2020

RANK Improvement WORKBOOK

Answer key and Hint of Objective & Conventional *Questions*

Mechanical Engineering

Material Science

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Publications

1

Crystal System

LEVEL 1 Objective Questions

1.	(a)
2.	(d)
3.	(c)
4.	(a)
5.	(b)
6.	(b)
7.	(c)
8.	(a)
9.	(a)
10.	(c)
11.	(a)
12.	(b)
13.	(a)
14.	(d)
15.	(a)
16.	(b)
17.	(d)
18.	(d)
19.	(a)

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LEVEL 2 Objective Questions

20.	(c)
21.	(3)
22.	(1.44)
23.	(b)
24.	(b)
25.	(b)
26.	(78.5)
27.	(a)
28.	(d)
29.	(a)
30.	(a)
31.	(c)
32.	(d)
33.	(d)
34.	(d)
35.	(d)
36.	(b)
37.	(c)

■■■■

LEVEL 3 Conventional Questions

Solution : 38

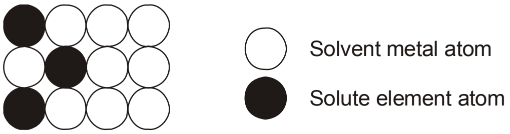
(i) Crystallographic Axes: Axes which are used to define the position of a crystal face in space by the intercepts of the face on three imaginary lines. These will define a coordinate system within the crystal.
Interfacial Angle: Interfacial angle between the two crystal faces as the angle between the lines that are perpendicular to the faces. Such a lines are called the poles to the crystal face.

(ii) The BCC unit cell consists of a net total of two atoms, the one in the center and eight from the corners. The co-ordination number is 8 and Atomic Packing Factor (APF) in BCC is 0.68.

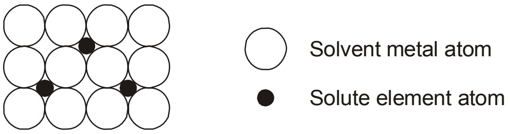
In the FCC arrangement, again there are eight atoms at corners of the unit cell and one atom centered in each of the faces. The atom in the face is shared with the adjacent cell. The co-ordination number is 12 and APF is 0.74.

(iii) In alloys there is a solute and solvent. Solute are the minor elements that is added to the solvent, which is major element. When the particular crystal structure of the solvent is maintained during alloying, the alloy is called solid solution.

Substitutional Solid Solution: If the size of the solute atom is similar to the solvent atom, the solute atoms can replace solvent atoms and form a substitutional solid solution. An example is brass, an alloy of zinc and copper, in which zinc (solute atoms) is introduced into lattice of copper.



Interstitial Solid Solution: If the size of the solute atom is much smaller than that of the solvent atom, each solute atom can occupy an interstitial position, such a process forms an interstitial solid solution. An important family of interstitial solid solutions is steel, in which carbon atoms are present in interstitial positions.



Solution : 39

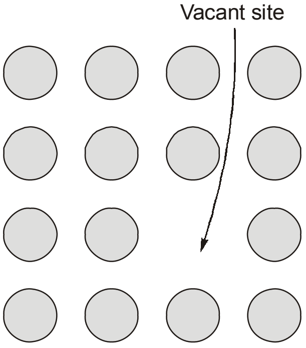
Major imperfections in the crystal structure of metals

1. Point defects
   - (i) Vacancies
   - (ii) Interstitial atoms
   - (iii) Impurities
2. Line defects : Dislocations
   - (i) Edge dislocation
   - (ii) Screw dislocation
3. Surface or Grain boundaries defects
   - (i) Grain boundaries
   - (ii) Tilt boundaries
   - (iii) Twin boundaries

4. Volume defects : Stacking faults

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

   (i) **Vacancies:** Vacancies are empty atomic sites in crystal lattice. Vacancies may arise in a crystal lattice due to imperfect packing during solidification or crystallization and they may also arise due to thermal vibrations of atoms at elevated temperatures since at higher temperatures the probability of atoms jumping out of their lattice position is more. When the density of vacancies becomes relatively large it is possible for them to cluster together to form voids in the lattice.



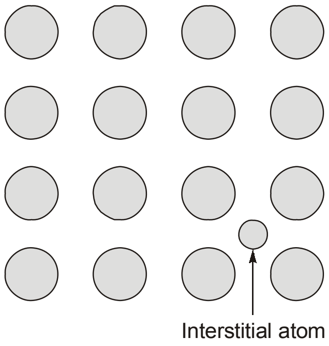
Vacancy defect

   Figure shows the vacancy defect. The lattice planes will be distorted when the atoms surrounding a vacancy come close together.

   (ii) **Interstitial (atom) defect:** Interstitial defect arises when an atom occupies an interstitial position i.e. between the atoms in the lattice of the ideal crystal.

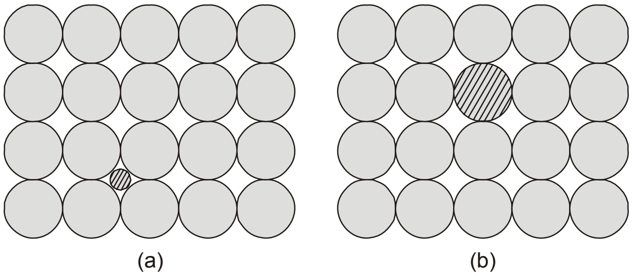
   Figure shows the interstitial defect. The interstitial atom may be either a normal atom of the crystal or a foreign atom. Interstitial defect occurs if the atomic packing factor of the crystal structure is low.

   The interstitial defect produces lattice distortion because in order to occupy an interstitial position in a perfect crystal (ideal crystal), the atom tends to push the surrounding atoms farther apart. If the interstitial atom is smaller than the rest of the atoms in the crystal, the lattice distortions produced will be negligible.



Interstitial defect

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


(a) (b)

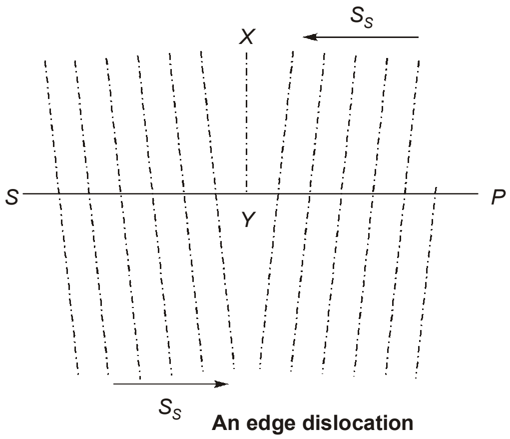
Impurities : (a) Substitutional impurity, (b) Interstitial impurity

   Substitutional impurity atom refers to that atom which substitutes for or replaces a parent atom in the crystal. **For example** in brass, zinc is a substitutional atom in the copper lattice. Interstitial impurity atom refers to that atom which occupies an interstitial position i.e., between the atoms of the ideal crystal. **For example** - the presence of carbon in iron where carbon occupies an interstitial position in the iron lattice structure without displacing any of the parent atoms of iron lattice from their positions.

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

2. **Line Defects-Dislocations:** The most important two dimensional or line defect is the dislocation. A dislocation may be defined as a disturbed region between two substantially perfect parts of a crystal. It occurs when an imperfection extending along a line has a length much larger than the lattice spacing. There are two basic types of dislocations :

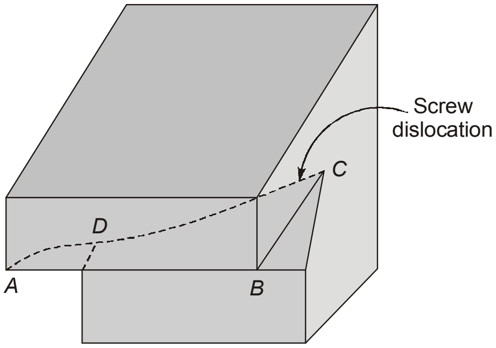
   (i) **Edge dislocation:** Figure shows an edge dislocation in a simple cubic crystal. The line marked as SP represents the slip plane of the crystal and the dashed lines represent the crystal planes perpendicular to the slip plane.
   The plane marked '*X*' at the top of the figure ends at point '*Y*'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



An edge dislocation

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

   (ii) **Screw Dislocation :** A screw dislocation is shown schematically in figure. The upper front portion of the crystal has been sheared by one atomic distance of the left relative to the lower front portion. No slip has taken place to the rear portion of the line *DC* and therefore *DC* is a dislocation line. The plane *ABCD* is the slip plane The designation screw for this lattice defect is derived from the fact that the lattice planes of the crystal, spiral the dislocation line *DC*.



