distance to be 3.499 Å.**

**Ans.****Given :** Interatomic distance = 3.499 Å.**To Find :** Atoms per square millimeter on (100) planes of lead.

1. As we know, the structure of lead is FCC (Fig. 3.)

**Fig. 3.** Atomic concentration in an FCC lattice.

2. The given interatomic distance = 3.499 Å

$$\therefore 2r = 3.499 \text{ Å}$$

3. If  $a$  is the side of the square,

$$\sqrt{2a^2} = 4r \quad (\text{length of the diagonal})$$

$$\therefore a = \frac{4r}{\sqrt{2}} = \frac{2 \times 3.499}{\sqrt{2}} = 4.95 \text{ Å}$$

$$\text{Area of (100) plane} = (4.95 \times 10^{-7})^2 \text{ mm}^2$$

4. No. of atoms in the plane = 2

$$\begin{aligned} \text{Atoms/mm}^2 &= \frac{2}{(4.95 \times 10^{-7})^2} \\ &= 8.16 \times 10^{12} \text{ atoms/mm}^2 \end{aligned}$$

- b. NaCl structure has FCC structure. The density of NaCl is 2.18 cm<sup>3</sup>. Calculate the distance between two adjacent atoms.**

**Ans.**

**Given :** Density of NaCl = 2.18 cm<sup>3</sup>.

**To Find :** The distance between two adjacent atoms.

1. Number of effective atoms per unit cell in FCC structure = 4  
2. Molecular weight of NaCl = Atomic weight of Na + Atomic weight of Cl

$$= 23 + 35.5 = 58.5 \text{ gm}$$

3. As 58.5 gm of NaCl contains  $6.023 \times 10^{23}$  molecules of NaCl.

$$\therefore \text{Weight of } 6.023 \times 10^{23} \text{ molecules} = 58.5 \text{ gm}$$

$$\text{Therefore weight of 4 molecules} = \frac{58.5 \times 4}{6.023 \times 10^{23}} \text{ gm}$$

This is the weight of unit cell whose volume is  $a^3$ .

4. We know that,  $\rho = \frac{M}{V}$

$$\frac{58.5 \times 4}{6.023 \times 10^{23} \times a^3} = 2.18 \text{ gm/cm}^3$$

$$\therefore a^3 = \frac{58.5 \times 4}{6.023 \times 10^{23} \times 2.18}$$

$$a = 5.63 \times 10^{-8} \text{ cm} \quad (\because 1 \text{ Å} = 10^{-8} \text{ cm})$$

$$\text{or, } a = 5.63 \text{ Å}$$

5. The lattice constant ' $a$ ' is the unit cell dimension. In crystals of NaCl, it is twice the distance between adjacent atoms.

$$\therefore \text{Distance between two adjacent atoms} = \frac{5.63}{2} = 2.82 \text{ Å}$$

4. Attempt any **one** part of the following :

(7 × 1 = 7)

- a. What is a dislocation? What are different types of dislocation? Explain and draw their neat sketches and mark burger vector in each case.

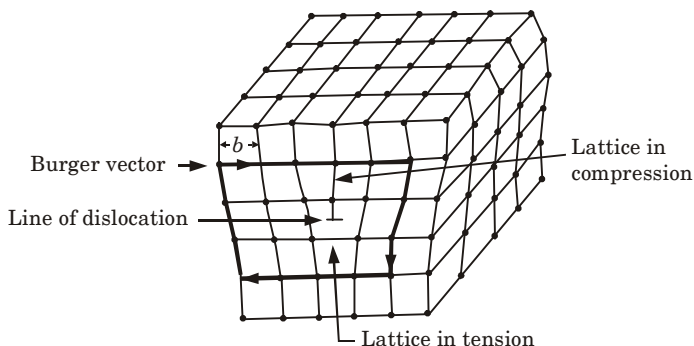
**Ans.**

**A. Dislocation :** A linear disturbance of the atomic arrangement which can very easily occur on the slip plane through the crystal is known as dislocation.

**B. Types of Dislocation :**

**i. Edge Dislocation :**

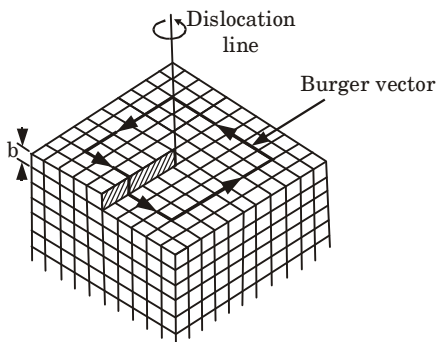
1. An edge dislocation is formed by adding an extra partial plane of atoms to the crystal.
2. (Fig. 4) shows the introduction of an extra half plane in a perfect crystal, resulting in an edge dislocation.
3. The position of the dislocation line is marked by the symbols  $\perp$  and  $\top$  indicating the involvement of extra planes from the top (positive sign) and bottom (negative sign) of the crystal, respectively.
4. The vertical line of the symbol  $\perp$  points in the direction of the dislocation line in the extra partial plane.
5. Near the dislocation, the crystal is distorted due to the presence of zones of compression and tension in the crystal lattice.
6. The dislocation line is a region of higher energy than the rest of the crystal.
7. The lattice above the dislocation line is in a state of compression, whereas below this line, the lattice is in tension.



**Fig. 4.** Edge dislocation with burger vector.

**ii. Screw Dislocation :**

1. The formation of a screw dislocation is shown in (Fig. 5).
2. The geometry of the screw dislocation has an interesting effect on the solidification process.
3. A screw dislocation has its displacement or Burger vector parallel to the linear defect but there is a distortion of the plane.
4. In this, the atoms are displaced in two separate planes perpendicular to each other and the distortion follows a helical or screw path.



**Fig. 5.** Screw dislocations with burger vector.

5. In this type of dislocation, shear stresses are associated with adjacent atoms and extra energy is involved along the dislocation.
6. A screw dislocation does not exhibit climb motion.
7. Three effects of a screw dislocation are of great importance :
  - i. The force required to form and move a screw dislocation is probably somewhat greater than that required to initiate an edge dislocation.
  - ii. Plastic deformation is possible under low stress, without breaking the continuity of the lattice.
  - iii. Screw dislocation causes distortion of the lattice for a considerable distance from the centre of the line and takes the form of spiral distortion of the planes. Dislocations of both types (combinations of edge of screw) are closely associated with crystallization as well as deformation.

**b. Explain the term creep, its mechanism and stages.**

**Ans.** This question is out of syllabus from session 2019-20.

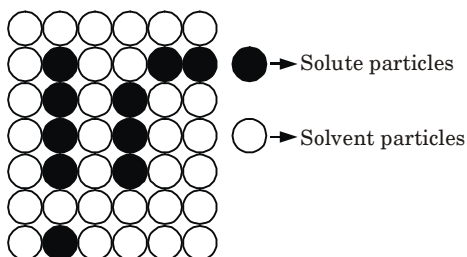
5. Attempt any **one** part of the following : (7 × 1 = 7)

**a. Write short note on solid solution and its types.**

**Ans.**

**A. Solid Solutions :**

1. A solid solution is a solid state solution of one or more solutes in a solvent.
2. Such a mixture is considered as a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes, and when the mixture remains in a single homogeneous phase.
3. Solid solutions form readily when solvent and solute atoms have similar sizes and electron structures, so that it is chemically homogeneous and the component atoms of the elements cannot be distinguished physically or separated mechanically.
4. There is a homogeneous distribution of two or more constituents in the solid state so as to form a single phase or solid solution.

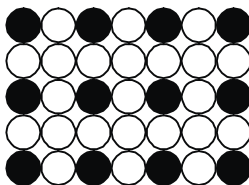


**Fig. 6.** Solid solutions.

**B. Types of Solid Solutions :** These are of following two types :

**i. Substitutional Solid Solution :**

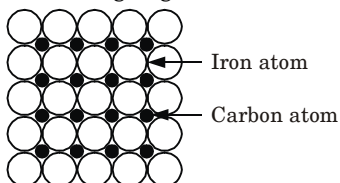
1. A solute atom may occupy two alternative positions in the lattice of solvent (matrix) metal.
2. If the two atoms are of comparable size, the solute atom will substitute at random for one of the matrix atoms in the crystal lattice. This kind of structure is called a substitutional solid solution.
3. For example, brass is an alloy of copper and zinc which forms solid solutions most readily as the atoms of these elements have similar sizes and electron structure.
4. Substitutional solid solutions are of two types :
  - i. Random substitutional solid solutions, and
  - ii. Ordered substitutional solid solutions.



