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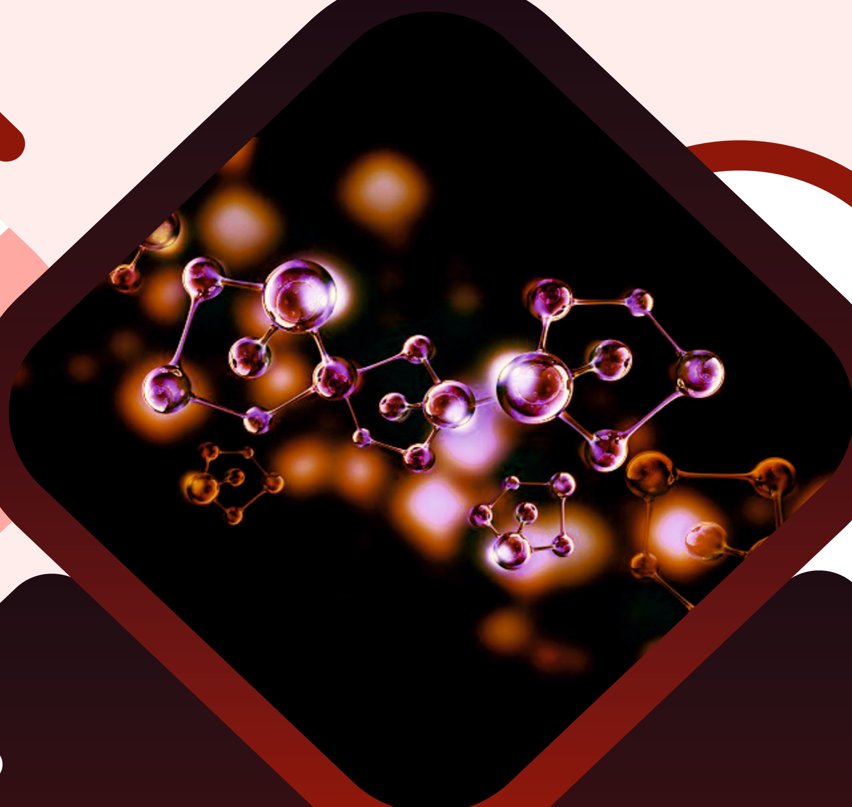

MECHANICAL ENGINEERING

ENGINEERING MATERIALS

Text Book & Workbook:

Theory with worked out Examples and Practice Questions

Engineering Materials

(Solutions for Text Book Practice Questions)

Chapter 1 Material Properties and Testing

01. Ans: (d)

Sol: The *total area under the stress–strain curve up to failure* represents the energy absorbed per unit volume by the material before it fractures. This property is called toughness.

- Ductility → measured by % elongation or reduction in area
- Ultimate strength → maximum stress on the curve
- Stiffness → related to slope of the elastic portion (Young's modulus)
- Toughness → area under the entire stress–strain curve

02. Ans: Reduction

Sol:

- Percent elongation measures overall plastic stretching
- Percent reduction in area measures localized deformation at fracture
- Both are obtained from a tensile test and together give a reliable indication of ductility

03. Ans: (c)

Sol:

For carbon steels, there is an approximate empirical relationship between Brinell Hardness Number (BHN) and ultimate tensile strength (UTS):

UTS (in N/mm^2) $\approx 3.45 \times$ BHN

Given: BHN = 100

UTS $\approx 3.45 \times 100 = 345\ N/mm^2$

04. Ans: (b)

Sol: The area under the stress–strain curve up to the proportional limit represents the energy absorbed per unit volume without permanent deformation. This is called proof resilience.

(a) Resilience – General ability of a material to absorb energy in the elastic range.

(b) Proof resilience – Maximum elastic energy per unit volume, equal to the area under the stress–strain curve up to the proportional point.

(c) Fracture toughness – Resistance to crack propagation.

(d) Toughness – Total energy absorbed up to fracture (entire stress–strain curve).

05. Ans: (a)

Sol: Stiffness of a metal refers to its resistance to elastic deformation when a load is applied. This property is characterized by the modulus of elasticity (Young's modulus).

(a) Modulus of elasticity – Measures the ratio of stress to strain in the elastic region and directly indicates stiffness.
(b) Yield strength – Indicates the stress at which plastic deformation begins.
(c) Ultimate tensile strength – Maximum stress a material can withstand before fracture.
(d) Elongation – Measure of ductility, not stiffness.

06. Ans: (a)

Sol: In the Izod impact test, the specimen is held vertically and is fixed at one end, while the other end is free to be struck by the pendulum. This arrangement makes the specimen act like a cantilever beam.

07. Ans: (b)

Sol: In a compression test of a circular specimen, the L/D ratio (length to diameter ratio) strongly affects the measured compressive strength due to buckling and barreling effects.

As the L/D ratio increases, the specimen becomes more slender and is more prone to buckling, which reduces the apparent compressive strength.

08. Ans: (c)

Sol: Ductility is the property of a material that allows it to be stretched or drawn into a fine wire without breaking. It is an important mechanical property, especially for metals like copper, aluminum, and steel, which are used in wires and cables. Ductile materials can undergo significant plastic deformation under tensile stress before fracture.

Other related properties include:

- Malleability – ability to be hammered into thin sheets
- Elasticity – ability to return to original shape after stress
- Rigidity – resistance to deformation

09. Ans: (d)

Sol: The metal that will readily fracture if struck with a hammer is cast iron. This is because cast iron is brittle, meaning it has very low ductility and cannot undergo significant plastic deformation before breaking. While it has high compressive strength, it is weak under tension or impact, so it fractures suddenly when hit.

In contrast, mild steel and nickel silver are ductile and can bend without breaking, and brass is tougher than cast iron. Therefore, among the given metals, cast iron is most prone to sudden fracture under impact, making it unsuitable for applications requiring toughness or flexibility.

10. Ans: (b)

Sol: The metal that can be easily drawn into wire is copper due to its high ductility. Ductility is the ability of a material to undergo significant plastic deformation under tensile stress without breaking. Copper is widely used in electrical wiring, cables, and telecommunication lines because it can be stretched into long, thin wires while retaining strength and conductivity.

Other metals like tin, lead, and zinc are either too soft, brittle, or lack sufficient tensile strength to be drawn into wire efficiently. Copper's combination of ductility, strength, and conductivity makes it ideal for wire production and many industrial applications.

11. Ans: (d)

Sol: For a tensile test specimen, the standard gauge length is:

$$L_0 = 5.65\sqrt{A}$$

For diameter d = 25 mm

$$A = \frac{\pi d^2}{4} = \frac{\pi(25)^2}{4} \approx 490.9\,\text{mm}^2$$

$$L_0 = 5.65\sqrt{490.9} \approx 5.65 \times 22.16 \approx 125\,\text{mm}$$

12. Ans: (c)

Sol: For elastic or small plastic strain, the true stress σ_t is related to engineering stress σ_e and engineering strain ε by:

$$\sigma_t = \sigma_e(1+\varepsilon)$$

Also, engineering stress in the elastic region is:

$$\sigma_e = E.\varepsilon$$

$$\sigma_e = E.\varepsilon = 2\text{GPa} \times 0.2$$

$$\sigma_e = 0.4\,\text{GPa} = 400\,\text{MPa}$$

$$\sigma_t = \sigma_e(1+\varepsilon) = 400\,\text{MPa} \times (1+0.2)$$

$$\sigma_t = 400 \times 1.2 = 480\,\text{MPa}$$

13. Ans: (a)

Sol: In impact tests (like Charpy or Izod), a notch is deliberately provided on the specimen to concentrate stress at a specific point. This makes the material more likely to fracture at that point and helps measure its notch sensitivity or brittleness under sudden loading.