Representation of a screw dislocation

3. **Surface Defects:** Surface defects may include grain boundary, tilt boundary, twist boundary, twin boundary etc.

   (i) **Grain Boundaries:** Grain boundary is formed when two growing grain surfaces meet each other and these grain boundaries separate crystals or grains of different orientation in polycrystalline materials. The orientation difference between neighbouring grains is usually greater than 10-15° and for this reason these grain boundaries are called high angle grain boundaries. In grain boundaries the atom packing is imperfect and most of the atoms at the boundaries are in highly strained and distorted positions.

(ii) **Tilt Boundaries:** Tilt boundaries are formed by edge dislocations and are regarded as an array of edge dislocations located one above the other. When the orientation difference between two crystals is less than 10°, the distortion in the boundary is not very drastic and these boundaries are called low angle tilt boundaries.

(iii) **Twist Boundaries:** Other low angle boundaries formed by screw dislocations are called as twist boundaries.

(iv) **Twin Boundaries:** Another type of surface imperfections are twin boundaries. A twin boundary separates two parts of a crystal having the same orientation.

4. **Volume Defects:** Volume defects are stacking faults which are created by a fault in the stacking sequence of close packed atomic planes in crystals such as *FCC* and *HCP*. Consider **for example** the stacking arrangement in an *FCC* crystal *ABC ABC ABC ABC*. If an A plane indicated by an arrow is missing then the stacking sequence becomes

ABC BC ABC ABC

which is a surface defect and is called as stacking fault. Stacking faults are more frequently found in deformed metals.

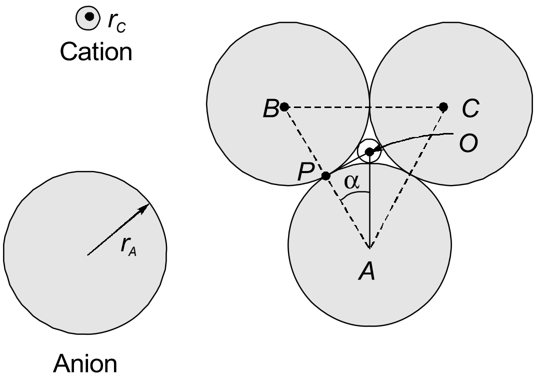
The presence of these imperfections or defects in metallic crystals impairs the physical and mechanical properties of metal and alloys.

The theoretical strength of a metal (the force required to separate the bond between adjoining atoms) turns out to be several million Newtons per square metre, but the ordinary strength of metals is 100 to 1000 times less. This is because of occurrence of defects in the crystal structure.

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

Solution : 40

For this coordination, the small cation is surrounded by three anions to form an equilateral triangle as shown here, triangle *ABC*; the centers of all four ions are coplanar.



This boils down to a relatively simple plane trigonometry problem. Consideration of the right triangle *APO* makes it clear that the side lengths are related to the anion and cation radii r_A and r_C as

$$\overline{AP} = r_A$$

and

$$\overline{AO} = r_A + r_C$$

Furthermore, the side length ratio $\frac{\overline{AP}}{\overline{AO}}$ is a function of the angle α as

$$\frac{\overline{AP}}{\overline{AO}} = \cos\alpha$$

The magnitude of α is 30°, since line $\overline{AO}$ bisects the 60° angle *BAC*. Thus,

$$\frac{\overline{AP}}{\overline{AO}} = \frac{r_A}{r_A + r_C} = \cos 30° = \frac{\sqrt{3}}{2}$$

Solving for the cation-anion radius ratio,

$$\frac{r_C}{r_A} = \frac{1 - \frac{\sqrt{3}}{2}}{\frac{\sqrt{3}}{2}} = 0.155$$

Solution : 41

To determine the value of *N*, the number of atomic sites per cubic meter for copper, from its atomic weight A_{Cu}, its density ρ, and Avogadro's number N_A, according to

$$N = \frac{N_A \rho}{A_{Cu}} \qquad \ldots (1)$$

$$= \frac{(6.023 \times 10^{23} \text{ atoms/mol})(8.4 \text{ g/cm}^3)(10^6 \text{ cm}^3/\text{m}^3)}{63.5 \text{ g/mol}}$$

$$= 8.0 \times 10^{28} \text{ atoms/m}^3$$

Thus, the number of vacancies at 1000°C(1273 K) is equal to

$$N_u = N\exp\left(-\frac{Q_v}{kT}\right)$$

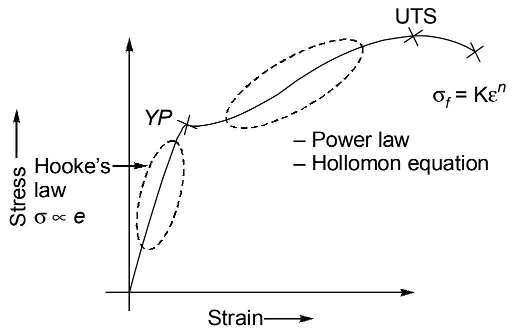
$$= (8.0 \times 10^{28} \text{ atoms/m}^3)\exp\left[\frac{-(0.9\,\text{eV})}{(8.62 \times 10^{-5} \text{ eV/K})(1273\text{ K})}\right]$$

$$= 2.2 \times 10^{25} \text{ vacancies/m}^3$$

Solution : 42

Upon cold working (temperature less then 0.4 temperature where temperature is melting point in K) the number of dislocations in the material increases. How much dislocation multiplication takes place, is the property of material and it is expressed by work hardening exponent (*n*) in the flow curve equations $\sigma_f = K\epsilon^n$, where *k* is strength coefficient, σ_f is true stress and ϵ is true strain.

Higher is the value of *n*, more dislocations will be created upon cold working the material. These dislocations piles up at the grain boundary and creates a dislocation forest. Since dislocation-dislocation interactions are repulsive in nature, this dislocations forest create a back stress in the movement of dislocation. This increases the strength of material upon unloading the specimen from the region of work hardening and reloading in opposite direction, back stresses now support the movement of dislocation. As a result of that yield point in opposite direction appears prematurity. This phenomenon is called Bauschinger effect.



Nominal UTS

$$\sigma_0 = 400 \text{ MPa}$$
$$e = 0.35$$

So

$$\in = \ln(1 + e) = \ln(1.35) = 0.3$$
$$\sigma_f = \sigma_0(1 + e) = 400(1.35) = 540 \text{ MPa}$$

at UTS

$$n = \in = 0.3$$
$$\sigma_f = K \in^n$$
$$540 = K(0.3)^{0.3}$$
$$K = 775$$

So power law equation is,

$$\sigma_f = 775 \in^{0.3}$$

Solution : 43

1. Copper and Nickel
2. Iron and Carbon

(a) Copper and Nickel : Cu-Ni forms a substitutional solid solution if melted Cu and Ni with any composition is cooled, a solid solution begins to freeze out. This solid solution is richer in Ni than are liquid solution.

(b) Iron and Carbon : Fe-C forms an interstitial solid solution, the C-atom occupy interstitial position in crystal structure of substance Fe. The Fe-Fe_3C are characterized by following individual phases. The phases that exist in Fe-C phase diagram are

1. α ferrite (BCC)
2. γ-autenite (FCC) solid solution
3. δ ferrite (BCC) [solid solution]
4. Fe_3c (iron carbide or cementite)
   [an intermetallic compound and liquid Fe-C solution]

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2

Alloy and Binary Phase Diagram

LEVEL 1 Objective Questions

1.	(c)
2.	(a)
3.	(d)
4.	(d)
5.	(b)
6.	(b)
7.	(d)
8.	(c)
9.	(c)
10.	(b)
11.	(a)
12.	(a)

LEVEL 2 Objective Questions

13.	(c)
14.	(1.41)
15.	(c)
16.	(0.10)
17.	(0.62)
18.	(c)

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LEVEL 3 Conventional Questions

Solution : 19

(i) In **heterogeneous nucleation**, the surface of some different substance, such as the wall of the container, acts as the centre upon which the first atoms, ions or molecules of the crystal become property oriented. In **homogeneous nucleation**, a few particles come into correct juxtaposition in the course of their random movement through bulk of medium. Heterogeneous nucleation is more common.