**Fig. 7.** Substitutional solid solutions.

**ii. Interstitial Solid Solutions :**

1. There are few relatively small atoms that can be accommodated in the intersites between solvent atoms to form an interstitial solid solution.
2. Carbon in iron is the example of such a type of solution which is the basis of steel hardening (Fig. 8).



**Fig. 8.** Interstitial solid solutions.

3. Interstitial solid solutions normally have very limited solubility and are generally considered of secondary importance.

4. In some alloys, both interstitial and substitutional solid solutions are formed to an appreciable extent.
- b. What do you understand by lever rule ? Determine the mass fraction of the phases present at  $184^\circ\text{C}$  in a sample of lead and tin with 45 % tin in it.**

**Ans.**

**A. Lever Rule :**

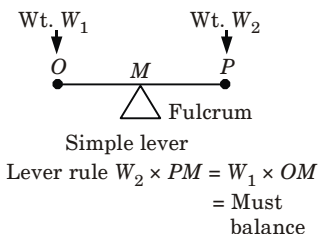
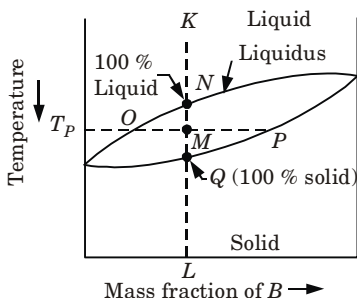
1. The lever rule is a tool used to determine weight percentages of each phase of a binary equilibrium phase diagram.
2. It is used to determine the percent weight of liquid and solid phases for a given binary composition and temperature that is between the liquidus and solidus line.
3. To determine the relative amounts of two phases, an ordinate or vertical line is erected at a point on the composition scale which gives the total composition of the alloy.
4. The intersection of this ordinate with the given isothermal line is the fulcrum of a simple lever system.
5. The ordinate  $KL$  intersects the temperature line at a point  $M$ .
6. The relative lengths of lever arms  $OM$  and  $MP$  multiplied by the amount of phases present must balance.
7. The length  $MP$  shows the amount of liquid, whereas the length  $OM$  indicates the amount of solid. Therefore,

$$\text{The percentage of solid present} = \frac{OM}{OP} \times 100$$

$$\text{The percentage of liquid present} = \frac{MP}{OP} \times 100$$

Where,  $OM + MP = OP = \text{Total composition of alloy between liquidus and solidus, say at } T_p$ .

8. The isothermal (line  $OMP$ ) can be considered a tie line since it joins the composition of two phases in equilibrium at a specific temperature  $T_p$ .



**Fig. 9.** The phase diagram used for deriving the lever rule.



**B. Numerical :****Given :** Sn = 45 %,  $T = 184^\circ\text{C}$ .**To Find :** Mass fraction of phases.

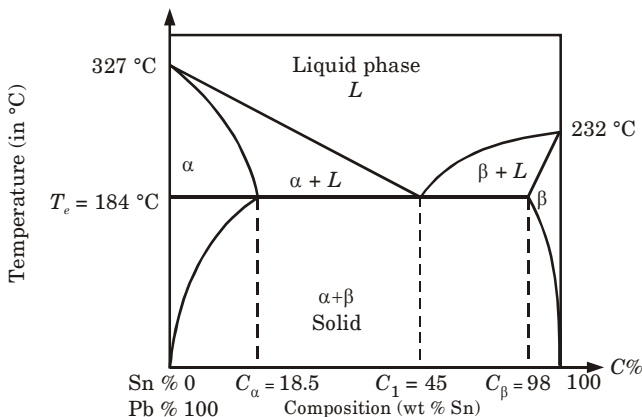
1. From lead-tin phase diagram,

$$C_\alpha = 18.5, C_\beta = 98, C_1 = 45$$

2. Mass fractions in terms of weight percentage tin,

$$W_\alpha = \frac{C_\beta - C_1}{C_\beta - C_\alpha} = \frac{98 - 45}{98 - 18.5} = 0.667$$

$$W_\beta = \frac{C_1 - C_\alpha}{C_\beta - C_\alpha} = \frac{45 - 18.5}{98 - 18.5} = 0.333$$

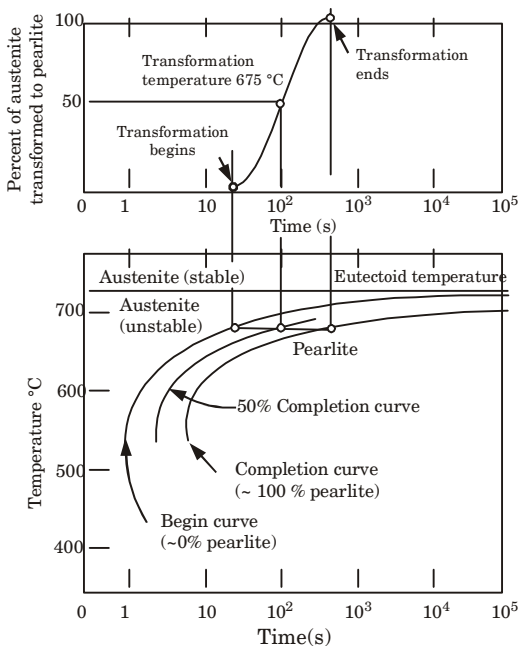
**Fig. 10.** The lead-tin phase diagram.

6. Attempt any **one** part of the following : (7 × 1 = 7)
- a. **Draw and explain the TTT diagram for eutectoid steel. Explain important transformations taking place in it on cooling.**

**Ans.**

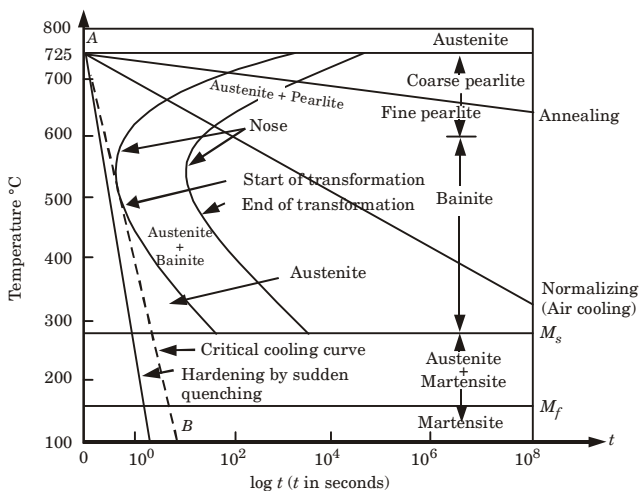
1. Temperature-Time-Transformation diagram represents a relation between starting and ending of the formation of different microstructures.
2. Its shape is same as the English alphabet 'C' so it is known as C-curve.
3. The nose of this curve indicates the least time taken for a particular transformation.
4. The line passes through the nose (or tangent at the nose of C-curve) is known as critical cooling curve and its slope is termed as critical cooling rate.

5. In the (Fig. 11) transformation of austenite to pearlite is shown. The left most C-curve shows the starting of transformation of austenite into pearlite.
6. At this curve 0 % pearlite, 100 % austenite is present. Then the dashed curve represents that 50 % of austenite transforms into pearlite and the right most C-curve represents (completion curve) 100 % pearlite transformation.
7. These curves are accurate only for transformations in which the temperature of alloy is held constant throughout the duration of the reactions.



**Fig. 11.** TTT diagram.

8. Thus these plots are also known as isothermal transformation diagrams or TTT diagrams.
9. Depending upon different cooling rate various microstructures can be obtained like pearlite (coarse or fine), bainite, austenite + martensite and martensite.
10. When cooling rate is slow, we get line pearlite which is done by annealing.
11. In normalizing the cooling rate is high by which we get bainite structure.
12. A complete feature of TTT diagram to show its different phase is shown in (Fig. 12).



**Fig. 12.** The TTT curve showing temperature and log (time) variation for an eutectoid steel, and its different phases.