14. Ans: (b)

Sol: In the stress–strain curve of mild steel, the ultimate tensile stress (UTS) is higher than the yield stress because of work hardening. After the steel yields, it undergoes plastic deformation, during which dislocations move and interact, making further deformation more difficult. This increases the stress required to continue stretching the metal, so the stress rises to the ultimate value. The initial slip of planes causes yielding, but the subsequent strain hardening strengthens the metal. Twinning and interatomic forces play minor roles. Thus, work hardening is the main reason why mild steel's UTS exceeds its yield stress.

15. Ans: (c)

Sol: In tensile testing, smaller specimens often show higher strength because the likelihood of large defects is lower. Defects like voids, cracks, or inclusions act as stress concentrators and cause early failure. A smaller specimen has less volume, so the chance of having a critical defect decreases, allowing the material to sustain higher stress before fracture.

16. Ans: (b)

Sol: In the Brinell hardness test, a hard steel or tungsten carbide ball is pressed into the surface of the specimen under a specific load. The most commonly used ball diameter for general metals is 10 mm.

17. Ans: (b)

Sol: Ultimate Tensile Strength (UTS) for steels:

$$\text{UTS (MPa)} \approx 3.45 \times \text{BHN}$$

Brinell Hardness Number (BHN) = 50

$$\text{UTS} = 3.45 \times 50$$

$$= 172.5 \text{ MPa} \approx 175 \text{ MPa}$$

18. Ans: (c)

Sol: In the Vickers hardness test, the indentor is a diamond in the shape of a square-based pyramid with an angle of 136° between opposite faces. This design allows for accurate measurement of hardness on a wide range of materials.

19. Ans: (a)

Sol: In the Rockwell hardness test, the indentor depends on the scale:

- For hard materials (like steel), a sphero-conical diamond cone of 120°, also called a Brale diamond, is used.
- For softer materials, a steel or tungsten carbide ball is used instead.

20. Ans: (d)

Sol: In the Vickers hardness test, the formula

$$\text{VHN} = \frac{1.854\,P}{D^2}$$

where: P = applied load (in kgf)

D = diagonal of the square-shaped indentation left by the diamond pyramid

The vickers test uses a square-based pyramid indentor, and the hardness is calculated from the diagonal of the impression, not the indentor itself.

21. Ans: (c)

Sol: True strain (ε_t) = $\ell n\left(\frac{\ell_f}{\ell_0}\right) = \ell n\left(\frac{A_0}{A_f}\right)$

Since volume is approximately constant during plastic deformation:

$$A_0.\ell_0 = A_f.\ell_f \Rightarrow \frac{\ell_f}{\ell_0} = \frac{A_0}{A_f}$$

For a circular rod, $A = \frac{\pi D^2}{4}$, so:

$$\varepsilon_t = \ell n\left(\frac{A_0}{A_f}\right) = \ell n\left(\frac{D_0^2}{D_f^2}\right) = 2\ell n\left(\frac{D_0}{D_f}\right)$$

$$\varepsilon_t = 2\,\ell n\left(\frac{50}{25}\right) = 2\,\ell n(2)$$

$$\ell n(2) \approx 0.693$$

$$\varepsilon_t = 2 \times 0.693 = 1.386$$

22. Ans: (c)

Sol: For rubber and very thin sheets, standard hardness testers like Vickers or Brinell cannot be used because they require significant thickness and leave permanent impressions.

Instead, a Shore durometer or Scleroscope (Schores schaloriscope) is used, which measures surface hardness by indentation or rebound without damaging thin materials.

23. Ans: (b)

Sol: The Shores Scleroscope measures hardness based on the rebound of a diamond-tipped hammer dropped on the material. The higher the rebound height, the harder the material.

24. Ans: (a)

Sol: The Mohs hardness test is based on the material's resistance to scratching. In this test, a material of known hardness is used to scratch the surface of the test material, and the hardest material that can scratch it determines its Mohs hardness.

25. Ans: (b)

Sol: For very highly brittle materials (like glass, ceramics, or hard brittle carbides), standard indentation tests (Vickers, Brinell, Barcol) may cause cracking or fracture. Instead, the Mohs hardness test, which is based on scratching, is suitable because it does not require large loads or plastic deformation.

26. Ans: (d)

Sol: In the Mohs hardness test, hardness is measured by a material's ability to scratch another material. In this case, quartz (hardness 7) cannot scratch the glass, which means the glass is harder than quartz. Topaz (hardness 8), however, can scratch the glass, indicating that the glass is softer than topaz.

Therefore, the hardness of the glass lies between 7 and 8 on the Mohs scale. This shows that glass is relatively hard but not as hard as topaz. Such reasoning is commonly used to estimate the hardness of brittle materials using standard reference minerals.

27. Ans: (c)

Sol: The bend test involves bending a specimen, usually a metal rod or sheet, until it fractures or shows a certain bend. This test is primarily used to measure the material's ability to undergo plastic deformation without cracking, which is a measure of ductility.

28. Ans: (b)

Sol: The Charpy test measures the energy absorbed by a material during sudden fracture, especially at a notch. While it is often used to compare brittleness, in engineering terms, the absorbed energy is also directly related to the material's fracture toughness, which quantifies its resistance to crack propagation under impact.

29. Ans: (a)

Sol: Malleability is the property of a material that allows it to be hammered, pressed, or rolled into thin sheets or plates without cracking or breaking. It reflects the material's ability to undergo plastic deformation under compressive stress. Metals like gold, silver, and copper exhibit high malleability.

30. Ans: (d)

Sol: The resistance to fatigue of a material is its ability to withstand repeated or fluctuating stresses over a long period without failure. This property is quantified by the endurance limit, which is the maximum stress a material can endure for an effectively infinite number of load cycles without developing fatigue cracks. Unlike ultimate tensile strength or elastic limit, which relate to single-load performance, the endurance limit specifically addresses cyclic loading conditions common in machinery and structural components. Materials with a high endurance limit, such as steel, are preferred in applications like shafts, gears, and springs, where repeated stresses occur.

31. Ans: (a)

Sol: When a material is loaded within its elastic limit, it follows Hooke's Law, meaning the stress is directly proportional to strain. The proportionality constant is Young's modulus (E). This relationship holds only in the elastic region, where the material returns to its original shape after unloading.

32. Ans: (b)

Sol: The property of a material that enables it to resist fracture under high impact load is called toughness.

- Toughness is the total energy a material can absorb before fracturing, combining both strength and ductility. It is measured by impact tests like Charpy or Izod.

33. Ans: (c)

Sol: Proof stress is the stress at which a material begins plastic deformation, indicating the start of yielding. For materials like mild steel, which lack a distinct yield point, a small offset (commonly 0.2%) is used to define this stress. It helps engineers design safely within elastic limits.

34. Ans: (c)

Sol: A non-destructive test (NDT) evaluates a material without causing damage. Among the given options, radiography is non-destructive, as it uses X-rays or gamma rays to detect internal flaws like cracks or voids. Tests like impact, Charpy, and tensile are destructive because they fracture or permanently deform the specimen.

35. Ans: (c)

Sol: Materials whose properties are the same in all directions are called isotropic materials. This means that characteristics like strength, elasticity, and thermal expansion do not depend on the direction in which they are measured. Most metals in bulk form are approximately isotropic.