(ii) **Nucleation and growth:** Nucleation is the first step in the formation of either a new structure or phase via self assembly or self organization. Once nucleation starts, crystals begins to grow in size and number, by progressive addition of atoms in growth phase.

(iii) **Embryos and Nuclei:** An embryo is a tiny particle of solid that forms the liquid as atoms cluster together. The embryo is unstable and may either grow in a stable nuclei or re-dissolve. While nucleus is a tiny particle of solid that is large enough to be stable, nucleation occurs and growth of solid begins.

(iv) **Supercooling and Sublimation:** Supercooling is the process of lowering the temperature of liquid or gas below its freezing point without becoming a solid. Sublimation is the transition of a substance directly from the solid to gas phase without passing through liquid phase.

Solution : 20

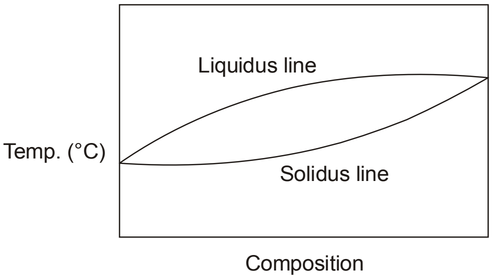
(i) **Gibbs phase rule and level rule:** Gibbs phase rule applies to non-reactive multi component heterogeneous systems in equilibrium and is given by: $F = C - P + 2$, where F is the number of degrees of freedom, C is the number of components and P is the number of phases in equilibrium.

The lever rule is a tool used to determine weight percentages of each phase of a binary equilibrium phase diagram. In an alloy with two phases, α and β, which themselves contain two elements, A and B, the lever rule states that the weight percentages of the α phase is

$$X_\alpha = \left(\frac{c-b}{a-b}\right), \text{ where}$$

a is wt% of element B in α-phase
b is wt% of element B in β-phase
c is wt% of element B in entire alloy

(ii) **Isomorphous System:** Isomorphous system is one, where complete liquid and solid solubility occurs. For example the Cu-Ni alloy where complete solubility occurs because Cu and Ni have the same crystal structure, electronegativity and valency.



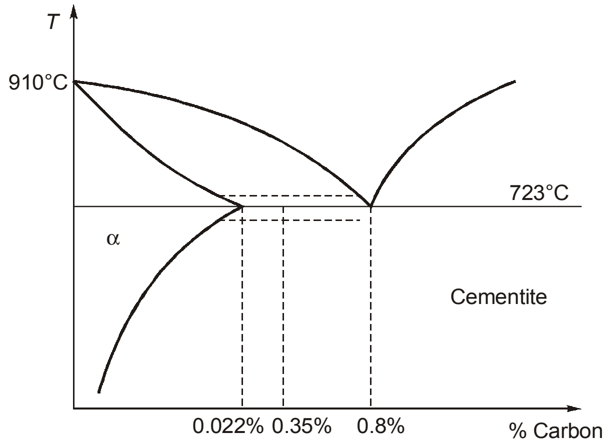
Isomorphous system phase diagram

(iii) **Peritectic reaction in steel:** In Peritectic reaction, a liquid and solid phase of fixed proportions react at a fixed temperature to yield a single solid phase.

$$\underset{\text{(Molten liquid)}}{L} + \underset{\text{(Delta ferrite)}}{\delta} \xrightleftharpoons[\text{(1495°C)}]{\text{(0.18\% Carbon)}} \underset{\text{(Gamma–Austenite)}}{\gamma}$$

Solution : 21

Alloy composition → 99.65wt% Fe, 0.35 wt% C



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

Fraction of cementite phase, $$F_{Fe_3C} = \frac{0.35-0.022}{6.67-0.022} = 0.05$$

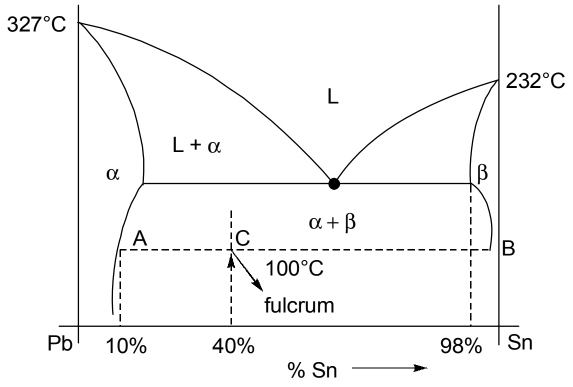
To calculate pro-eutectoid ferrite, a tie line has to be selected above eutectoid temperature.

$$F_{\text{pro}-\alpha} = \frac{0.8-0.35}{0.8-0.022} = 0.57$$

$$F_{\text{eut}-\alpha} = F_\alpha - F_{\text{Pro}-\alpha} = 0.95-0.57 = 0.38$$

and $$F_{\text{Pearlite}} = 1 - F_{\text{Pro}-\alpha} = 1-0.57 = 0.43$$

Solution : 22



From the above figure

$$m_\alpha = \frac{98-40}{98-10} = 0.659$$

$$m_\beta = 0.341$$

Before calculating the volume fraction, the density of α and β has to be calculated

$$\frac{100}{\rho_\alpha} = \frac{10}{\rho_{Sn}} + \frac{90}{\rho_{Pb}} \qquad \text{So, } \frac{100}{\rho_\alpha} = \frac{10}{7.24} + \frac{90}{11.23}$$

and

$$\frac{100}{\rho_\beta} = \frac{98}{\rho_{Sn}} + \frac{2}{\rho_{Pb}} \qquad \text{So, } \frac{100}{\rho_\beta} = \frac{98}{7.24} + \frac{2}{11.23}$$