- b. What are brasses and bronzes ? How are they classified ? Give the composition, properties, microstructure and applications of any two of each.**

**Ans.**

**I. Brasses (Cu – Zn Alloys) :**

1. Brass is an alloy of copper and zinc. In brasses Cu and Zn proportions vary and gives rise of various types of brasses and improve its properties.
  2. Good property brasses can be achieved by adding a small amount of alloying elements. As addition of lead alloy by 1 to 1.5 % improves its strength and machining property but reduces its thermal and electrical conductivity.
  3. The important quality of brass is its corrosion resistant property towards exposure of environment. Thus brasses are used for electroplating of metals. They have good fabrication properties.
- A. Classification :** These alloys are classified on the basis of their alloying elements. For example :

Family	Principal Alloying Element
Yellow brass	Zn
Leaded brass	Pb
Nickel brass	Ni

**B. Properties, Application and Microstructure Composition of Two Type of Brass :****a. Yellow Brass (Muntz Metal) :****i. Properties :**

1. It has high fatigue limit and good yield strength.
2. It has excellent machinability.

**ii. Application :** It is used for hot working processes like rolling, extrusion and stamping etc.

**iii. Microstructure Composition :** Its composition is 60 % Cu + 40 % Zn.

**b. Leaded Brass :****i. Properties :**

1. It has excellent corrosion resistant property.
2. It has good strength.

**ii. Application :** It is used for making of plates and tubes etc.

**iii. Microstructure Composition :** Its composition is 62.5 % Cu + 36 % Zn + 1.5 % Pb.

**II. Bronze (Copper-Tin Alloy) :**

1. Bronzes are the alloys of copper and tin. The composition of bronzes generally 75 to 95 % copper and 5 to 25 % tin.
2. Bronzes are hard and resistant to surface wear. Corrosion resistant properties of bronzes are comparatively better than brasses.

**A. Classification :** They are classified on the basis of constituent in its alloying element. For example :

Family	Principal Alloying Element
Phosphor bronze	Phosphorous (P)
Aluminium bronze	Aluminium (Al)
Silicon bronze	Silicon (Si)

**B. Properties, Application and Microstructure Composition of Two Type of Bronze :****a. Phosphor Bronze :****i. Properties :**

1. Bronzes containing phosphorus are called phosphor bronze.
2. Due to presence of phosphorus its strength and ductility increases.
3. There is a very large change occur in the strength as it changes from 280 MPa to 2300 MPa during rolling or drawing operation.
4. It has good wearing quality and corrosion resistant property to salt water.

**ii. Application :** It is specially used for bearings, worm wheels and gears. Its other uses are in making of nuts, linings and springs etc.

**iii. Microstructure Composition :** Its composition is 87-90 % Cu, 9-10 % Sn and 1-3 % P.

**b. Silicon Bronze :****i. Properties :**

1. Silicon Bronze is a high strength engineering alloy.
2. It can be easily cast, rolled, forged, stamped and pressed in both hot and cold working processes.

**ii. Application :** It is used for making boilers, tanks, stoves etc.

**iii. Microstructure Composition :** Its composition is 96 % Cu, 3 % Si and 1 % Mg or Zn.

7. Attempt any **one** part of the following : (7 × 1 = 7)

**a. What are various methods of plastic processing ?**

**Ans.** This question is out of syllabus from session 2019-20.

**b. Explain in detail classification and applications of composite materials.**

**Ans.** This question is out of syllabus from session 2019-20.



**B. Tech.**  
**(SEM. III) ODD SEMESTER THEORY**  
**EXAMINATION, 2019-20**  
**MATERIAL ENGINEERING**

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**Time : 3 Hours****Max. Marks : 100**

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**Note :** Attempt **all** Section. If require any missing data; then choose suitably.

**Section-A**

1. Attempt **all** questions in brief. (2 × 10 = 20)
- a. What is unit cell ?
- b. Draw the planes for given miller indices (111) and (101).
- c. What is the difference between ductile and brittle fractures ?
- d. Differentiate between NDT and destructive testing.
- e. What is Gibb's phase rule ?
- f. What is invariant reaction? Write eutectic reaction.
- g. What is the difference between annealing and normalizing ?
- h. Enlist the quenching medium in descending order of their cooling rate.
- i. What are the different constituents present in HSS and why ?
- j. What are the uses of copper and aluminum ? Enlist them.

**Section-B**

2. Attempt any **three** of the following : (10 × 3 = 30)
- a. What are the different types of imperfections present in the crystal ? Explain them.
- b. What is factor of safety and what is its importance ? Also explain the Tresca and Von-Mises failure theory.

- c. What is solid solution? What is the difference between interstitial and substitutional solid solutions ?
- d. Why we prefer tempering after hardening ? Explain in details.
- e. What is cast iron ? What are the different types of cast iron ? Explain them with proper applications.

### Section-C

- 3. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Define atomic packing factor and determine the atomic packing factor for FCC and BCC.
  - b. What is hardness ? Explain Brinell and Vickers hardness testing techniques.
- 4. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Explain the Griffith criteria of brittle fracture.
  - b. What is fatigue limit ? Draw *S-N* curve and explain its importance.
- 5. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Draw Fe-C equilibrium diagram. What are the different informations we get from this diagram ? Explain.
  - b. What is the difference between eutectic and eutectoid phase diagrams ? Explain with suitable example.
- 6. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. Draw TTT diagram. What are the applications of this diagram ? Explain.
  - b. Write short note on : Austempering and martempering.
- 7. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. What is the purpose behind alloying the steels ? What are the different types of steels are available and what are their applications ? Explain.
  - b. Write the composition and application of brass and bronze.



## SOLUTION OF PAPER (2019-20)

**Note :** Attempt **all** Section. If require any missing data; then choose suitably.

### Section-A

1. Attempt **all** questions in brief.

(2 × 10 = 20)

**a. What is unit cell ?**

**Ans.** Unit cell may be defined as 3-D arrangement of small group of atoms.

**b. Draw the planes for given miller indices (111) and (101).**

**Ans.**

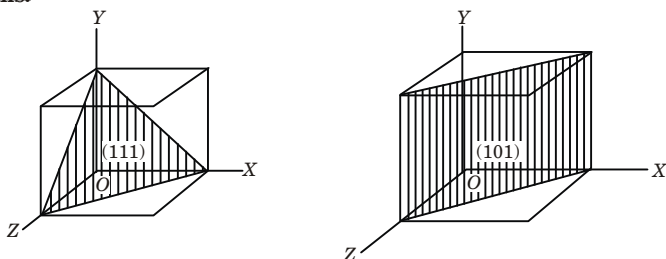


Fig. 1.

**c. What is the difference between ductile and brittle fractures ?**

**Ans.**

S.No.	Brittle Fracture	Ductile Fracture
1.	It occurs with no or little plastic deformation.	It occurs with large plastic deformation.
2.	The rate of propagation of the crack is fast.	The rate of propagation of the crack is slow.
3.	It occurs suddenly without any warning.	It occurs slowly.

**d. Differentiate between NDT and destructive testing.**

**Ans.**

S.No.	Destructive Testing	Non-destructive Testing
1.	It includes measuring various mechanical or chemical properties.	It is used to determine the integrity of a material.
2.	It deals in physical testing.	It is mostly deals in modern technologies.
3.	Equipments are portable.	Equipments are not portable.



**e. What is Gibb's phase rule ?****Ans.**

1. Gibbs phase rule provides the theoretical foundation for characterizing the chemical state of a system, and predicting the equilibrium relations of the phases present as a function of physical conditions such as pressure and temperature.
2. It is expressed mathematically as follows :

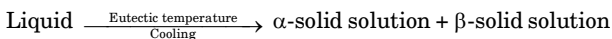
$$P + F = C + n$$

$$P + F = C + 2$$

$$\therefore n = \text{number of external factors} \\ = 2 \text{ (temperature and pressure)}$$

**f. What is invariant reaction? Write eutectic reaction.****Ans.**

1. When liquid of eutectic composition is slowly cooled to the eutectic temperature, the single liquid phase transforms simultaneously into solid forms. This transformation is known as invariant reaction or eutectic reaction.
2. It is given as,

**g. What is the difference between annealing and normalizing ?****Ans.**

S. No.	Annealing	Normalizing
1.	It requires low heating range.	It requires high heating range.
2.	Mechanical properties obtained are better.	Mechanical properties obtained are not as good as in annealing.
3.	Grain size is not so uniform.	Grain size is uniform.