36. Ans: (a)

Sol: UTS (MPa) $\approx 3.45 \times$ BHN

Where BHN = 45

UTS = $3.45 \times 45 = 155.25$ MPa ≈ 157 MPa

37. Ans: (a)

Sol: The creep behavior of metals is the time-dependent plastic deformation that occurs when a material is subjected to a constant stress at high temperature over a long period.

The primary phenomenon causing creep is slip, which is the movement of dislocations along crystallographic planes under stress.

38. Ans: (a)

Sol: The main difficulty in plotting a true stress–true strain curve during a tensile test arises because true stress requires the actual cross-sectional area of the specimen at each instant, which continuously decreases as the specimen elongates. Accurately measuring this changing area during the test is very challenging.

39. Ans: (d)

Sol: The fracture toughness of a material is a measure of its resistance to crack propagation. It depends on the material's ability to absorb energy and undergo plastic deformation at the crack tip before fracturing.

40. Ans: (b)

Sol: In microhardness tests like the Vickers hardness test, the indentor is a square-based diamond pyramid, and the angle between opposite faces of the pyramid is 136°.

41. Ans: (a)

Sol: The strength of a material is its ability to resist applied forces. It is defined as the resistive force per unit cross-sectional area under load, which is essentially the stress at which the material fails. Strength measures how much load a material can carry before breaking.

42. Ans: (a)

Sol: Creep is the property of a material to undergo gradual, time-dependent deformation when subjected to a constant load or stress, especially at high temperatures. Unlike instantaneous deformation, creep occurs slowly over time, and its study is important for designing components like turbines, boilers, and pressure vessels that operate under prolonged stress.

43. Ans: (d)

Sol: The endurance strength of a metal is determined by its ability to resist failure under repeated or cyclic loading. This is measured using a fatigue test, which subjects the material to fluctuating stresses over many cycles, identifying the maximum stress it can withstand indefinitely without fracture.

44. Ans: (b)

Sol: Impact strength measures a material's ability to absorb energy under sudden or dynamic loading. It depends on both toughness, which indicates how much energy the material can absorb before fracture, and strength, which indicates resistance to applied stress. Materials with high toughness and strength have higher impact strength.

45. Ans: (b)

Sol: Impact strength measures a material's ability to absorb energy during sudden fracture. It is determined using Izod and Charpy tests, where a notched specimen is struck by a pendulum. These tests evaluate how materials resist brittle fracture under dynamic loading, providing important data for structural applications.

46. Ans: (b)

Sol: Malleability is the ability of a metal to withstand compressive forces without cracking, allowing it to be hammered or rolled into thin sheets.

Metals like gold, silver, and copper exhibit high malleability. It is distinct from ductility, which involves stretching under tensile loads, rather than compression.

47. Ans: (a)

Sol: Resilience is the ability of a material to absorb energy when it is elastically deformed and release that energy upon unloading. It represents the energy stored per unit volume in the elastic region.

48. Ans: (d)

Sol: Severe vibration subjects a material to repeated and fluctuating stresses over time. Such cyclic loading can cause fatigue failure, even when stresses are below the material's strength. Therefore, severe vibration is considered a fatigue condition of design, not impact, shock, or static loading.

49. Ans: (b)

Sol: Workability is the ability of a material to be easily shaped or deformed during manufacturing processes such as rolling, forging, or extrusion. It is also known as formability, indicating how well a material can undergo plastic deformation without cracking or failure.

50. Ans: (d)

Sol: Machinability is influenced by several material properties. The ability to undergo plastic deformation affects chip formation, toughness influences cutting forces and tool wear, and grain orientation affects surface finish and ease of cutting. Therefore, machinability depends on all these factors combined.

51. Ans: (b)

Sol: The correct expression for diamond pyramid hardness (DPH) is $1.854 \times P/D^2$.
This formula is used in the Vickers hardness test, where P is the applied load and D is the average diagonal length of the indentation.

52. Ans: (b)

Sol: The ability of a material to resist elastic deformation is called stiffness. It indicates how much a material deforms under an applied load within the elastic limit. Materials with high stiffness show very small elastic deformation when subjected to stress.

53. Ans: (b)

Sol: During impact testing, a notched specimen is fractured by a standard blow from a pendulum hammer. This test, such as the Charpy or Izod impact test, measures the energy absorbed by the material during sudden loading. It helps evaluate the material's toughness and its ability to resist shock or impact loading.

54. Ans: (b)

Sol: Fatigue testing using the Wohler fatigue machine is carried out by rotating a test specimen that carries a constant load with the help of a motor. As the specimen rotates, it is subjected to repeated cyclic stresses. This method helps determine the fatigue strength and endurance limit of a material under fluctuating loading conditions.

55. Ans: (b)

Sol: Critical resolved shear stress (CRSS) is defined as the minimum value of shear stress resolved along a specific slip plane and slip direction at which plastic deformation begins in a crystal. When this critical value is reached, atomic planes start to slide over each other, resulting in slip. Therefore, option (b) correctly describes CRSS.

56. Ans: (a)

Sol: The fatigue strength of a material can slightly increase with repeated cyclic stresses due to cyclic hardening. When a material is subjected to repeated loading below its ultimate strength, its dislocations rearrange, and the microstructure adapts, making it more resistant to further deformation. This temporary increase in strength continues until the material reaches a stabilized state. Unlike cold working, which is a permanent strengthening process, this effect occurs naturally during controlled cyclic loading before fatigue failure eventually begins.

57. Ans: (a, c, d)

Sol: In the Rockwell hardness testing method, the hardness of a material is determined by measuring the depth of penetration of an indenter under a specific load. This method is quick, making it suitable for testing industrial components efficiently.

The test load is applied in two stages: a minor load is first applied to seat the indenter, followed by a major load for measurement. Rockwell uses spherical (ball) or conical (brale) indenters, not the inverted pyramid type used in the Vickers test.

Therefore, statements (a), (c), and (d) are Correct, while (b) is INCORRECT.

Chapter 2 Crystal Structure and Defects

01. Ans: (b)

Sol: Grain boundaries have atoms with higher energy compared to atoms inside the grains because they are less ordered and more loosely packed. This makes them more chemically reactive, so corrosive chemicals tend to attack these regions first. As a result, intergranular corrosion occurs along the grain boundaries, weakening the material even if the grains themselves remain relatively unaffected.

02. Ans: (c)

Sol: Polymers are made of macromolecules formed by repeating units called monomers. Metallic materials do not specifically require valence 5 – 7, and ceramics have strong ionic or covalent bonds, not a long-range electron matrix bond. Ceramics are strong in compression but brittle, so their weakness is due to brittleness, not weak bonding.

03. Ans: (c)

Sol: The coordination number of a Face-Centered Cubic (FCC) crystal structure is 12. This means each atom is in contact with 12 nearest neighboring atoms – 4 in the same plane, 4 in the plane above, and 4 in the plane below. The high coordination number contributes to the dense packing and high ductility of FCC metals, making them relatively strong and malleable compared to other crystal structures.

04. Ans: (a)

Sol: Brass, an alloy of copper and zinc, typically adopts a Face-Centered Cubic (FCC) crystal structure. This is because copper, the primary component, naturally has an FCC lattice, and adding zinc maintains the FCC arrangement, giving brass good ductility and malleability.

05. Ans: (b)

Sol: Work hardening (strain hardening) occurs when a metal's dislocation density increases during plastic deformation, making it stronger and harder.