So $\rho_\alpha = 10.64$ g/cc

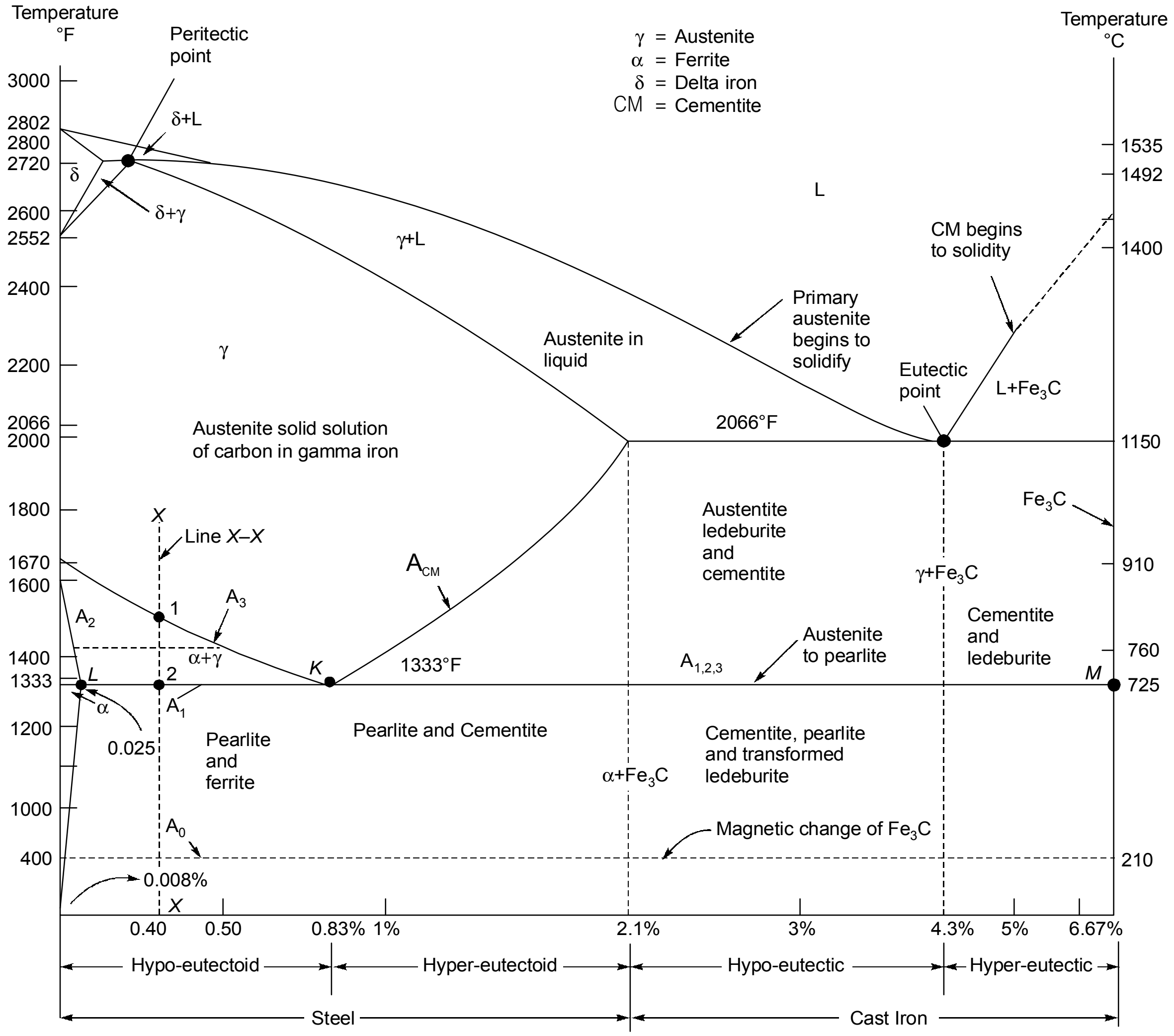
and $\rho_\beta = 7.29$ g/cc

volume fraction of α

$$V_\alpha = \frac{\dfrac{m_\alpha}{\rho_a}}{\dfrac{m_\alpha}{\rho_\alpha} + \dfrac{m_\beta}{\rho_\beta}} = \frac{\dfrac{0.659}{10.64}}{\dfrac{0.659}{10.64} + \dfrac{0.341}{7.29}} = \frac{0.0019}{0.0619 + 0.0466} = 0.57(57\%)$$

$$V_\beta = 1 - V_\alpha$$
$$= 0.43\,(43\%)$$

Solution : 23



Calculation of % content will be made by lever rule.

The amount of austenite slightly above 723°C is calculated from the line *LK* itself. i.e. taking *LK* as tie line.

(a) Weight % of austenite $= \dfrac{L2}{LK} = \dfrac{0.4-0.025}{0.83-0.025}$

$$= \frac{0.375}{0.805} = 0.4658 \text{ or } 46.58\% \qquad \text{...(i)}$$

(b) Weight % of ferrite $= \dfrac{2K}{LK} = \dfrac{0.83-0.4}{0.83-0.025} \Rightarrow \dfrac{0.43}{0.805} \Rightarrow 0.534 \Rightarrow 53.4\%$

$$= \frac{0.4}{0.775} = 0.516 \text{ or } 51.6\% \qquad \text{...(ii)}$$

(c) Weight % of proeutectoid ferrite slightly below 723°C is same as that slightly above, i.e. 48.4% ...(iii)

(d) For calculating eutectoid ferrite, the weight of carbide will have to be substracted form total mass of ferrite and cementite. Just below isothermal line LKM ferrite and pearlite are present and lever arm will extend upto ordinate representing 6.67%C.

Weight % of total (ferrite + cementite) just below 723°C

$$= \frac{6.67-0.4}{6.67-0.025} = \frac{6.27}{6.645} = 0.943 \text{ or } 94.3\%$$

Weight % of Fe_3C just below 723°C

$$= \frac{0.4-0.025}{6.67-0.025} = \frac{0.375}{6.645} = 0.0564 \text{ or } 5.64\%$$

Weight % of eutectoid ferrite = total ferrite – proeutectoid ferrite

$$= 94.3 - 51.6 = 42.7\%$$

Weight % of eutectoid cementite (by difference)

$$= 100 - 46.58 - 5.64 - 42.7 = 5.08\% \qquad \text{...(iv)}$$

Solution : 24

By lever rule,

$$\% \text{ total ferrite} = \frac{6.67-x'}{6.67-0.025} = \frac{6.67-x'}{6.645}$$

$$\% \text{ proeutectoid ferrite} = \frac{0.80-x'}{0.80-0.025} = \frac{0.80-x'}{0.775}$$

$$\% \text{ eutectoid ferrite} = \% \text{ total ferrite} - \% \text{ proeutectoid ferrite}$$

or
$$\frac{10}{100} = \frac{6.67-x'}{6.645} - \frac{0.80-x'}{0.775}$$

$$0.51498 = 5.169 - 0.775x' - 5.316 + 6.645x'$$

$$0.66198 = 5.87x'$$

$$\therefore \quad x' = 0.1128$$

The steel has 0.1128%C.

■■■■

3

Heat Treatment of Steels

LEVEL 1 Objective Questions

1. (a)

2. (c)

3. (d)

4. (d)

5. (c)

6. (c)

7. (b)

8. (c)

9. (a)

10. (a)

11. (a)

12. (a)

13. (c)

14. (d)

15. (b)

16. (c)

17. (d)

18. (d)

19. (c)

LEVEL 2 Objective Questions

20. (b)

21. (a)

22. (d)

23. (c)

24. (c)

25. (d)

26. (b)

27. (b)

28. (b)

29. (a)

30. (d)

31. (a)

32. (a)

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LEVEL 3 Conventional Questions

Solution : 33

The factors that influence the M_s and M_f temperature are:

(i) Alloying element, adding alloying elements increase the extent to which martensite forms.

(ii) Specimen size and shape, the extent of martensite formation increases as the specimen cross-section decreases and as the degree of shape irregularity increases.

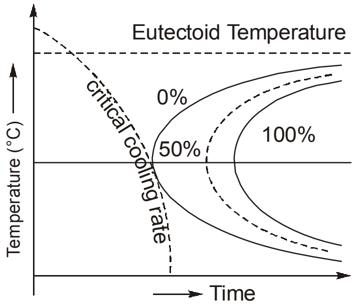
(iii) Quenching medium, the more severe the quench, the more martensite is formed. Agitating the medium also enhances the severity of quench.

Temper embrittlement is caused by the segregation of impurities along the grain boundaries at temperature between 480°C and 590°C in alloy steels. Controlling the presence of impurities in the composition of alloys, step quenching can avoid the temper brittleness.

Spheroidizing is a form of heat treatment for Iron-based alloys, mostly carbon steels, in order to convert them into ductile and machinable alloys. It is conducted at temperatures that are slightly below the eutectoid temperature, (prolonged heating) followed by a slow cooling process. Unlike the laminar shapes of cementite which act as stress raisers, spheroidities, are less conducive to stress concentration because of their rounded shapes. The structure has higher toughness and lower hardness.

Solution : 34

The critical cooling rate is the cooling rate that is tangential to the TTT diagram at the nose of the curve. Cooling at or faster than critical cooling rate will transform the austenite to martensite and not to pearlite or bainite.



- Critical cooling rate depends upon amount of carbon and alloying elements.
- With increase in the carbon content and alloying elements (except Cobalt), the critical cooling rate decreases i.e., shift of nose of TTT curve to the right.
- Shift of nose to the right gives an idea about hardenability; lower the cooling rate, higher is the hardenability.
- Lower cooling rate reduces the tendency of warping and cracking.
- Critical cooling rate also depend on size of job and cooling medium.

Solution : 35

(1) Nitriding

In nitriding the N content of the surface is increased, this is done by heating the steel in the atmosphere of NH_3 gas. The parts to be nitrided are placed in an air tight container. NH_3 is passed continuously over the work pieces at a temperature of 500 to 650°C, NH_3 gas dissociates as follows

$$2NH_3 \rightarrow 2N + 3H_2$$

This atomic state of nitrogen diffuses into steel surfaces and react with alloys of steel making a case containing the alloy nitrides. Thus the presence of alloying elements such as Al, Cr, Mo etc. is necessary, in order to obtain a case of maximum hardness Medium C-steel containing 3% of alloying elements produces hardest case on the steel surface.

The most common size of nitriding case is 0.3 to 5 mm thick, it requires 30-40 hrs at 500-520°C. The time can be reduced by using a double state process in which the work is first heated at 500-520°C and then at 550-600°C for the nitriding process. After nitriding the work is cooled in the furnace in the spring of ammonia.

Advantages :

(a) It increases the hardness of surface layer which is harder as compared to carburising.
(b) It increases wear resistance, endurance limit and resistance to corrosion.
(c) No heat treatment is required after nitriding.

Uses : Nitriding is used during manufacture of gears components of M/c tools cylinders of powerful engines, cylinder liners, gauges, cams, values etc.