**h. Enlist the quenching medium in descending order of their cooling rate.**

**Ans.** Quenching medium in descending order of their cooling rate are :  
water > oil > forced air

**i. What are the different constituents present in HSS and why ?****Ans.**

1. 18 % tungsten, 4 % chromium and 1 % vanadium with a carbon content of 0.6 to 0.7 % are the main constituents present in HSS. This alloy is termed as 18 : 4 : 1 while an increase of vanadium to 2 % produces 18 : 4 : 2 steels.
2. These constituents are present in HSS to achieve high hardness, high compressive strength and outstanding wear resistance.

**j. What are the uses of copper and aluminum ? Enlist them.**

**Ans. Uses of Copper :**

1. It is used in making electric wires and cables.
2. It is used for winding purposes in making of motors and coils etc.
3. It is used in electrotyping, electroplating industries.

**Uses of Aluminum :**

1. It is used for making overhead cables.
2. It is used for making kitchen cookware or utensils.
3. Due to its light weight it is used in aircraft engineering.

### Section-B

**2. Attempt any three of the following : (10 × 3 = 30)**

**a. What are the different types of imperfections present in the crystal ? Explain them.**

**Ans.** Imperfections in crystals can be classified in following types :

**i. Point Imperfections :**

1. Point defects are where an atom is missing or is in an irregular place in the lattice structure.
2. These defects are completely local in effect.
3. Point imperfections are always present in crystals and their presence results in a decrease in the free energy.
4. The number of defects at equilibrium concentration at a certain temperature can be computed as,

$$n = Ne^{-E_d/kT}$$

Where,  $n$  = Number of imperfections,

$N$  = Number of atomic sites per mole,

$k$  = Boltzmann's constant,

$E_d$  = The free energy required to form the defect, and

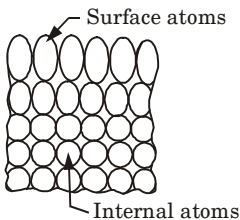
$T$  = Absolute temperature.

**ii. Line Imperfection or Dislocations :**

1. A linear disturbance of the atomic arrangement which can very easily occur on the slip plane through the crystal is known as dislocation.
2. Dislocation is a two-dimensional line defect and is a very important crystal imperfection. It is responsible for the deformation of metals by slip phenomenon.
3. It may also be concluded that it is the region of localized lattice disturbances separating the slipped and unslipped regions of a crystal.
4. These are formed in the process of solidification of metals and mainly in their plastic deformation of strain hardening, yield point, creep and fatigue and brittle fractures.
5. There are two types of dislocation :
  - i. Edge dislocations, and
  - ii. Screw dislocations.
7. These dislocations are responsible for the useful property of ductility in metals, ceramic and polymers.

**iii. Surface and Grain Boundary Imperfections :**

1. These defects are two-dimensional and are due to a change in the stacking of atomic planes on or across a boundary, twin boundary, stacking faults, etc.
2. The external surface of the material is an imperfection itself because the atomic bonds do not extend beyond it.
3. Since these surface atoms are not entirely surrounded by other (Fig. 2), they possess higher energy than internal atoms.

**Fig. 2.**

4. Surface atoms have neighbours on only one side while atoms inside the crystal have neighbour on both sides.

**b. What is factor of safety and what is its importance ? Also explain the Tresca and Von-Mises failure theory.****Ans.**

**A. Factor of Safety :** It is the ratio of ultimate stress to the working stress.

**B. Importance :** It increases the safety and reduces the risk of failure of a product.

**C. Tresca Theory :**

1. Tresca states that failure of a material (or plastic deformation) will occur when the maximum shear stress in a material reaches the value of maximum shear stress at elastic limit.
2. Let principal stresses at a point in the material are  $\sigma_1$ ,  $\sigma_2$  and  $\sigma_3$  ( $\sigma_1 > \sigma_2 > \sigma_3$ ). So maximum shear stress is given by,

$$\frac{\sigma_1 - \sigma_3}{2} = \tau_{\max}$$

3. Plastic deformation occurs when  $\tau_{\max}$  is equal to  $K$  ( $K$  = Maximum shear stress at elastic limit or shear yield stress). So according to Tresca's theory for plastic deformation,

$$\frac{\sigma_1 - \sigma_3}{2} = K \quad \dots(1)$$

4. For uniaxial tension condition,

$$\begin{aligned} \sigma_1 &= \sigma_y \\ \sigma_2 &= \sigma_3 = 0 \end{aligned} \quad \text{(Tensile yield stress)}$$

5. For uniaxial compression condition,

$$\begin{aligned} \sigma_1 &= \sigma_2 = 0 \\ \sigma_3 &= -\sigma_y \end{aligned} \quad \text{(Compressive yield stress)}$$

6. For uniaxial tension condition, putting the value of  $\sigma_1$  and  $\sigma_3$  in eq. (1), we get

$$\frac{\sigma_y - (0)}{2} = K$$

$$K = \frac{\sigma_y}{2}$$

7. For uniaxial compression condition, putting the value of  $\sigma_1$  and  $\sigma_3$  in eq. (1), we get

$$\frac{0 - (-\sigma_y)}{2} = K$$

$$K = \frac{\sigma_y}{2}$$

#### D. Von-Mises Theory :

1. Mises states that failure (plastic deformation) of a material will occur when the total shear strain energy per unit volume in strained material reaches a value equal to the shear strain energy per unit volume at the elastic limit.
2. Energy of distortion is given as,

$$U = \frac{1}{12G} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] \quad \dots(2)$$

Here  $U$  is the shear strain energy per unit volume,  $\sigma_1$ ,  $\sigma_2$  and  $\sigma_3$  are the principal stresses,  $G$  is the shear modulus.

3. So,  $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 12G \times U = C \quad \dots(3)$   
Where,  $C = \text{Constant}$ .

4. For uniaxial tensile loading  $\sigma_1 = \sigma_y$ ,  $\sigma_2 = \sigma_3 = 0$

Putting the value in eq. (3), we get

$$(\sigma_y - 0)^2 + (0 - 0)^2 + (0 - \sigma_y)^2 = C$$

$$2\sigma_y^2 = C \quad \dots(4)$$

5. Considering yielding under pure torsion,

For pure shear :  $\sigma_1 = K$ ,  $\sigma_2 = 0$ ,  $\sigma_3 = -K$

Putting these values in eq. (3), we get

$$(K - 0)^2 + (0 - (-K))^2 + (-K - K)^2 = C$$

$$6K^2 = C \quad \dots(5)$$

6. Equating the eq. (4) and eq. (5), we get

$$2\sigma_y^2 = 6K^2$$

$$K = \frac{\sigma_y}{\sqrt{3}}$$

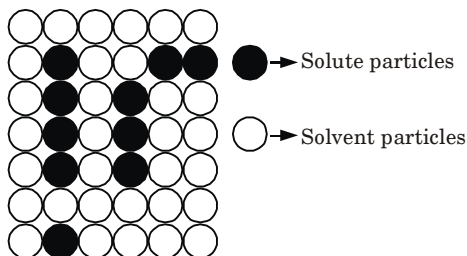
- c. What is solid solution? What is the difference between interstitial and substitutional solid solutions ?

**Ans.**

#### A. Solid Solutions :

1. A solid solution is a solid state solution of one or more solutes in a solvent.

2. Such a mixture is considered as a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes, and when the mixture remains in a single homogeneous phase.



**Fig. 3.** Solid solutions.

3. Solid solutions form readily when solvent and solute atoms have similar sizes and electron structures, so that it is chemically homogeneous and the component atoms of the elements cannot be distinguished physically or separated mechanically.
4. There is a homogeneous distribution of two or more constituents in the solid state so as to form a single phase or solid solution.

**B. Difference Between Substitutional and Interstitial Solid Solution :**

S. No.	Substitutional Solid Solution	Interstitial Solid Solution
1.	Solid-state solutions that form when the solute atoms replace the solvent atoms.	Solid-state solutions that form when solute atoms enter into the holes between solvent atoms of the lattice.
2.	Form only if the solute atoms are large enough to replace the solvent atoms in the lattice.	Form only if the solute atoms are small enough to enter the holes of the lattice.
3.	The solute atoms enter the solvent lattice substitutionally.	The solute atoms enter the solvent lattice interstitially.
4.	The atomic size of the solutes is nearly similar to the size of solvent atoms.	The atomic size of solute atoms should be about 40 % of the size of solvent atoms.
5.	<b>Examples :</b> Cu-Au system, Ag-Au system, etc.	<b>Examples :</b> H, Li, Na and B.