Among the options:

- Brass work-hardens faster because it has a substitutional alloy structure, which impedes dislocation movement more than pure metals like copper, silver, or lead.
- Copper and silver are pure metals with higher ductility and slower work hardening.
- Lead is very soft and deforms easily, showing minimal work hardening.

06. Ans: (b)

Sol: Aluminium has a Face-Centered Cubic (FCC) crystal structure. This arrangement allows atoms to be closely packed, giving aluminium its high ductility, malleability, and good electrical conductivity. FCC metals generally deform easily under stress due to the availability of multiple slip systems.

07. Ans: (b)

Sol: Mild steel, which is mostly iron with a small amount of carbon, has a B.C.C. crystal structure at room temperature (known as ferrite). In this structure, each atom is surrounded by 8 nearest neighbors. B.C.C. metals are less densely packed than FCC metals, making mild steel stronger but less ductile compared to FCC metals like aluminium or copper.

08. Ans: (b)

Sol: Welding introduces residual stresses and can make the heat-affected zone of a saw blade brittle. Annealing involves heating the metal and then slowly cooling it, which relieves internal stresses, softens the material, and improves toughness, reducing brittleness caused by welding.

09. Ans: (c)

Sol: Gibbs phase rule relates the number of degree of freedom (F), the number of components (C), and the number of phases (P) in a system at equilibrium:

$$\mathbf{F = C - P + 2}$$

It tells us how many variables (like temperature, pressure, and composition) can be changed independently without changing the number of phases in a system.

10. Ans: (a)

Sol: A dislocation is an imperfection or defect in the regular arrangement of atoms in a crystal structure. Dislocations allow metals to deform plastically under stress, making them less brittle. They are different from slip (movement along a plane), fracture (breaking of the material), or impurity (foreign atoms in the crystal).

11. Ans: (c)

Sol: In a crystal, a line imperfection is called a dislocation, specifically an edge dislocation. This occurs when an extra half-plane of atoms is inserted into the crystal lattice, creating a defect along a line. Line imperfections allow metals to deform plastically under stress. Other defects, like Frenkel and Schottky defects, are point defects, involving missing or displaced atoms, and are not considered line imperfections.

12. Ans: (a)

Sol: The INCORRECT relation between lattice constant a and atomic radius R is $R^2 = 4a^2$. This does not match any standard crystal structure.

The other relations are correct:

$16R^2 = 3a^2$ for FCC,

$64R^2 = 3a^2$ for BCC,

and $16R^2 = 2a^2$ for HCP.

Therefore, only option 1 is wrong, while the rest correctly describe the relationship between atomic radius and lattice constant.

13. Ans: (c)

Sol: Mechanical work hardening (or strain hardening) strengthens a metal by plastic deformation, which increases the number of dislocations in the crystal lattice. These dislocations interact and pile up, restricting further movement of grains and making the metal harder and stronger. It is not limited to the surface or internal core alone.

14. Ans: (c)

Sol: Precipitation hardening, also called age hardening, is mainly used in non-ferrous alloys like aluminium, copper, and nickel alloys. The process involves solution treatment, quenching, and aging, where fine precipitates form within the metal matrix. These precipitates impede dislocation movement, increasing strength and hardness. Although some steels can be age-hardened, it is most commonly applied to non-ferrous alloys.

15. Ans: (d)

Sol: Solid solution hardening is a strengthening method where solute atoms are added to a metal's crystal lattice. It is favored by:

(a) size difference between solute and solvent atoms, which creates lattice strain,

(b) a larger number of solute atoms, which increases obstacles to dislocation movement, and

(c) formation of interstitial solid solutions, where small atoms distort the lattice.

All these factors impede dislocations, increasing the metal's strength and hardness.

16. Ans: (c)

Sol: When impurities are added to a material, they create point defects in the crystal structure. These include substitutional defects, where impurity atoms replace host atoms, and interstitial defects, where smaller impurity atoms occupy spaces between the host atoms. Such defects modify the material's properties, like strength, hardness, and conductivity. They are different from line defects such as screw or edge dislocations, which involve dislocations in the crystal lattice.

17. Ans: (b)

Sol: Line defects, also called crystal dislocations, are one-dimensional defects in a crystal lattice. They occur along a line where atoms are misaligned, allowing plastic deformation to occur more easily. Examples include edge dislocations and screw dislocations. They are different from point defects (0D) or three-dimensional defects like voids or inclusions.

18. Ans: (a)

Sol: The Burgers vector represents the magnitude and direction of strain caused by a dislocation in a crystal. It measures how much the atoms in the lattice are displaced due to the dislocation, helping to describe the lattice distortion. This vector is essential for understanding plastic deformation and slip in metals. It is not related to applied stress or general twinning, but specifically to the strain from dislocations.

19. Ans: (a)

Sol: A twin boundary defect occurs when a portion of the crystal lattice is a mirror image of the adjacent lattice across a specific plane called the twin plane. This happens due to an angular dislocation, which reorients atoms to form the mirrored arrangement. Twinning is different from ordinary slip or dislocation movement and is a distinct crystal defect mechanism.

20. Ans: (c)

Sol: Stacking faults are planar defects that occur when the normal sequence of atomic planes in a crystal is interrupted. For example, in an FCC crystal, the typical ABCABC… stacking may locally become ABCABABC… This disruption changes the local structure and can affect the material's mechanical properties, such as slip behavior, without involving vacancies or dislocations directly.

21. Ans: (d)

Sol: Viscoelastic deformation occurs in materials like polymers, where the response to stress is time-dependent and temperature-sensitive. It involves molecular motion, where chains or groups of molecules slide or rearrange under applied stress. Therefore, viscoelastic behavior depends on:

- Time (duration of applied stress),
- Temperature, and
- Molecular sliding or rearrangement.

All these factors together govern the viscoelastic response.

Chapter 3 Phase Diagrams

01. Ans: (a)

Sol:

- The iron-carbon equilibrium diagram (phase diagram) is determined under equilibrium conditions, showing stable phases at given temperatures and compositions.
- The TTT (Time-Temperature-Transformation) curves are determined under non-equilibrium conditions, as they describe how phases transform over time when cooling at different rates, capturing kinetic effects rather than just equilibrium states.

02. Ans: (c)

Sol: *Increasing the carbon content in plain carbon steel:*

- Increases tensile strength because carbon atoms hinder dislocation motion, strengthening the steel.
- Increases hardness for the same reason, making the steel more resistant to deformation.
- Ductility and malleability decrease with higher carbon, so options mentioning these are INCORRECT.

Higher carbon makes steel stronger but less ductile.

03. Ans: F.C.C

Sol: At 1000°C, iron exists in the gamma (γ) phase, which has a Face-Centered Cubic (FCC) crystal structure.

Iron undergoes several allotropic transformations with temperature. Below 912°C it is alpha iron (BCC), between 912°C and 1394°C it changes to gamma iron (FCC), and above 1394°C it again becomes delta iron (BCC).

Therefore, at 1000°C, iron clearly has an FCC structure.

04. Ans: (c)

Sol: During annealing of cold-worked metals, first stress relief occurs where internal stresses are reduced. Next, recrystallization takes place, forming new strain-free grains. Finally, with continued heating or holding time, grain growth occurs as larger grains grow at the expense of smaller ones.

05. Ans: (b)

Sol: The compound Fe_3C present in steel is known as cementite. It is a hard and brittle phase of iron carbide found in steel microstructures. Ferrite is pure iron (α-iron), austenite is FCC iron with dissolved carbon, and martensite is a supersaturated solid solution formed by rapid quenching.