Disadvantages :

(a) The case produced is brittle.
(b) The process is costly compared to carburising.

(2) Cyaniding

In cyaniding a thick case of high hardness and wear resistance is produced on C-alloy steels. Work is immersed in molten salt bath containing NaCN which is heated to 820-860°C. This is usually followed by water quenching. The cyanide bath consists of 20-30% NaCN, 25-50% NaCl and 25-50% Na_2CO_3. The time required for cyaniding depends on the depth of case required. For 0.15- 0.5mm, 30-90 minutes are required.

$$2NaCN + O_2 \rightarrow 2\,NaCNO\ (Air)$$
$$2NaCNO + O \rightarrow NaCO_3 + CO + 2N\ (Atom)$$
$$2CO + O \rightarrow CO_2 + C\ (Atomic)$$

The atomic C diffused into steel the work can be directly quenched as soon as it is taken out of bath then low temperature tempering is done at 200°C. The case obtained by cyaniding is of high wear resistant and endurances limit compared to carburising. It should be noted that hardness at case varies in the following sequence

Nitriding > Cyaniding > Carburizing

Cyaniding is used to produce light cases on small parts like small shafts, worms, gears, nuts, springs, pins etc.

Advantages :

1. It requires less time than carburising.
2. There is less distortion of the work piece
3. Resistance to corrosion and wear is high.

Disadvantages :

1. High cost.
2. Cyaniding bath is toxic hence the worker needs protection.

(3) Flame Hardening

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

As soon as the desired temperature is achieved water is immediately sprayed which cools the surface. By proper control of heating and cooling operation the core is not affected by the treatment. The thickness of hardened layer is 2-4 mm and its structure is martensite. The structure of underline layers is troostomartensite.

Advantages :

(a) There is practically no distortion of the work piece because only small sections of the work piece are heated.

(b) As heating rate is high the work surface remains clean.

(c) The process can easily be automated.

(d) The process is more efficient for large work piece as compared to induction heating. It is very economical for large work.

Disadvantages :

(a) Very thin sections may get distorted extensively.

(b) Over heating may cause crack.

(4) Induction Hardening

This process is employed to increase hardness, wear resistance and endurances limit of the surface of the work piece. The heat treatment is given to the surface only by supplying excessive heat to the surface followed by drastic quenching, the surface is heated to the austenite range and then quenched immediately to form martensite. The structure of core remains un changed because it is not effected by heat, the components should contain 0.4 - 0.5% carbon or sufficient alloying elements as chromium Ni, or Mo. The work is placed in Helical coils called inductor the coil consist of several turns of water cooled cu tubing. Alternate current is passed through the inductor and thus alternate magnetic field sets up. The field induces eddy currents on the surface layers and heat is generated. The current density is not uniform through out the cross-section of the work piece. Approximate the 90% of the heat is generated in the work layer of thickness (x) represented by

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

Where f is the frequency, μ is the magnetic permeability and ρ is the electrical resistivity of the metal of the work piece. The heating rate in the range of transformation temperatures is upto 300°C/sec for hypoeutectoid steels and subsequently the heating time is very small (2 - 50 sec's). The high frequency current is supplied by motor generator and vacuum tube generator. When it is required to increase the strength of the core the work should be normalized before induction hardening. The quenching temperature depends upon the rate of heating if the rate is 500°C/sec it is 1000°C and if it is 250°C/sec it is 900°C. Induction hardening can be performed in three ways :

1. The whole work surface is heated at one time and quenched. This procedure is used for hardening surfaces of small components like shafts and sharp of tools.
2. The sections of work are heated and quenched consequently. This procedure is used for hardening generals of crank shaft teeth of gears and cams of cam shaft.
3. The work in made to travel with respect to stationary inductor or vice versa and spray quenching is done. This procedure is used for hardening long shafts and axles. Generally induction heating is followed by low temperature tempering at about 180°C.

Advantages :

1. Time required is very small hence the process is very quick and productivity is high.
2. Scale is not formed hence machining time is saved moreover material is not lost due to scale formation.
3. The process can be automated.
4. Depth of hardness can be controlled easily.
5. Distortion is reduced.
6. Due to high speed grain growth decarburising do not occur.
7. Both external and internal surfaces can be hardened.
8. It is an efficient mass production method. Almost all components can be uniformly hardened i.e. the quality of all the components is uniform.
9. Where ever required the hardening can be localised and there is no need to protect the remaining surfaces.

Disadvantages : Each type of work piece requires different fixtures for its holding, each time one piece can be heat treated where as different work pieces can be treated at one time in carburizing and nitriding.

Solution : 36

Ductile iron, also known as ductile cast iron, nodular cast iron, spheroidal graphite iron and *SG* iron, is a type of cast iron invented in 1943 by Keith Millis. While most varieties of cast iron are brittle, ductile iron is much more ductile and elastic, due to its nodular graphite inclusions.

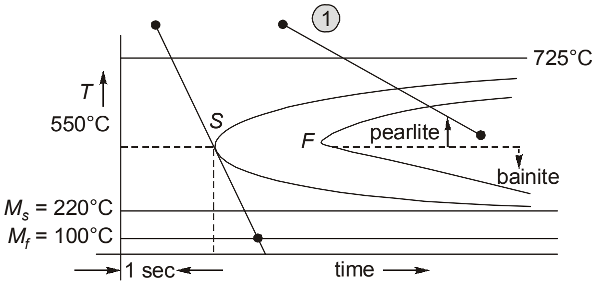
S.G. iron is an engineering material distinguished by its high strength, toughness and ductility, combined with excellent casting properties and good machinability. It has a high modulus of elasticity and good resistance to corrosion and wear.

In the *TTT*-diagram there appears two lines other than *C*-curves at 220°C and 100°C horizontal to time axis.

220°C-$M_s \rightarrow$ Start of martensite

100°C-$M_f \rightarrow$ Finish of martensite

If the cooling rate is such that, it just touches the nose of *TTT* diagram is called critical cooling rate (*CCR*). Any cooling rate greater than (or) equal to *CCR* will not produce pearlite and in the microstructure carbon will freeze at its location and it is like colloidal solution of carbon (or) cementite in ferrite. This phase of iron is called 'martensite', which is the hardest phase of iron.



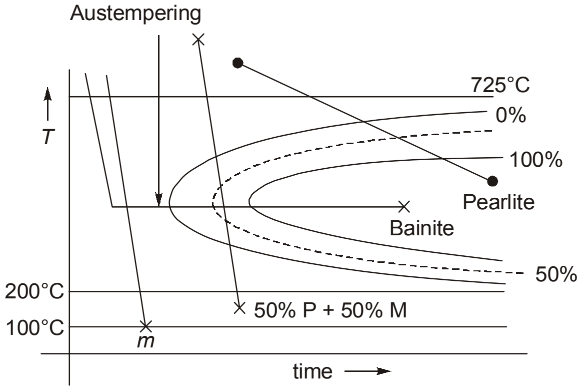
Critical Cooling Rate

All the lines on *TTT* diagram are that of decomposition of austenite into some other micro structure. Once the austenite converts into some other microstructure it never reconverts again. The slow cooling process produce coarse structure and fast cooling process produce fine structure. It can be observed that bainite cannot be produced by continuous cooling. To produce bainite, the sample has to be quenched below the nose of *TTT* diagram but above martensite start line (220°C). The sample is then maintained at this temperature for substantial period of time till entire austenite converts into bainite. The process is called **Austempering**.

The advantages of austempering are:

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

Only small sections are suitable for austempering because big sections can not be cooled rapidly to avoid formation of pearlite. Steel sections less than 12 mm thick are suitable for austempering.



Different cooling rate results to different microstructure

Upon quenching austenite specimen into water since surface is coming in contact with the quenched medium. It will immediately convert into martensite but the core is still austenite. After some time when core converts into martensite its volume will expand because martensite is having lower density. This produces crack over the surface. Cracks in quenching are due to density difference and not due to thermal stresses.