**d. Why we prefer tempering after hardening ? Explain in details.**

**Ans.**

1. Hardening of steel is a process in which the structure of steel is converted from austenite at a higher temperature to martensite at a lower temperature.
2. Martensite at the lower temperature is hard, strong and brittle, being a meta-stable phase in the Fe-C phase diagram.
3. Unless the meta-stable martensite is tempered at a slightly higher temperature for some time, the purpose of hardening the structure of steel gets defeated as the alloy may fail like papad (brittle substance).
4. On tempering the hard martensite, the structure of steel acquires some ductility while retaining its strength and durability of the steel.
5. Hence, we prefer tempering after hardening.

**e. What is cast iron ? What are the different types of cast iron ? Explain them with proper applications.**

**Ans.**

**A. Cast Iron :**

1. Cast iron is very useful engineering material. It contains more carbon percentage (approximately  $2\% < C < 4.5\%$ ).
2. When pig iron is melted with coke and limestone in cupola furnace, it produces cast iron.
3. Coke acts as a fuel and limestone acts as flux.
4. Fluxes are used to separate the impurities from the pig iron (like oxides and fuel ash etc.).

**B. Types of Cast Iron and their Application :**

**a. Grey Cast Iron :**

**i. Composition :**

Element	Percentage (%)
Carbon	2.5 – 4.0 %
Silicon	1.0 – 3.0 %
Manganese	0.25 – 1.0 %
Sulphur	0.02 – 0.25 %
Phosphorus	0.05 – 1.0 %

**ii. Application :**

1. Engine cylinder block.
2. Flywheel, gear box cases etc.

**b. Malleable Cast Iron :****i. Composition :**

Element	Percentage (%)
Carbon	2.00 – 2.60 %
Silicon	1.10–1.60 %
Manganese	0.20–1.00 %
Sulphur	0.04–0.18 %
Phosphorus	0.18 % (max.)

**ii. Application :** Steering brackets, hubs, crankshafts.**c. Spheroidal Cast Iron (SG Iron) :****i. Composition :**

Element	Percentage (%)
Carbon	3.2 to 4.5 %
Silicon	1.0 to 3.00 %
Manganese	0.1 to 1.00 %
Sulphur	0.3 % (max.)
Phosphorus	0.1 % (max.)

**ii. Application :** Gear, cam shaft and crank shaft.**d. White Cast Iron :****i. Composition :**

Element	Percentage (%)
Carbon	1.8 to 3.6 %
Silicon	0.5 to 1.9 %
Manganese	0.25 to 0.80 %
Sulphur	0.06 to 0.20 %
Phosphorus	0.06 to 0.18 %

**ii. Application :** White cast iron serves as the raw material for malleable cast irons.**Section-C****3. Attempt any one part of the following :****(10 × 1 = 10)**

- a. Define atomic packing factor and determine the atomic packing factor for FCC and BCC.

**Ans.**

**A. Atomic Packing Factor :** It is defined as the fraction of the space occupied by atoms in the unit cell.

**B. Atomic Packing Factor for FCC :**

$$\begin{aligned} \text{PF} &= \frac{\text{Volume occupied by the atoms in a unit cell}}{\text{Unit cell volume}} \\ &= \frac{v}{V} = \frac{4 \times \frac{4}{3} \pi r^3}{a^3} = \frac{16\pi r^3}{3(2\sqrt{2}r)^3} = \frac{16\pi r^3}{3 \times 8 \times 2\sqrt{2} r^3} = \frac{\pi}{3\sqrt{2}} \\ &\quad (\because a = 2\sqrt{2}r) \\ &= 0.74 \text{ or } 74 \% \end{aligned}$$

**C. Atomic Packing Factor for BCC :**

$$\begin{aligned} 1. \text{ Packing factor, } \text{PF} &= \frac{\text{Volume of all atoms in unit cell}}{\text{Volume of unit cell}} = \frac{v}{V} \\ &= \frac{2 \times \frac{4}{3} \pi r^3}{a^3} = \frac{8\pi r^3}{3a^3} = \frac{8\pi r^3 3\sqrt{3}}{3(4r)^3} \\ &\quad \left( \because a = \frac{4}{\sqrt{3}} r \right) \\ &= \frac{\sqrt{3}\pi}{8} = 0.68 \text{ or } 68 \%. \end{aligned}$$

- b. What is hardness ? Explain Brinell and Vickers hardness testing techniques.

**Ans.**

**A. Hardness :**

1. The term hardness is defined as the property of metal by virtue of which it is able to resist abrasion, indentation (or penetration) and scratching by harder bodies.
2. It is measured by the resistance of the metal which it offers.

**B. Brinell Hardness Test :**

1. In this test a standard hardened steel ball of diameter  $D$  is pressed into the surface of the specimen by a gradually applied load  $P$  which is maintained on the specimen for a definite period of time.
2. The impression of the steel ball (indenter) so obtained is measured by a microscope and the Brinell hardness number (BHN) is found by the following relations,

$$\text{BHN} = \frac{\text{Load in kg}}{\text{Area of impression or indentation of steel ball in m}^2}$$



$$= \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \quad \dots(1)$$

Where,

$P$  = Applied load,  $D$  = Diameter of steel ball, and  
 $d$  = Diameter of the impression, measured with a microscope.

3. A Brinell hardness tester is shown in (Fig. 4).
4. In this test, the test sample is placed on the top of the test table which can be raised by the elevating screw so that test sample just touches the ball.
5. The desired load is applied either mechanically or by oil pressure.
6. During this period the steel ball moves to the position of the sample and makes an impression or indentation.
7. The indentation diameter is measured at two places, either on the screen provided with the machine or by coinciding the two points of a reading microscope.
8. The Brinell hardness is determined from the eq. (1) after substituting the values of  $P$ ,  $D$  and  $d$ .

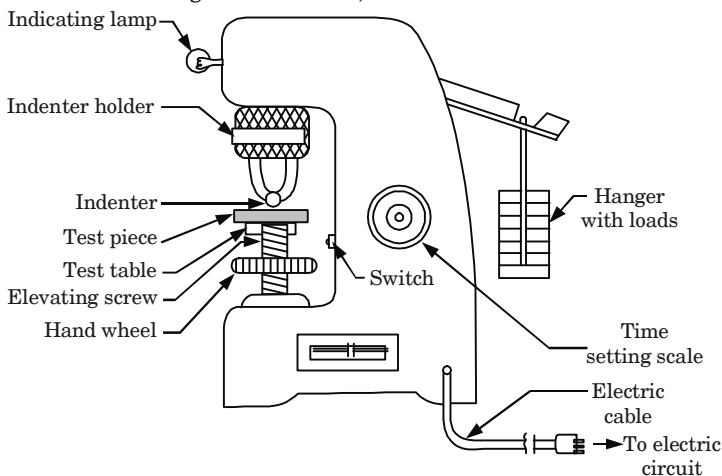


Fig. 4.

### C. Vickers Hardness Test :

1. In this method of hardness testing a square based diamond pyramid is used as indenter.
2. The drawback of the flattening of the steel ball in testing harder materials is eliminated.
3. This method uses the indentation produced by the indenter (diamond pyramid). The indenter gives geometrically similar impressions under different loads from 5 to 120 kg.
4. The value of Vickers hardness can be obtained by the following expression :

$$VPN = DPN = \frac{2 P \sin \theta / 2}{d^2}$$

Where, VPN = Vickers Pyramid Number,  
 DPN = Diamond Pyramid Number,  
 $P$  = Load,  
 $\theta = 136^\circ$  = Angle between opposite face of diamond pyramid, and  
 $d$  = Average length of two diagonals, (mm).