06. Ans: (d)

Sol: A TTT (Time–Temperature–Transformation) diagram shows how austenite transforms into other phases such as pearlite, bainite, or martensite with respect to time and temperature under non-equilibrium cooling conditions.

07. Ans: (c)

Sol: Gray cast iron typically contains 2–4% carbon, which is present mainly in the form of graphite flakes. This high carbon content gives gray cast iron good castability, damping capacity, and machinability.

08. Ans: (b)

Sol: In white cast iron, carbon is present mainly in the combined form as cementite (Fe_3C). This makes white cast iron hard and brittle, unlike gray cast iron where carbon exists as free graphite.

09. Ans: (d)

Sol: In the iron–carbon equilibrium diagram, the eutectic reaction takes place at approximately 1130°C with a carbon content of 4.3%. At this point, liquid iron transforms into a mixture of austenite and cementite, known as ledeburite. This eutectic composition is important in cast irons and strongly influences their microstructure and mechanical properties.

10. Ans: (b)

Sol: In the iron–carbon equilibrium diagram, the eutectoid reaction occurs at 723°C with a carbon content of approximately 0.8%. At this point, austenite (γ-iron with carbon) transforms into a fine mixture of ferrite and cementite, called pearlite. This transformation is crucial in steels, as it determines their hardness, strength, and ductility.

11. Ans: (d)

Sol: Pearlite is a lamellar microstructure formed during the eutectoid transformation of austenite in steel. It consists of alternating layers of soft, ductile ferrite (α-iron) and hard, brittle cementite (Fe_3C). This combination gives pearlite a balance of strength and ductility, making it an important structural component in steels.

12. Ans: (b)

Sol: Case hardening works best on low carbon steels because their surface carbon content can be increased through processes like carburizing, forming a hard outer layer (cementite) while the low-carbon core remains soft and ductile. Medium-carbon steels are already harder in the core, so the benefit of case hardening is less significant compared to low-carbon steels.

13. Ans: (c)

Sol: In steel, carbon directly affects the critical temperatures (A_1, A_3, and A_cm) that determine phase transformations during heat treatment. Higher carbon content lowers the A_1 temperature (eutectoid temperature) and changes the start and finish temperatures for austenite formation. Other elements like sulfur, phosphorus, and chromium influence hardness, corrosion resistance, or hardenability, but carbon is the main factor controlling the critical transformation temperatures.

14. Ans: (a)

Sol: High carbon steel with 0.85% C is near the eutectoid composition. When it is cooled very slowly from 1000°C, the austenite transforms completely into pearlite, which is a lamellar mixture of ferrite and cementite. Very little or no ferrite or cementite exists separately, so the steel consists almost entirely of pearlite at room temperature.

15. Ans: (c)

Sol: The critical temperature of steel is the temperature to which it must be heated so that, upon quenching, it undergoes a phase transformation to form martensite, making the steel hard. This temperature depends on the carbon content of the steel and corresponds to the start of austenite formation (A_3 for hypoeutectoid steels, A_{cm} for hypereutectoid steels).

16. Ans: (b)

Sol: Gamma iron (γ-iron or austenite) exists in the temperature range 912°C to 1394°C. Its crystal structure is face-centered cubic (FCC), which allows more slip systems, making it more ductile compared to alpha iron (BCC).

17. Ans: (d)

Sol: In nodular (ductile) iron, graphite exists in the form of spherical nodules rather than flakes. This spheroidal shape reduces stress concentration points, improving ductility and toughness compared to gray cast iron, where graphite occurs as flakes. The spherical graphite helps nodular iron resist brittle fracture while maintaining good castability.

18. Ans: (b)

Sol: Alpha iron (α-iron) is body-centered cubic (BCC) and paramagnetic below 770°C (ferromagnetic below 770°C). When heated to 910°C, it transforms into gamma iron (γ-iron) with a face-centered cubic (FCC) structure. This transformation is part of the allotropic changes in iron with temperature, which are important in steel heat treatment and phase diagrams.

19. Ans: (c)

Sol: Pearlite is a lamellar microstructure formed during the eutectoid transformation of austenite in steel. It consists of alternating layers of soft, ductile ferrite (α-iron) and hard, brittle cementite (Fe_3C). This combination gives pearlite a balance of strength and ductility, making it an important structural component in steels.

20. Ans: (b)

Sol: Diamond is the hardest naturally occurring material due to its strong covalent bonding in a tetrahedral crystal structure. Its hardness makes it highly resistant to scratching, cutting, or abrasion, which is far greater than ceramics, high-speed steel, or cementite (Fe_3C). Diamond is widely used in cutting tools, abrasives, and industrial applications because of this exceptional hardness.

21. Ans: (a)

Sol: Eutectoid steel contains approximately 0.8% carbon. When cooled slowly, austenite transforms completely into pearlite at the eutectoid temperature (723°C). Pearlite is a lamellar mixture of ferrite and cementite, but in eutectoid steel, the entire structure is pearlite, with no free ferrite or cementite. This gives eutectoid steel a balance of strength and hardness.

22. Ans: (d)

Sol: The increasing order of brittleness for steel microstructures is:

Bainite: Tough and less brittle than others.

Troostite: Slightly harder, moderately brittle.

Pearlite: Harder, more brittle than bainite and troostite.

Martensite: Hardest and most brittle due to trapped carbon in the BCT lattice.

23. Ans: (a)

Sol: When molten iron is cooled below 1394–1395°C, it transforms into gamma iron (γ-iron or austenite). Gamma iron has a Face-Centered Cubic (FCC) structure and is non-magnetic. This phase exists up to 912°C, above which it transforms to alpha iron (BCC, ferromagnetic). The FCC structure of γ-iron allows more slip systems, making it more ductile than BCC α-iron.

24. Ans: (b)

Sol: When molten iron cools below 910°C, it transforms into alpha iron (α-iron) with a Body-Centered Cubic (BCC) structure.

At this temperature, α-iron is non-magnetic, because the Curie temperature for ferromagnetism is 770°C. Only when cooled further below 770°C does it become magnetic. This BCC structure is less dense than FCC gamma iron and provides α-iron with softness and ductility.

25. Ans: (c)

Sol: When iron cools below 768°C (the Curie temperature), alpha iron (α-Fe), which already has a BCC structure, becomes ferromagnetic.

Above 768°C, α-iron is non-magnetic, even though it retains the BCC crystal structure. This change in magnetic property is due to the alignment of atomic magnetic moments in the BCC lattice at temperatures below the Curie point.

26. Ans: (b)

Sol: Ledeburite is a eutectic microstructure found in cast irons with about 4.3% carbon. It forms when liquid iron solidifies into a mixture of austenite (γ-Fe) and cementite (Fe_3C) at the eutectic temperature (~1130°C).

Ledeburite has a coarse, acicular appearance under the microscope and is very hard and brittle, unlike pearlite, which is a lamellar mixture of ferrite and cementite.

27. Ans: (a)

Sol: Sorbite is a tempered pearlite microstructure obtained by tempering martensite at a moderate temperature. It consists of soft ferrite matrix with finely dispersed cementite particles, giving a good combination of strength and toughness. Unlike bainite or pearlite, sorbite is very fine and uniform, improving mechanical properties while reducing brittleness.

28. Ans: (b)

Sol: In the Fe-C equilibrium system, the peritectic reaction occurs at about 1493°C. Below the peritectic point, delta iron (δ-iron, BCC) gradually transforms into gamma iron (γ-iron, FCC) as it cools. This transformation is part of the allotropic changes of iron, which include δ → γ → α iron, and is important in steel solidification and heat treatment.