■■■■

4

Mechanical Testing, Corrosion Prevention and Control & Mechanical Propeties of materials

LEVEL 1 Objective Questions

1.	(b)
2.	(d)
3.	(c)
4.	(b)
5.	(d)
6.	(d)
7.	(c)
8.	(d)
9.	(a)
10.	(b)
11.	(c)
12.	(d)
13.	(c)
14.	(d)
15.	(a)
16.	(b)
17.	(d)

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LEVEL 2 Objective Questions

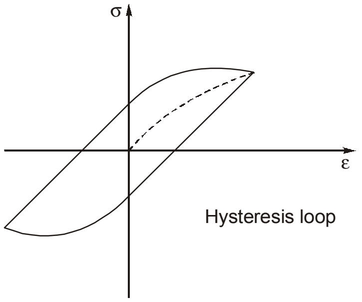
18.	(d)
19.	(a)
20.	(a)
21.	(a)
22.	(d)
23.	(d)
24.	(c)
25.	(b)
26.	(b)
27.	(c)
28.	(d)
29.	(a)
30.	(b)
31.	(b)
32.	(b)
33.	(b)
34.	(d)
35.	(a)

■■■■

Solution : 36

(i) Discontinuous yielding or yield point phenomenon occurs in mild steels due to the segregation of impurity solute atoms (Carbon in steel) around dislocations so as to reduce the strain energy associated with the distorted atomic arrangement. The dislocations which are understood to be the cause of plastic deformation are pinned to these interstitial solutes and hence becomes immobile, with the initiation of the plastic deformation there is an ample increase in the number of dislocations due to the formation of cottrell atmosphere.

This leads to high population of dislocations and the movement of dislocations are restricted and cause the yield point phenomenon. This is common in mild steels subjected under tension.



(ii) The area between the load and unload curves is called hysteresis loop.Specimens loaded cyclically to as to alternate between tension and compression can exhibit hysteresis loop if the loads are high enough to induce plastic flow (stresses above yield point).

The enclosed area in the loop is strain energy per unit volume released as heat in each loading cycle.

Solution : 37

There are three stages in the mechanism of fatigue failure-Initiation, propagation and final rupture.

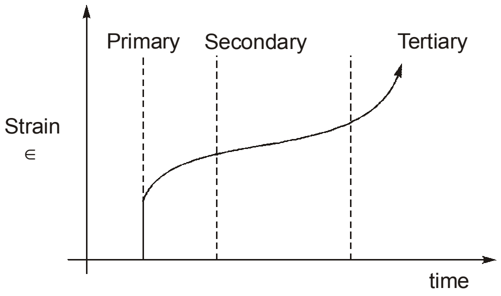
Initiation: It is the most complex stage of fatigue fracture. The most significant factor about the initiation stage of fatigue failure is that the irreversible changes in the metal caused by repetitive shear stresses.

Propagation: The propagation stage of fatigue causes the microcrack to change direction and grow perpendicular to the tensile stress.

Final Rupture: As the propagation of the fatigue crack continuous, gradually reducing the cross-sectional area of the part, it eventually weakens the part and causes final rupture eventually.

Creep Failure: There are three stages in creep failure mechanism - Primary, Secondary and Tertiary.

In the initial stages, the strain rate is relatively high, but slows with increasing time. This is due to work hardening. The strain rate eventually reaches a minimum and becomes near constant this is due to the balance between work hardening and rise in stress due to decrease in area. This state is secondary or steady-state creep. In tertiary creep, the strain rate exponentially increases with stress because of necking phenomenon. Fracture occurs at the tertiary stage.



Solution : 38

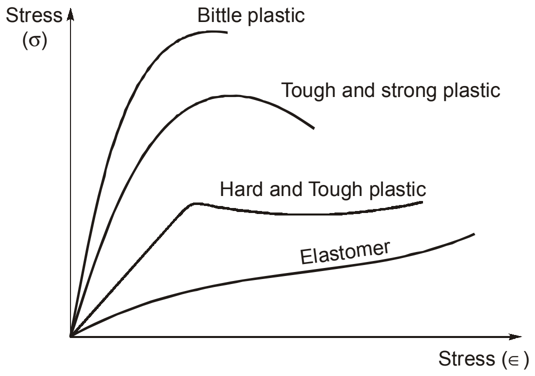
Corrosion is the deterioration of a material due to its interaction with its surroundings. Although this definition is applicable to any type of material, it is usually reserved for metallic alloys. Of the 105 known chemical elements, approximately eighty are metals, and about half of these can be alloyed with other metals, giving rise to more than 40,000 different alloys. Each of the alloys will have different physical, chemical, and mechanical properties, but all of them can corrode to some extent, and in different ways.

Corrosion is natural phenomenon. When newly made steel is first exposed to air, its originally shiny surface will be covered with rust in a few hours. The tendency of metals to corrode is related to the low stability of the metallic state. Metals occurs either in the pure metallic state, the zero oxidation state, or in the form of compounds with other elements (they acquire positive states of oxidation). In the natural world, the most metals are found as compound with other elements, indicating the greater stability of their oxidized forms. For this reason, to obtain the pure metal form are of its compound, it is necessary to put in energy. The reverse is true when a metal is exposed to its environment, it tends to release this stored energy through the processes of corrosion. This is rather analogous to what happens when an object is suspended at a point above the ground (equivalent to the metallic state). When allowed to fall or reach to stable state, it returns to a position of minimum energy on the ground (equivalent to the metal's oxidized state).

The chemical reactions that take place in corrosion processes are reduction-oxidation (redox) reactions. Such reactions require a species of material that is oxidized (the metal), and another that is reduced (the oxidizing agent). Thus the complete reaction can be divided in to two partial reactions: one oxidation and the other reduction. In oxidation, the metal loses electrons. The zone in which this happens is known as the anode. In the reduction reaction, the oxidizing agent gains the electrons that have been shed by the metal, and the zone in which this happens is the cathode.

Solution : 39

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



(i) **Brittle fracture:** It is characterized by no yield point, a region of Hookean behaviour at low strains and failure characterized by chonchoidal lines such as seen in inorganic glasses.

(ii) **Yield behaviour:** It is characterized by a maximum in the stress-strain curve followed by yielding deformation which is usually associated with crazing or shear banding and usually ductile failure. Ductile failure exhibits a large extent of deformation on the failure surface. Yield behaviour can result in necking which exhibits a close to constant load regime and a terminal increase in the stress.

(iii) **Rubber like behaviour:** It is characterized by the absence of a yield point maximum but exhibiting a plateau in an engineering stress-strain curve. Often rubber-like behaviour exhibits a terminal increase in the stress followed by failure which results in a tear with little permanent deformation exhibited in the failure surface.

The mechanical properties of polymer are highly sensitive to —

1. Rate of deformation
2. Temperature of polymer
3. Chemical nature of environment such as the presence of oxygen, water or organic solvents, etc.

Amorphous polymers do not have a specific melting point, but they do undergo a distinct change in their mechanical behaviour across a narrow range of temperature. At low temperatures, they are hard, rigid, brittle and glassy; at high temperatures, they are rubbery or leathery. The temperature at which a transition occurs is called the glass-transition temperature (T_g). The glass transition temperature various with different polymers. For example room temperature is above T_g for some polymers, below it for others.

Solution : 40

(a) The modulus of elasticity is the slope of the elastic or initial linear portion of the stress-strain curve. The strain axis has been expanded in the inset, figure, to facilitate this computation. The slope of this linear region is the rise over the run, or the change in stress divided by the corresponding change in strain; in mathematical terms,

$$E = \text{slope} = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

As the line segment passes through the origin, it is convenient to take both σ_1 and ε_1 as zero. If σ_2 is arbitrarily taken as 150 MPa, then ε_2 will have a value of 0.0016. Therefore,

$$E = \frac{(150 - 0)\text{MPa}}{0.0016 - 0} = 93.8 \text{ GPa}$$

(b) The 0.002 strain offset line is constructed as shown in the inset; its intersection with the stress-strain curve is at aproximately 250 MPa, which is the yield strength of the brass.