5. This method is used to determine the hardness of very thin and very hard materials. It also facilitates the ease of measurement of a diagonal of the indentation area, as compared to circular dimensions which are difficult to measure exactly.
  6. The values of Brinell and Vickers hardness are practically the same upto 300. Vickers test can be carried out accurately on polished surfaces but does not give accurate results when used for rough surfaces.
4. Attempt any **one** part of the following : (10 × 1 = 10)  
 a. **Explain the Griffith criteria of brittle fracture.**

**Ans.**

1. Griffith has postulated a criterion for the propagation of pre-existing cracks in a brittle material.
2. The crack could come from a number of sources such as a collection of dislocations, a flaw which occurred during solidification, or a surface scratch.
3. As the crack becomes longer, the material on both sides of the crack can no longer store elastic energy because tensile stress cannot be transmitted across the crack. Thus, an increase in crack length causes the release of elastic energy.
4. Griffith postulated that when the elastic energy released by extending a crack was equal to the surface energy required for crack extension, the crack would grow.
5. For an elliptical crack (Fig. 5), the maximum stress at the tips is given by :

$$\sigma_{\max} = 2 \sigma \sqrt{C / R}$$

Where,  $R$  = Radius of curvature at the tip, and  
 $\sigma$  = Applied stress perpendicular to length  $2C$ .

6. The elastic strain energy for unit volume is given by,

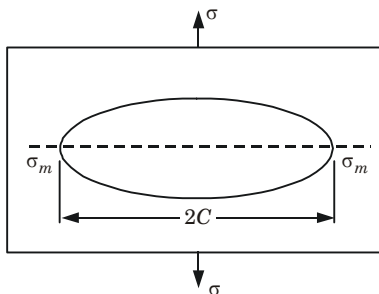
$$\begin{aligned} U_E &= \frac{\sigma^2}{2E} \times \text{Area} \times \text{Width} \\ &= \frac{\sigma^2}{2E} \times \pi 2C \times C = \frac{\sigma^2}{E} \pi C^2 \end{aligned}$$

7. If the surface energy per unit area is  $\gamma$  then the surface energy for a crack of length  $2C$  and unit width will be,

$$U_S = (2 \gamma C) \times 2 = 4 \gamma C$$

We multiply by 2 because there are two faces.

8. Applying Griffith's criterion, if the crack is to propagate, the change in surface energy with crack length must equal to the change in elastic strain energy.



**Fig. 5.** Model for Griffith's fracture theory.

$$\frac{dU_E}{dC} = \frac{dU_S}{dC}$$

$$\frac{d}{dC} \left( \frac{\pi C^2 \sigma^2}{E} \right) = \frac{d}{dC} (4\gamma C)$$

$$\sigma = \sqrt{\left( \frac{4\gamma E}{\pi C} \right)}$$

9. This result shows that the stress necessary to cause fracture varies inversely as the square root of the crack length and so the tensile stress of a completely brittle material will depend on the length of the largest existing crack in the material.
- b. What is fatigue limit ? Draw S-N curve and explain its importance.**

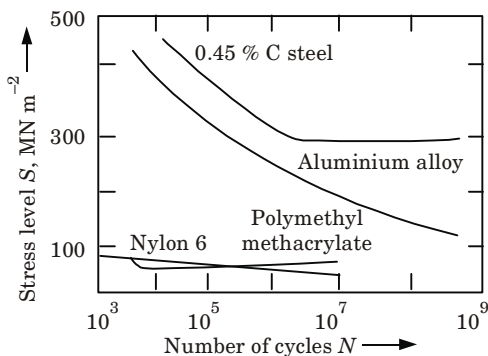
**Ans.**

**A. Fatigue Limit :**

1. Fatigue limit is also known as endurance limit.
2. The endurance limit of a material is defined as the maximum amplitude of completely reversed stress that the standard specimen can sustain for an unlimited number of cycles without fatigue failure.
3. Since the fatigue test cannot be conducted for unlimited or infinite number of cycles,  $10^6$  cycles is considered as a sufficient number of cycles to define the endurance limit.
4. The endurance limit is affected by factors such as the size of the component, shape of component, the surface finish, temperature and the notch sensitivity of the material.
5. Examples of parts in which fatigue failures are common in transmission shafts, connecting rods, gears, vehicle suspension springs and ball bearings.

**B. S-N Curve :**

1. *S-N* curve represents the dependence of the life of the specimen, in number of cycles to failure  $N$ , on the maximum applied stress  $\sigma$ .
2. *S-N* curve is the basic method of presenting engineering fatigue data.
3. Typical *S-N* curves obtained by means of the rotating beam machine are shown in the (Fig. 6).
4. (Fig. 6) shows the number of cycles of stress which a metal can endure before failure increases with decreasing stress.
5. Generally,  $N$  is taken as the number of cycles of stress to cause complete fracture of the specimen. Fatigue tests at low stresses are usually carried out for  $10^7$  cycles and sometimes to  $5 \times 10^8$  cycles for non-ferrous metals.
6. For a few important engineering materials such as steel and titanium, the *S-N* curve becomes horizontal at a certain limiting stress. Below this limiting stress, which is called the fatigue limit, or endurance limit, the material can presumably endure an infinite number of cycles without failure.



**Fig. 6.** The *S-N* curves for different materials.

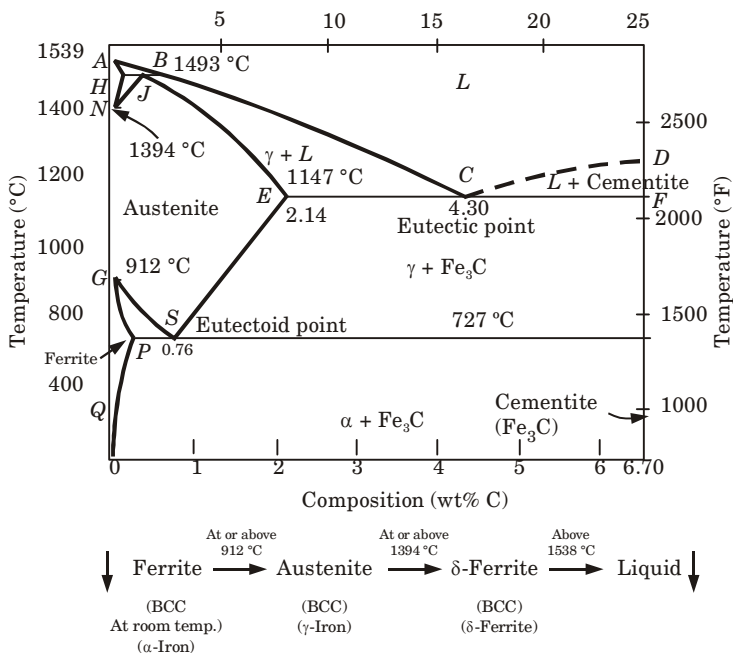
7. Most non-ferrous metals like aluminium, magnesium and copper alloys have *S-N* curve which slopes gradually downward with increasing number of cycles. These materials do not have a true fatigue limit because the *S-N* curve never becomes horizontal.
  8. The *S-N* curve is also known as the Wohler curve.
- C. Importance of S-N Curve :** It is very useful way to visualize time to failure for a specific material.
5. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. **Draw Fe-C equilibrium diagram. What are the different informations we get from this diagram ? Explain.**

**Ans.**

**A. Iron-carbon Equilibrium Diagram :**

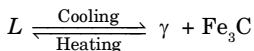
1. In (Fig. 7), Fe-C phase diagram is shown. Carbon is an interstitial impurity in iron and soluble in iron.

2. There are different types of solid phases of iron-carbon solid solution as :
  - a. At room temperature, ferrite ( $\alpha$ -iron) is stable and it has a BCC crystal structure.
  - b. At temperature 912 °C, ferrite transforms to austenite ( $\gamma$ -iron).
  - c. Above the temperature 1394 °C, austenite transforms to a BCC crystal structure  $\delta$ -phase.  $\delta$ -phase has a melting point of 1538 °C.
3. Cementite ( $\text{Fe}_3\text{C}$ ) forms when solubility limit of carbon in  $\alpha$ -ferrite is exceeded below 727 °C.
4.  $\text{Fe}_3\text{C}$  also co-exists with the  $\gamma$ -phase in the region 727 °C to 1147 °C.
5. Cementite is very hard and brittle in nature. Cementite is only a metastable compound and it is not an equilibrium compound.



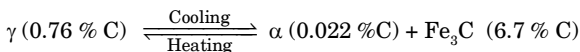
**Fig. 7.** Fe-C phase diagram.