29. Ans: (a)

Sol: Martensite forms in steel when austenite is quenched rapidly, preventing carbon diffusion. Low-carbon steel (0.2%C) requires a very high cooling rate to transform austenite into martensite because slower cooling allows the formation of ferrite and pearlite instead. Cooling below the critical rate will not produce martensite, while extremely rapid quenching (like 700°C/sec) ensures a diffusionless transformation into the hard, brittle martensitic structure.

30. Ans: (b)

Sol: The hardness of martensite increases with carbon content but reaches its maximum practical hardness (~ 64 RC) at about 0.6%

carbon. Low-carbon steels form softer martensite, while higher carbon steels become harder but also very brittle. At around 0.6 %C, martensite achieves a balance of maximum hardness and manageable brittleness in as-quenched condition, making it ideal for many heat-treated steel applications.

31. Ans: (c)

Sol: Very low carbon steels (below 0.1 %C) contain mostly ferrite, which is too soft to form martensite upon quenching. Since martensite formation requires sufficient carbon in austenite, these steels cannot be hardened effectively by the hardening process. They remain soft and ductile, and only surface hardening or alloying can improve their hardness.

32. Ans: (c)

Sol: Temperature 'c' is best for fastest solutionizing because it lies just inside the single-phase solid region, allowing quick diffusion and phase dissolution.

Higher temperature 'd' involves partial melting, slowing uniform solid solution formation.

Lower temperatures ('a', 'b') are in two-phase zones, so solutionizing is incomplete or slower.

33. Ans: (a)

Sol: Given:

Liquid phase composition, $C_L = 20\%$ A

Solid phase composition, $C_S = 70\%$ A

Overall composition, $C_0 = 40\ \%$ A

Fraction of solid,

$$f_s = \frac{C_L - C_0}{C_L - C_S}$$

$$f_s = \frac{20-40}{20-70} = \frac{-20}{-50} = 0.4$$

34. Ans: (a, b, d)

Sol: In a binary phase diagram, several important features occur at the eutectic point. First, the freezing point of the alloy is the minimum in the system, lower than that of either pure metal, making option (a) correct.

Second, a eutectic mixture solidifies at a constant temperature, similar to pure metals, so option (b) is correct.

Third, at the eutectic temperature, the liquid transforms simultaneously into two solid phases ($\alpha + \beta$), which makes option (d) correct.

The eutectic reaction, however, is reversible upon heating and cooling, so option (c) is incorrect.

Chapter 4 Heat Treatment Process of Steels

01. Ans: (c)

Sol:

- Hyper-eutectoid steel has carbon content greater than eutectoid (~0.8% C).
- For full annealing, it is heated to about 30–50°C above the lower critical temperature (AC_1) but below ACm, to avoid forming a continuous cementite network.
- Heating above AC_3 is used for hypo-eutectoid steels, not hyper-eutectoid steels.

02. Ans: (d)

Sol: Hardness and tensile strength in austenitic stainless steel can be increased only by cold working. These steels have a stable austenitic structure that does not transform during heat treatment, so processes like normalizing, hardening, or martempering are ineffective. Cold working causes strain hardening, which increases dislocation density, thereby improving strength and hardness while reducing ductility.

03. Ans: (d)

Sol: In steel, hardness increases as the microstructure becomes finer and more strained. Spheroidite is the softest structure due to rounded cementite particles. Coarse pearlite is harder than spheroidite, while fine pearlite is harder because of closely spaced lamellae. Martensite is the hardest due to its supersaturated, distorted crystal structure.

04. Ans: (b, c)

Sol: Hardness of steel improves significantly with cyaniding and normalizing.

Cyaniding is a case-hardening process that diffuses carbon and nitrogen into the surface, producing very high surface hardness and wear resistance.

Normalizing increases hardness moderately by refining grain structure and forming fine pearlite.

Annealing and tempering generally soften steel or reduce hardness, so they do not greatly improve hardness.

05. Ans: (c)

Sol: High carbon steel is hardened by heating above the critical temperature to form austenite and then rapidly quenching it to obtain martensite, which is a very hard structure. Tempering, normalizing, and annealing are used to modify or reduce hardness, not to produce maximum hardness.

06. Ans: (a)

Sol: Good weldability requires low carbon equivalent (CE) to reduce the risk of cracking and formation of hard, brittle microstructures. Steels with a carbon equivalent in the range of 0.2 to 0.4% weld easily without special precautions. Higher CE values reduce weldability and require preheating or post-weld heat treatment.

07. Ans: (a)

Sol:

- Hypereutectoid steel has carbon content greater than 0.8%.
- Upon full annealing, the steel is slowly cooled from above AC_1, forming pearlite in the interior of grains.
- Excess cementite (from carbon above eutectoid) precipitates along grain boundaries.
- Unlike hypo-eutectoid steel, there is no ferrite, and martensite only forms with quenching.

08. Ans: (d)

Sol: The primary objective of full annealing is to increase ductility and machinability of steel. The process involves heating the steel above its critical temperature and then slowly cooling it, which softens the material, relieves internal stresses, and refines the grain structure. This makes the steel easier to cut, shape, or form. Unlike hardening, annealing does not increase strength or hardness but improves workability and toughness.

09. Ans: (c)

Sol:

- Spheroidising is a heat treatment process in which steel is heated below the eutectoid temperature for a long time.
- This transforms the lamellar or network cementite into globular or spherical particles dispersed in a ferrite matrix.
- The resulting structure, called spheroidite, improves ductility and machinability, especially in high carbon steels, making it easier to machine or deform.

10. Ans: (b)

Sol: **In cast iron, carbon exists in two forms:** free (graphite) and chemically combined. The chemically combined carbon is present as cementite (Fe_3C), a hard and brittle iron–carbon compound. Cementite strongly influences the hardness and brittleness of cast iron. Other phases like ferrite, austenite, and martensite contain carbon in solid solution, but only cementite represents carbon in a fully chemically combined form, not as free graphite.

11. Ans: (b)

Sol:

- The main purpose of heat treatment is to alter the mechanical properties of metals, such as hardness, strength, toughness, ductility, and wear resistance.

- Heat treatment works by changing the microstructure of the metal through controlled heating and cooling.
- It does not change the chemical composition, corrosion properties, or surface finish directly.

12. Ans: (b)

Sol:

- Case-hardening is a process that hardens the surface layer of steel while keeping the core soft and tough.
- Cyaniding is a common case-hardening method in which carbon and nitrogen are diffused into the steel surface at high temperature, producing a hard, wear-resistant case.
- Tempering, annealing, and spheroidizing are not used for case-hardening.

13. Ans: (c)

Sol: After steel is hardened, it becomes very hard but also brittle because of internal stresses induced during rapid cooling. To relieve these stresses and improve toughness, the steel is subjected to tempering. In tempering, the hardened steel is heated to a moderate temperature and then cooled, which reduces brittleness, slightly decreases hardness, and enhances toughness. This process ensures that parts are strong yet durable for practical use.

14. Ans: (a)

Sol:

- Annealing is done to soften hardened steel, relieve internal stresses, and improve ductility and machinability.
- The steel is heated above its critical temperature (to form austenite) and then cooled slowly, usually in the furnace.
- Slow cooling allows uniform transformation of austenite into a softer microstructure like pearlite, preventing brittleness and cracking.