(c) The maximum load that can be sustained by the specimen is calculated by using below equation, in which σ is taken to be the tensile strength, from figure, 450 MPa. Solving for F, the maximum load, yields

$$F = \sigma A_0 = \sigma\left(\frac{d_0}{2}\right)^2\pi \Rightarrow 450\times10^6\left(\frac{12.8\times10^{-3}}{2}\right)^2\pi \Rightarrow 57905.835 \text{ N}$$

(d) To compute the change in length, Δl, it is first necessary to determine the strain that is produced by a stress of 345 MPa. This is accomplished by locating the stress point on the stress-strain curve, point *A*, and reading the corresponding strain from the strain axis, which is approximately 0.06. As l_0 = 250 mm, we have

$$\Delta l = \varepsilon l_0 = (0.06)(250 \text{ mm}) = 15 \text{ mm}$$

■■■■

5

Plastic, Ceramic, Composite & Nano Materials

LEVEL 1 Objective Questions

1.	(c)
2.	(c)
3.	(b)
4.	(d)
5.	(b)
6.	(b)
7.	(c)
8.	(d)
9.	(a)
10.	(a)
11.	(d)
12.	(d)
13.	(b)
14.	(c)
15.	(d)
16.	(b)
17.	(c)
18.	(b)
19.	(b)
20.	(d)

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LEVEL 2 Objective Questions

21.	(b)
22.	(c)
23.	(d)
24.	(c)
25.	(c)
26.	(b)
27.	(a)
28.	(d)
29.	(b)
30.	(c)
31.	(d)
32.	(a)
33.	(d)
34.	(b)
35.	(a)
36.	(a)
37.	(a)
38.	(a)
39.	(b)

■■■■

LEVEL 3 Conventional Questions

Solution : 40

Plastics can be broadly classified as:

(i) **Thermoplastics:** Plastics that return to its original hardness and strength on cooling, i.e. it is reversible. Examples - PTFE, Nylons, PVC, Polyethylenes, etc.

(ii) **Thermosetting Plastics:** Plastics having cross-linked structures of molecules with strong covalent bonds. These are permanently set. Examples-Epoxy, Polyester and Urethane.

Advantages of Plastic Material:

1. Corrosion resistance and resistance to chemicals.
2. Low electrical and thermal conductivity.
3. Low density.
4. High strength-to-weight ratio.
5. Wide choice of colors and transparencies.
6. Ease of manufacturing.
7. Relatively low cost.

Disadvantages:

1. Low strength,
2. Low stiffness,
3. High coefficient of thermal expansion,
4. Low useful temperature range,
5. Less dimensional stability in services over a period of time.

Solution : 41

(i) **Fillers** used are generally wood flour (fine saw dust), Silica flour (fine silica powder), clay, powdered mica, talc, Calcium Carbonate and short fibers of cellulose, glass. Fillers are important in reducing the overall cost of polymers. Depending upon their type, fillers may also improve the strength, hardness, toughness, abrasion resistance, dimensional stability or stiffness of plastics

(ii) **Plasticizers** are added to impart flexibility and softness by lowering their glass-transition temperature. They reduce the strength of the secondary bonds between the long-chain molecules and thus make the polymer soft and flexible.

(iii) **Colourant** either organic (dyes) or inorganic pigments are added in plastics to obtain plastics in wide variety of colours. Pigments are dispersed particles; they generally have greater resistance than dyes to temperature and light.

(iv) **Lubricants** may be added to polymers to reduce friction during their subsequent processing into useful products and to prevent parts from sticking to the moulds. Typical lubricants are linseed oil, mineral oil and waxes. It is also important in preventing thin polymer films from sticking to each other.

Solution : 42

Ceramic: Ceramics are compounds of metallic and non-metallic elements and include such compounds as oxides, nitrides and carbides. The bonding between the atoms in ceramic structure is generally covalent or ionic. Such bonds are much stronger than metallic bond consequently, they are hard, insulating and resistant to high temperature. Their electrical and thermal resistance are significantly higher than metals.

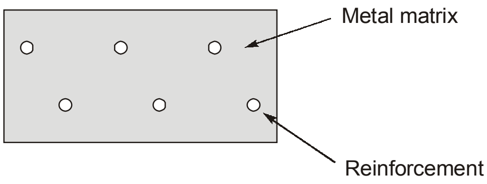
Ceramics are available as a single crystal or in polycrystalline form, consisting of many grains. Ceramics have numerous applications. It is used in electrical and electronics industry because they have high electrical resistivity, high dielectric strength. it is used in high temperature applications. Types of ceramics include Alumina, Tungsten, Carbide, Titanium Carbide, SiC, CBN, TiN, cermets etc.

Polymers: Polymers are generally organic compounds based upon Carbon and Hydrogen. These are long-chain molecules that are formed by polymerization, that is by linking and cross-linking of different monomers. A monomer is the basic building block of a polymer. Polymers offer many advantages such as corrosion resistance and resistance to chemicals, low density, high strength to height ratios, wide choice of colours and transparencies but their strength, stiffness and melting temperature are generally much lower than those of metals and ceramics. Due to their light weight, ease of forming into different shapes, polymers are preferred for engineering applications.

Composites: These are combination of two or more chemically distinct and insoluble phases. Its properties and structural performance are superior to these of the constituents acting independently. The polymer matrix composites (PMC) consists of fibers (the discontinuous or dispersed phase). Commonly used fibers are glass, graphite, aramids. Metals and ceramics can be embedded with fibers, to improve their properties, these combinations are known as metal-matrix and ceramic-matrix composites. Composites are widely used in aircrafts, automobiles, sporting goods etc. due to their superior properties.

Solution : 43

Composites are materials in which a combination of 2 or more materials or phase is present. In metal matrix composites, there exist a matrix of light metal such as Aluminium, Magnesium or Titanium and another material such as carbon fibre, is dispersed into this metal matrix as reinforcing material.



Cross-section of MMC

Sometime the reinforcement can be another metal or organic compounds. *MMC* can operate at higher temperature than other composites; it is resistent to fire, it does not absorb moisture, have better electrical and thermal conductivity, are resistant to radiation damage, have higher specific strength, creep resistance, and dimensional stability.

The reinforcing materials are mainly carbon fibre, silicon carbide. It serves structural task as well as provide wear resistance and also affect friction coefficient and thermal conductivity.

Reinforcement can be of continuous type or discontinuous type. Discontinuous type reinforcement provides isotropic character.

Application: 1. Carbide drills, 2. Defence applications such as tank armours, 3. Sometimes automotive disc brakes are made of MMC.

Solution : 44

(a) The modulus of elasticity of the composite is calculated using below equation

$$E_{cl} = E_m V_m + E_f V_f$$

$$E_{cl} = (3.4\text{ GPa})(0.6) + (69\text{ GPa})(0.4) = 29.64\text{ GPa}$$

(b) To solve this portion of the problem, first find the ratio of fiber load to matrix load,

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

$$\frac{F_f}{F_m} = \frac{(69\text{ GPa})(0.4)}{(3.4\text{ GPa})(0.6)} = 13.5$$

or $$F_f = 13.5\,F_m.$$

In addition, the total force substained by the composite F_c may be computed from the applied stress σ and total composite cross-sectional area A_c according to

$$F_c = A_c\sigma = (250\text{ mm}^2)\,(50\text{ MPa}) = 12{,}500\text{ N}$$

However, this total load is just the sum of the loads carried by fiber and matrix phases; that is,

$$F_c = F_f + F_m = 12{,}500\text{ N}$$

Substitution for F_f from the above yields

$$13.5\,F_m + F_m = 12{,}500\text{ N}$$

or $$F_m = 862\text{ N}$$

whereas $$F_f = F_c - F_m = 12{,}500\text{ N} - 862\text{ N} = 11{,}638\text{ N}$$

Thus, the fiber phase supports the vast majority of the applied laod.

(c) The stress for both fiber and matrix phases must first be calculated. Then, by using the elastic modulus for each (from part a), the strain values may be determined.

For stress calculations, phase cross-sectional areas are necessary:

$$A_m = V_m A_C = (0.6)(250\text{ mm}^2) = 150\text{ mm}^2$$

and $$A_f = V_f A_c = (0.4)(250\text{ mm}^2) = 100\text{ mm}^2$$

Thus, $$\sigma_m = \frac{F_m}{A_m} = \frac{862\text{ N}}{150\text{ mm}^2} = 5.73\text{ MPa}$$

$$\sigma_f = \frac{F_f}{A_f} = \frac{11638\text{ N}}{100\text{ mm}^2} = 116.4\text{ MPa}$$

Finally, strains are computed as

$$\varepsilon_m = \frac{\sigma_m}{E_m} = \frac{5.73\text{ MPa}}{3.4\times10^3\text{ MPa}} = 1.69\times10^{-3}$$

$$\varepsilon_f = \frac{\sigma_f}{E_f} = \frac{116.4\text{ MPa}}{69\times10^3\text{ MPa}} = 1.69\times10^{-3}$$

Therefore, strains for both matrix and fiber phases are identical, which they should be, according to equation :

$$\epsilon_c = \epsilon_m = \epsilon = 1.69\times10^{-3}$$

■■■■

6

Properties and Application of Various Ferrous & their Alloys

LEVEL 1 Objective Questions

1. (a)

2. (d)

3. (b)

4. (d)

5. (d)

6. (a)

7. (b)

8. (a)

9. (c)

10. (a)

11. (c)

12. (a)

13. (a)

14. (d)

15. (c)

16. (b)

17. (a)

LEVEL 2 Objective Questions

18. (c)

19. (a)

20. (c)

21. (a)

22. (d)

23. (b)

24. (b)

25. (b)

26. (a)

27. (d)

28. (c)

29. (b)

30. (d)

31. (b)

32. (b)

33. (c)

34. (c)

35. (d)

36. (a)

■■■■

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LEVEL 3 Conventional Questions

Solution : 37

Generally, the following elements are alloyed to aluminium:

(i) **Copper:** It improves strength to weight ratio; has low resistance to corrosion and are heat treatable.