6. Eutectic point and eutectoid point of Fe-C equilibrium diagram are explained as following :
  - i. **Eutectic Point :**
    1. Eutectic point is shown in the phase diagram indicated as point C.
    2. At point C, Eutectic composition = 4.3 % carbon (percent by weight) Eutectic temperature = 1147 °C
    3. There is an equilibrium state between liquid state (L) and two solid phases ( $\gamma$  phase and cementite).



## ii. Eutectoid Point :

1. Point *S* is indicated as eutectoid point.
2. At point *S*, there is an equilibrium state between solid state and two solid phases ( $\alpha$  and cementite).
3. Eutectoid composition = 0.76 % carbon (percent by weight)



## B. Significance :

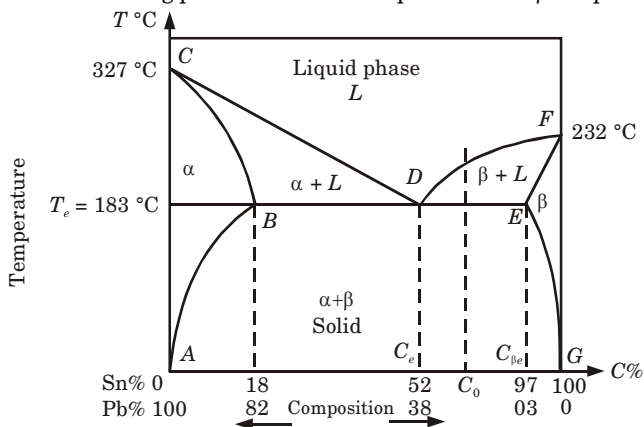
1. From the iron-carbon diagram we know that the value of  $\gamma$ -iron (austenite) compared with that of  $\alpha$ -iron (ferrite) reflects much greater solubility of carbon in  $\gamma$ -iron, with a maximum value of just over 2 wt % at 1147 °C.
2. This high solubility of carbon in  $\gamma$ -iron is of extreme importance in heat treatment, when solution treatment in the  $\gamma$ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed.

## b. What is the difference between eutectic and eutectoid phase diagrams ? Explain with suitable example.

**Ans.**

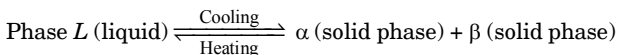
### A. Eutectic Phase Diagram :

1. When the melting points of the two components are not much different and a partial or negligible solid solubility exists between them, the phase diagram is called eutectic phase diagram.
2. In (Fig. 8), we choose lead and tin as there is not much difference in their melting points. The two solid phases  $\alpha$  and  $\beta$  are present.



**Fig. 8.** Binary phase diagram of lead-tin showing phases, eutectic point and eutectic composition.

3. In  $\alpha$ -phase very small amount of tin is dissolved in lead and in  $\beta$ -phase very small amount of lead is dissolved in tin.
4. In  $\alpha + \beta$  phase both tin and lead are dissolved in each other sufficiently.
5. BDE line separates the two phase regions of  $\alpha + L$  and  $\alpha + \beta$ ,  $\alpha + \beta$  and  $L$ ,  $\alpha + \beta$  and  $\beta + L$ . This line is called eutectic line and temperature corresponding to this line is called eutectic temperature.
6. At point  $D$  eutectic reaction occurs as liquid phase is in equilibrium with two solid phases.



7. At point  $D$ ,  
Degree of freedom,

$$D = C - P + 1$$

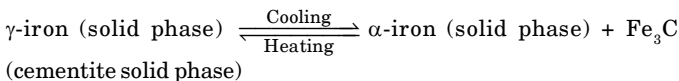
$$C = 2, P = 3$$

$$\text{So, } D = 2 - 3 + 1 = 0$$

8. At point  $D$ , eutectic temperature and eutectic reaction are called invariant temperature and invariant reaction.

### B. Eutectoid Phase Diagram :

1. In eutectoid phase diagram, a solid phase transforms into two other solid phases on cooling and on heating the two solid phases transforms into one solid phase means one solid phase is in equilibrium with two other solid phases.
2. A eutectoid reaction can be seen in iron-carbon equilibrium diagram.
3. Between austenite ( $\gamma$ -iron) and two solid phases of iron as ferrite ( $\alpha$ -iron) and cementite ( $\text{Fe}_3\text{C}$ ) an equilibrium occurs which is called eutectoid reaction.



4. The alloy composition towards left of the eutectoid point is called hypo-eutectoid and towards right of the eutectoid point is called hyper-eutectoid.

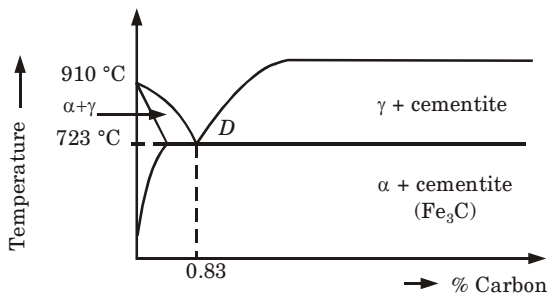


Fig. 9. Eutectoid phase diagram.

5. In the (Fig. 9), point *D* is called eutectoid point. The leftward region is called hypo-eutectoid (carbon percentage less than 0.8 %) and rightward region is called hyper-eutectoid (carbon percentage greater than 0.8 %).

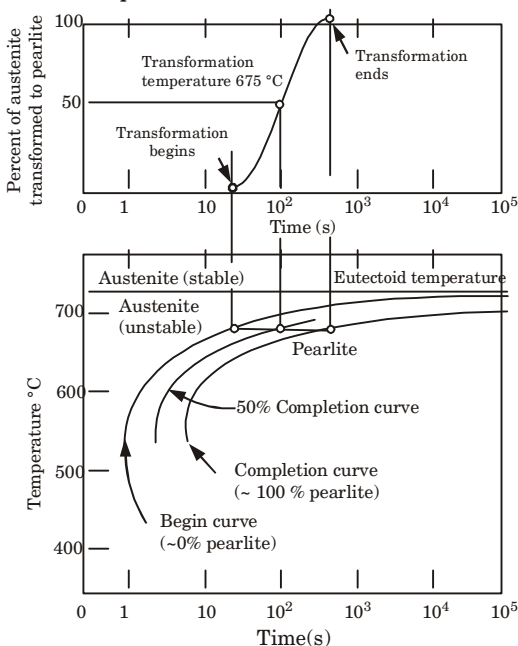
6. Attempt any **one** part of the following : (10 × 1 = 10)

a. **Draw TTT diagram. What are the applications of this diagram ? Explain.**

**Ans.**

**A. TTT-Diagram :**

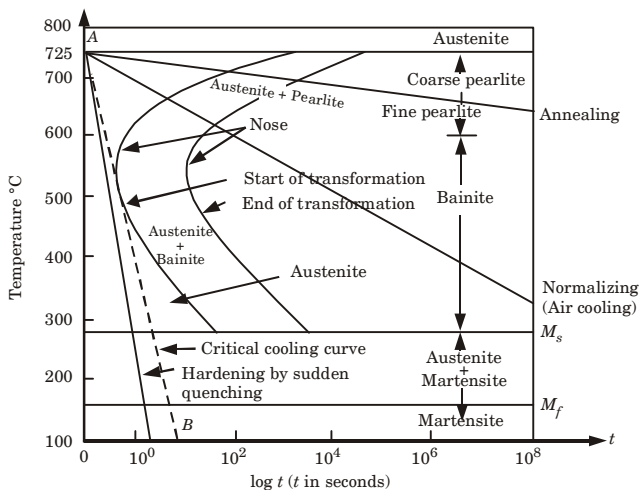
1. Temperature-Time-Transformation diagram represents a relation between starting and ending of the formation of different microstructures.
2. Its shape is same as the English alphabet 'C' so it is known as C-curve.
3. The nose of this curve indicates the least time taken for a particular transformation.
4. The line passes through the nose (or tangent at the nose of C-curve) is known as critical cooling curve and its slope is termed as critical cooling rate.
5. In the (Fig. 10) transformation of austenite to pearlite is shown. The left most C-curve shows the starting of transformation of austenite into pearlite.