15. Ans: (a)

Sol: After steel is hardened, it becomes very hard but also brittle due to internal stresses, called hardening strains. To relieve these stresses and reduce the risk of cracking, all hardened parts are tempered. Tempering involves heating the steel to a moderate temperature and then cooling it, which reduces internal stresses, slightly lowers hardness, and improves toughness, making the steel safer and more durable for practical applications.

16. Ans: (a)

Sol:

- Low carbon steel (typically $< 0.3\%$ C) is too soft to be hardened throughout by ordinary quenching.
- Its hardness can be improved only at the surface by case-hardening methods like

carburizing or cyaniding, which introduce carbon (and nitrogen in cyaniding) into the surface layer.
- Medium and high carbon steels can be hardened through direct quenching, not just surface treatment.

17. Ans: (b)

Sol:
- Hardening of carbon steel involves heating the steel above its critical temperature to form austenite.
- It is then rapidly cooled (quenched) in water, oil, or brine.
- This rapid cooling transforms austenite into martensite, a very hard and brittle structure.
- Slow cooling would produce softer structures like pearlite, not hardening.

18. Ans: (a)

Sol:
- Flame hardening uses an oxy-acetylene flame to heat only a specific part of the steel surface above the critical temperature.
- The heated area is then rapidly quenched, forming martensite in just that localized region.
- This allows selected portions of a part to be hardened while leaving the rest tough and ductile, which is ideal for tools, shafts, and edges.
- Induction hardening is also used, but flame hardening is more traditional for small, easily accessible areas.

19. Ans: (c)

Sol:
- Low-carbon steel (less than ~ 0.3% C) is too soft to be hardened throughout by ordinary quenching.
- Case hardening methods like carburizing or cyaniding add carbon to the surface, producing a hard, wear-resistant layer while keeping the core tough and ductile.
- High-carbon, high-alloy, and high-speed steels can be hardened by direct quenching, so case hardening is not the only method for them.

20. Ans: (b)

Sol:
- This describes the process of tempering or stress-relieving annealing after hardening.
- After heating the hardened steel to the tempering temperature, it is often left in the furnace to cool slowly.
- Slow cooling relieves internal stresses, increases ductility, and reduces brittleness, unlike quenching, which would retain hardness but keep brittleness.

21. Ans: (a)

Sol:

- When steel is hardened by heating above its critical temperature and quenching, it becomes very hard but also brittle due to hardening strains (internal stresses).
- Tempering involves reheating the hardened steel to a moderate temperature and then cooling it, which relieves these stresses, slightly reduces hardness, and increases toughness and ductility.
- Annealing, normalizing, and spheroidizing are not primarily used for stress relief after hardening.

22. Ans: (b)

Sol: Annealing is used to soften hard alloy and tool steels, relieve internal stresses, and improve machinability. The steel is heated to a suitable temperature and then slowly cooled, usually in the furnace. Carburizing hardens the surface, normalizing refines grain structure but does not sufficiently soften tool steels, and tempering only reduces brittleness after hardening, not fully soften the steel.

23. Ans: (b)

Sol: Excessive scaling during hardening occurs when steel is exposed to high temperatures for long periods. Proper control of furnace temperature prevents overheating, which reduces oxidation and scale formation on the steel surface. While atmosphere also influences scaling, temperature control is the primary factor emphasized in this context.

24. Ans: (d)

Sol: A pyrometer is the instrument used to measure and control high temperatures in industrial furnaces during heat treatment of steel. It can measure temperatures without direct contact, which is ideal for furnace environments. A hydrometer measures liquid density, a thermometer is limited at very high temperatures, and a dilatometer measures dimensional changes, not furnace temperature.

25. Ans: (c)

Sol: Low-carbon steel cannot be hardened throughout by ordinary quenching because of its low carbon content. Carburizing is a case-hardening process in which carbon is diffused into the surface layer at high temperature, followed by quenching. This produces a hard, wear-resistant surface while keeping the core soft and tough. Hardening, normalizing, and tempering do not significantly improve surface hardness in low-carbon steel.

26. Ans: (d)

Sol: Normalizing is a heat-treatment process in which an iron-based alloy is heated above its upper critical temperature and then cooled in still (standstill) air. This refines the grain structure and improves strength and toughness. Hardening involves quenching, tempering is reheating after hardening, and annealing uses slow furnace cooling.

27. Ans: (b)

Sol: Precipitation hardening (age hardening) occurs when an alloy is first heated to form a single-phase solid solution and then rapidly cooled to create a supersaturated solid solution. On subsequent aging, fine precipitates form within the matrix, which obstruct dislocation movement and significantly increase strength and hardness.

28. Ans: (b)

Sol: High-carbon steel becomes very hard but brittle after hardening. Tempering is carried out to reduce brittleness and relieve internal stresses by reheating the hardened steel to a moderate temperature and then cooling it. This process slightly reduces hardness while improving toughness and ductility. It does not increase hardness, change the steel into mild steel, or merely colour the metal.

29. Ans: (b)

Sol: When high-carbon steel is heated until red hot (above its critical temperature) and then quenched in cold water, rapid cooling occurs. This transforms austenite into martensite, a very hard and brittle structure. This process is called hardening. Tempering would require reheating after hardening, and normalizing involves air cooling, not quenching.

30. Ans: (a)

Sol: In high-carbon steels, slow cooling allows sufficient time for carbon diffusion, leading to the formation of pearlite at room temperature. Rapid cooling (quenching) is required to form martensite. Therefore, slow cooling prevents martensite formation, resulting in a microstructure that is almost entirely pearlite.

31. Ans: (a)

Sol: Annealing is a heat-treatment process in which a metal is heated to its critical temperature and then cooled very slowly, usually in the furnace. This process softens the metal, relieves internal stresses, improves ductility, and makes it easier to work with. Burnishing and planishing are mechanical finishing processes, and spheroidising is a special heat treatment for high-carbon steels to form globular cementite.

32. Ans: (c)

Sol:

- Age hardening (precipitation hardening) is mainly used for non-ferrous alloys like aluminum, copper, and titanium alloys, not commonly for plain carbon or alloy steels.
- Steels typically use Nitriding, Cyaniding, and Induction hardening to increase surface hardness or selectively harden parts.
- Therefore, age hardening is not generally applied to steels.

33. Ans: (b)

Sol: Steels are primarily designed and classified according to their carbon content, as it strongly influences their mechanical properties like hardness, strength, and ductility. Low-carbon steels are soft and easily shaped, medium-carbon steels offer a balance of strength and ductility, and high-carbon steels are hard and strong but less ductile. While alloying elements and tensile strength affect steel properties, carbon content remains the main basis for steel classification.

34. Ans: (c)

Sol:

- Brazing is a joining process, not a heat-treatment process. It involves melting a filler metal to bond two metal pieces without melting the base metals.
- Annealing, normalizing, and tempering are all heat-treatment processes used to alter the microstructure and mechanical properties of metals, such as hardness, strength, and ductility.

35. Ans: (d)

Sol:

- Tempering is performed after hardening to reduce brittleness and relieve internal stresses.
- It is most effective for low and medium carbon steels, which can be hardened and then tempered to achieve a balance of hardness, toughness, and ductility.
- Hyper-eutectoid steels are harder to harden uniformly, and tempering alone is not sufficient for them.

36. Ans: (d)

Sol:

- Maraging steels are extremely strong and tough steels that can withstand vibration and shock.
- They achieve their high strength through martensitic structure strengthened by precipitation hardening rather than carbon content.
- Bainitic steels and low-carbon steels do not provide the same combination of toughness and strength, and nitrided steel mainly has a hard surface but a softer core, making it less suitable for high-impact applications like aero engines.