(ii) **Manganese:** It improves workability, provides moderate strength and generally are not heat-treatable.

(iii) **Silicon:** It lowers melting point; forms an oxide film of a dark-gray to charcoal color and are not heat-treatable.

(iv) **Magnesium:** It provides good corrosion resistance and weldability. It ensures moderate to high strength and are not heat-treatable.

(v) **Magnesium and Silicon:** Provides medium strength, good formability, machinability, weldability and good corrosion resistance.

(vi) **Zinc:** Provides moderate to very high strength and are heat treatable.

Solution : 38

Plain carbon steel or carbon steel is a metal alloy. It is a combination of two elements, iron and carbon other elements added are manganese, silicon and copper.

Alloy steel is a steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties.

- **Chromium** improves toughness, hardenability, wear and corrosion resistance, it increases the depth of hardness penetration resulting from heat treatment by promoting carburization.
- **Nickel** improves strength, toughness and corrosion resistance, it improves hardenability.
- **Manganese** improves hardenability, strength, abrasion resistance and machinability, it deoxidizes the molten steel and reduces hot hardness.
- **Silicon** improves strength, hardness and electrical conductivity, it decreases magnetic hysteresis losses, machinability and cold formability.
- **Molybdenum** improves hardenability, wear resistance, toughness, creep resistance and hardness; it minimizes temper embrittement.
- **Vanadium** improves strength, toughness, abrasion, resistance and hardness at elevated temperatures, it inhibits grain growth during heat treatment.
- **Tungsten** improves strength and hardness at elevated temperatures.

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Iron, nickel and cobalt based alloys used primarily for high temperature applications are known as super alloys. or

Super alloys are nickel, cobalt or iron based alloys with excellent elevated temperature strength, creep properties and oxidation resistance.

Iron based super alloys contain	32 to 37% Iron 15 to 22% chromium 9 to 38% nickel
Cobalt based super alloys contain	35 to 65% cobalt 19 to 30% chromium upto 35% nickel

Nickel based super alloys contain
38 to 76% nickel
27% chromium
20% cobalt

Properties:

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

Application:

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

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

Cobalt based super alloys: Gas turbine engines.

Solution : 40

Properties of *y*-Alloys

1. It can be easily casted and hot worked. This is why it is extensively used for casting.
2. It retains its high strength and hardness at high temperature.
3. This can be worked mechanically.
4. The aging process is carried out at room temperature for about 5 days.
5. Specific gravity is 2.78 in cast conditions.
6. The Brinell hardness number is between 82 to 85 for cast conditions.
7. It has better strength at high temperature than duralumin.

Properties of Duralumin

1. Strength of duralumin is equal to that of mild steel but density is $\frac{1}{3}$ of steel. It is a light weight alloy having specific gravity 2.8.
2. Silicon remains as impurity in it and provides age hardening effect to duralumin. It means it hardens spontaneously when exposed to room temperature.
3. Magnesium present, improves resistance to corrosion, so it is corrosion resistant.
4. It is non-magnetic.
5. The co-efficient of linear expansion is 0.00023/°C.
6. It has high ductility and toughness.
7. It is a good conductor of heat and electricity.
8. It can not be casted but it has good machinability. Forged and stamped components can be manufactured by the use of this alloy.
9. Its tensile strength can be increased, by heat treatment without affecting its ductility. Maximum value of tensile strength is 4000 N/mm^2.
10. Blanking, forming and drawing operations can be easily done.
11. It can work at temperature 500°C
12. Specific heat is 0.214 and melting point is 650°C.

13. Brinell Hardness Number (BHN) for annealed alloy is 60 and for age hardened alloy it is 100.

Hindalium: It is an alloy of aluminium, magnesium, manganese and silicon produced by Hindustan Aluminium Corporation Ltd. It is produced in sheets of 16 gauge which are used for utensil manufacturing (cost of hindalium is $\frac{1}{3}$ of stainless steel).

Properties of Hindalium

1. Strong and hard.
2. Non reactive with food acids.
3. Good surface finish.
4. They are not easily scretching.
5. Cost is lower than stainless steel.

Magnalium: It has following properties,

1. It is an alloy of aluminium, magnesium copper, nickel and tin.
2. It is a light weight alloy. It's tensile strength is in the range of 20-25 kg/mm^2.
3. Percentage elongation is 7% for cold worked state and 30% for annealed state.
4. Brittle with poor castability. However, it can be welded.
5. Good machinability.

Solution : 41

Carbon steels in their commercial forms always contain certain amounts of other elements. Many of these elements enter the steel from the ores and it is difficult to remove them during the process of steel making. All commercial steels contain varying amounts of Mn, Si, S and P and frequently varying amounts of such elements in Cr, Ni, Mo and V. If alloying elements other than carbon are present only in small amounts (e.g. Mn upto 0.8%, Si upto 0.3%, etc.) then the steel is usually called low alloy steel or plain carbon steel. Sulphur and phosphorus when more than 0.05% of either is present, tend to make steel brittle, so that during steel making these elements are reduced to at least this value. Si has little effect on strength and ductility if less than 0.2% is present. As the content is rasied to 0.4% the strength is raised without effecting ductility, but above 0.4%o Si, the ductility is impaired. Si is added as deoxidiser and that part which does not make silicon dioxide remains in steel as impurity.

Mn is another alloying element which is present in most steels. If it exists in solid solution in the ferrite it has a strengthening effect. It may also exist in forms of Mn_3C which forms part of the pearlite of MnS. Upto 1% of Mn has Strengthening effects on steel and its presence in excess of 1.5% induces brittleness in steel. Excess Mn is added to melt during steel making to bring its level to desired value. It also acts as a deoxidiser.

Intentional addition of many other elements modifies the structure of steel and hence improves its properties. Steels to which such intentional additions have been made (including those steel which contain Mn in excess of 1% or Si in excess of 0.3%) are known as alloy steels. One particular effect of alloying is that it enables martensite to be produced with low rates of cooling and permits larger sections to be hardened than is possible with plain carbon steel.

The important elements that are used to alloy with steel in varying quantities are Ni, Cr, Mo, W, Mn and Si. The **BCC** metals like Cr, W and Mo when alloyed with steel tend to form carbides which reduce the proportion of Fe_3C in the structure. On the other hand the **fcc** elements like Ni, Al, Cu and Zr do not form carbides. Mn which has three allotropic complex structures also forms carbide.

Several advantages in terms of improved mechanical properties and corrosion resistance are obtained by adding one or several alloying elements.

The various advantages of alloy steel are :

(a) Higher hardness, strength and toughness on surface and over bigger cross-section.

(b) Better hardenability and retention of hardness at higher temperature (good for creep and cutting tools).

(c) Higher resistance against corrosion and oxidation.

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The alloying elements affect the properties of plain C steel in four ways:

(a) By strengthening ferrite while forming a solid solution. The strengthening effects of various alloying elements are in this order : Cr, W, V, Mo, Ni, Mn and Si.

(b) By forming carbides which are harder and stronger. Carbides of Cr and V are hardest and strongest against wear particularly during tempering. high alloy tool steel use this effect.

(c) Ni and Mn lower the austenite formation temperature while other alloying elements raise this temperature. Most elements shift eutectoid composition to lower C percentage.

(d) Most elements shift the isothermal transformation curve (TTT) to lower temperature, thus lowering the critical cooling rate. Mn, Ni, Cr and Mo are prominently effective in this respect.

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