**Fig. 10. TTT diagram.**



6. At this curve 0 % pearlite, 100 % austenite is present. Then the dashed curve represents that 50 % of austenite transforms into pearlite and the right most C-curve represents (completion curve) 100 % pearlite transformation.
7. These curves are accurate only for transformations in which the temperature of alloy is held constant throughout the duration of the reactions.
8. Thus these plots are also known as isothermal transformation diagrams or TTT diagrams.
9. Depending upon different cooling rate various microstructures can be obtained like pearlite (coarse or fine), bainite, austenite + martensite and martensite.
10. When cooling rate is slow, we get line pearlite which is done by annealing.
11. In normalizing the cooling rate is high by which we get bainite structure.
12. A complete feature of TTT diagram to show its different phase is shown in (Fig. 11).



**Fig. 11.** The TTT curve showing temperature and log (time) variation for an eutectoid steel, and its different phases.

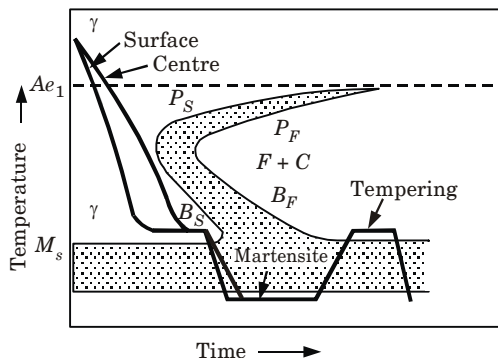
### B. Application of TTT Diagram :

1. It shows the structure that we obtained at different cooling rates.
2. It graphically describes the cooling rate required for the transformation of austenite to pearlite, bainite or martensite.
3. It shows the time required for transformation to various phases.

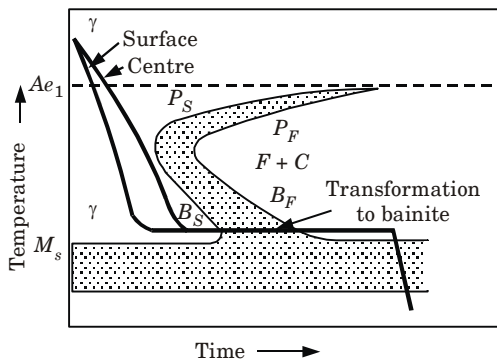
**b. Write short note on : Austempering and martempering.**

**Ans.****i. Martempering or Stepped Quenching :**

1. This is a hardening method that produces martensite. This method is also known as hardening by interrupted quenching.
2. First the steel is heated to the hardening temperature then quenched in a medium (salt bath) having a temperature slightly above the point where martensite starts to form (usually from 150° to 300 °C).
3. It is held until it reaches the temperature of the medium and then cooled further to room temperature in air or oil.
4. The holding time in quenching medium or bath should be sufficient to enable a uniform temperature to be reached throughout the cross section but not long enough to cause austenite decomposition.
5. Austenite is transformed into martensite during the subsequent period of cooling to room temperature.
6. This treatment provides a structure of martensite and retained austenite in the hardened steel.

**Fig. 12.** Heat treatment cycle for martempering.**ii. Austempering or Isothermal Quenching :**

1. It is very similar to martempering. Steel is austenitized and then quenched in a salt bath maintained at a constant temperature in the range of 260 °C to 400 °C.
2. The article is held at this temperature for long enough to allow isothermal transformation to be completed.
3. After the complete transformation of austenite to bainite, steel is cooled to room temperature in air. It is also called isothermal quenching.
4. The temperature of quenching lies below the nose of the TTT curve and above the  $M_s$  temperature.
5. Heat treatment cycle for austempering is shown in (Fig. 13).



**Fig. 13.** Heat treatment cycle for austempering.

6. The principal purpose of austempering is to obtain high impact strength and increased notch toughness at a given high hardness level.
7. Attempt any **one** part of the following : (10 × 1 = 10)
  - a. **What is the purpose behind alloying the steels ? What are the different types of steels are available and what are their applications ? Explain.**

**Ans.**

**A. Purpose of Alloying Elements of Steel :**

Purposes of alloying elements of steel are as follows :

1. To impart a fine grain size to steel.
2. To improve case hardening properties.
3. To improve elasticity.
4. To improve corrosion, fatigue resistance.
5. To improve hardness, toughness and tensile strength.
6. To improve machinability.
7. To improve high or low temperature stability.
8. To improve cutting ability.
9. To improve wear resistance.
10. To improve ductility.

**B. Types of Steels and their Applications :**

**i. High Speed Steel :**

1. High speed steels are widely used for cutting of metals where hardness must be retained at elevated temperatures.
2. These steels are obtained by alloying 18 % tungsten, 4 % chromium and 1 % vanadium with a carbon content of 0.6 to 0.7 %. This alloy is termed as 18 : 4 : 1 while an increase of vanadium to 2 % produces 18 : 4 : 2 steels.
3. In addition to heat resistance high speed steels have the desirable properties of high hardness, high compressive strength and outstanding wear resistance.

**Application :** This steel is used for high speed cutting tools.

**ii. Heat Resisting Steel :**

1. Steels which must be resistance to creep at high temperatures must contain molybdenum. Silicon and chromium impart resistance to oxidation and scaling.
2. Steels which are satisfactory upto about 700 °C operating temperature are : C = 0.15 %, Si = 0.5 to 20 %, Mn = 0.5 % maximum, Ni = none, Cr = 1.0 to 6 %, Mo = 0.5 %

**Application :** These are used in valves of internal combustion engines in rolled or in forged condition.

**iii. Silicon Steel :**

1. Improves the electrical properties of steel.
2. Silicon imparts fatigue strength and resistance to steel.
3. Steel containing silicon is more ductile than plain carbon steel.
4. Steel containing 3 to 5 % silicon has very low magnetic hysteresis.

**Application :**

- i. Steel with Mn = 1 %, Si = 2 %, C = 0.4 to 0.6 % has very high elastic limit and is used for springs.
- ii. With Cr = 5 to 7 %, Si = 2 to 4 %, C = 0.4 to 0.5 % steel retain its hardness and resistance to oxidation even at red heat. Such steels are used for internal combustion engines.
- iii. 13 % silicon content steel has very high corrosion resistance so it is used in chemical industries.

**iv. Stainless Steel :**

1. Stainless steel is a metal alloy, made up of steel mixed with elements such as chromium, nickel, molybdenum, silicon, aluminum and carbon.
2. Iron mixed with carbon to produce steel is the main component of stainless steel.
3. Chromium is added to make it resistant to rust. The addition of nickel enhances corrosion resistance properties in case of aggressive usage.

**Application :** It is used for making kitchen utensils, to manufacture cook ware, surgical instruments and also used in food processing plants.

**b. Write the composition and application of brass and bronze.**

**Ans.**

**A. Composition and Application of Brasses :****1. Gliding Metal :**

- i. **Composition :** Its composition is 85 % Cu + 15 % Zn.
  - ii. **Application :** It is used for making bullet envelopes, drawn container and dress jewellery.
2. **Cartridge Brass :**
    - i. **Composition :** Its composition is 70 % Cu + 30 % Zn.
    - ii. **Application :** It is used for making cold rolled sheets, wire drawing, deep drawing, pressing and tube manufacturing etc.

**3. 63/37 Brass :**

i. **Composition :** Its composition is 63 % Cu + 37 % Zn.

ii. **Application :** It is used for cold press work.

**4. Yellow Brass (Muntz Metal) :**

i. **Composition :** Its composition is 60 % Cu + 40 % Zn.

ii. **Application :** It is used for hot working processes like rolling, extrusion and stamping etc.

**B. Composition and Application of Bronzes :****1. Phosphor Bronze :**

i. **Composition :** Its composition is 87-90 % Cu, 9-10 % Sn and 1-3 % P.

ii. **Application :** It is specially used for bearings, worm wheels and gears. Its other uses are in making of nuts, linings and springs etc.

**2. Silicon Bronze :**

i. **Composition :** Its composition is 96 % Cu, 3 % Si and 1 % Mg or Zn.

ii. **Application :** It is used for making boilers, tanks, stoves etc.

**3. Beryllium Bronze :**

i. **Composition :** Its composition is 97.7 % Cu and 2.3 % beryllium.

ii. **Application :** It is suitable for making of springs, heavy duty electrical switches, cams and bushings etc.



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