37. Ans: (b)

Sol:

- In the iron–carbon (Fe–C) equilibrium system, the eutectoid point is where austenite transforms into pearlite upon slow cooling.
- This occurs at a temperature of 723°C with a carbon content of 0.8%.
- *Other temperatures correspond to different transformations:* 910°C is the upper critical temperature (AC_3), 1400°C and 1530°C relate to melting points of alloys and pure iron.

38. Ans: (b)

Sol:

- The critical cooling rate is the minimum rate of cooling required to transform austenite into martensite.
- Factors that increase hardenability (like alloying with Cr, Mo, Mn, Ni) reduce the critical cooling rate, meaning the steel can form martensite even when cooled more slowly.
- Conversely, low hardenability steels require faster cooling to achieve full martensitic transformation.

39. Ans: (b)

Sol:

- Bainite is a microstructure formed in steel by isothermal transformation of austenite at temperatures between pearlite and martensite formation.
- It consists of ferrite matrix with fine, elongated or spheroidized cementite particles dispersed uniformly.
- This structure gives good strength and toughness, lying between pearlite and martensite in hardness.

40. Ans: (c)

Sol:

- Full annealing involves heating steel above its upper critical temperature (AC_3) or AC_1 for hypo/hyper-eutectoid steels).
- After heating, the steel is cooled very slowly, usually inside the furnace.
- This slow cooling allows the formation of a soft, uniform microstructure (coarse pearlite or ferrite + pearlite), relieving internal stresses and improving ductility and machinability.
- Quenching or air cooling would make the steel harder, not fully annealed.

41. Ans: (c)

Sol:

- Process annealing is used to soften cold-worked steel without changing its phase.
- It is done below the lower critical temperature (AC_1) and below the recrystallization temperature, so the steel's microstructure stays mostly the same, but internal stresses are relieved.

- Heating below AC_1 ensures there's no phase transformation, which aligns with process annealing.
  So while "below lower critical temperature" sounds close, the defining criterion is actually below the recrystallization temperature.

42. Ans: (b)

Sol:

- Tempering is performed after hardening to reduce brittleness and relieve internal stresses.
- The hardened steel is heated to a temperature below the lower critical temperature (A_1) so that no phase transformation occurs.
- This allows the martensitic structure to soften slightly, improving toughness and ductility without losing much hardness.
- Heating above A_1 or A_3 would cause unwanted phase changes.

43. Ans: (c)

Sol:

- Aus-tempering is a controlled isothermal heat treatment of steel, where austenitized steel is quenched to a temperature above martensite start (Ms) and held until transformation occurs.
- This produces a bainitic microstructure, which consists of ferrite with fine cementite, giving a good combination of strength and toughness.
- Martensite forms by rapid quenching, while ledeburite and pearlite are different microstructures.

44. Ans: (d)

Sol:

- Surface hardening (like flame or induction hardening) aims to harden only the surface layer of the steel while keeping the core tough.
- The steel is heated above the upper critical temperature (AC_3) for a short time to prevent overheating and distortion.
- Rapid quenching, usually in water, forms martensite on the surface, increasing hardness, while the core remains softer.

45. Ans: (a)

Sol:

- Carburizing is a case-hardening process where carbon is diffused into the surface of low-carbon steel to form a hard, wear-resistant layer, while the core remains soft and tough.
- The carbon content increases only at the surface, not uniformly or in the core.
- Nitrogen diffusion is done in nitriding, not carburizing

46. Ans: (c, d)

Sol:

Normalizing is a heat-treatment process applied to cast or forged steel, where the material is heated above the upper critical temperature (AC_3) and then cooled in still air. This process serves multiple purposes. Firstly, it eliminates the coarse dendritic structure formed during casting, resulting in a uniform microstructure. Secondly, it removes internal stresses caused by uneven cooling, welding, or forging operations. Additionally, normalizing slightly refines the grain structure, improving mechanical properties like strength and toughness. While it may modestly increase hardness, the main goals are stress relief and structural uniformity, making the steel easier to machine and work with.

Chapter 5 Ferrous and Non-Ferrous Metals

01. Ans: (a)

Sol: In High Speed Steel (HSS) tool materials, molybdenum can almost completely replace tungsten without significantly changing the material properties.

This is why HSS is classified into:

- **T-series (tungsten-based)**
- **M-series (molybdenum-based)**

Molybdenum provides similar hardness, hot hardness, and wear resistance as tungsten, often at lower cost.

Carbon, cobalt, and vanadium play different roles (hardness, hot hardness, grain refinement) and cannot replace tungsten completely.

02. Ans: (d)

Sol: Monel metal is a nickel-based alloy containing copper as the major alloying element (typically about 65–70% nickel and 20–30% copper), along with small amounts of iron and manganese. It is known for its excellent corrosion resistance and high strength.

03. Ans: (a)

Sol: Gunmetal is a type of bronze commonly used for journal bearings due to its good wear resistance and corrosion resistance. The standard composition of gunmetal is approximately:

Copper (Cu) = 88%

Tin (Sn) = 10%

Zinc (Zn) = 2%

This composition provides good strength, machinability, and bearing properties.

04. Ans: (a)

Sol: In 18-4-1 High Speed Steel, the numbers represent alloying element percentages: 18% tungsten for hot hardness, 4% chromium for strength and wear resistance, and 1% vanadium for grain refinement and tool life improvement.

05. Ans: (d)

Sol: High-silicon cast iron (12–18% Si) forms a protective silicon-rich oxide layer on its surface, giving it excellent resistance to acids and corrosive environments. It is therefore widely used in chemical and corrosion-resistant applications.

06. Ans: (b)

Sol: Among copper, steel, wrought iron, and brass pipes of the same diameter, steel is the least corrosion resistant. Copper and brass have good natural corrosion resistance, and wrought iron resists corrosion better than steel due to its fibrous slag content.

07. Ans: (b)

Sol: In grey cast iron, carbon exists as graphite flakes. These flakes interrupt the metallic matrix, giving the iron its characteristic grey fracture, good machinability, high damping capacity, and relatively low tensile strength compared to other cast irons.

08. Ans: (c)

Sol: Adding magnesium to cast iron transforms the graphite from flakes into spheroidal or nodular shapes, producing ductile (nodular) cast iron. This modification reduces stress concentration points, greatly improving tensile strength, ductility, and toughness compared to grey cast iron. Magnesium acts as a nodulizer, making the iron suitable for components requiring both strength and resistance to fracture.

09. Ans: (b)

Sol: Grey cast iron typically contains 2.5 – 4.5% carbon and 1 – 3% silicon. This high carbon content, mostly in the form of graphite flakes, gives it good castability, machinability, and damping properties, but relatively low tensile strength.

10. Ans: (a)

Sol: Malleable iron is produced by heat-treating white cast iron, which converts combined carbon (cementite) into small, rounded (nodular) graphite aggregates. These nodules improve ductility and toughness, making malleable iron suitable for applications requiring some flexibility without breaking. Unlike grey cast iron, the graphite is spheroidal rather than flake-shaped.

11. Ans: (b)

Sol: Steel is produced from cast iron by reducing its high carbon content (typically 2 – 4% in cast iron) to a much lower level (usually 0.02 – 2%). Removing excess carbon improves ductility, toughness, and strength, making the material suitable for a wide range of structural and engineering applications. Other impurities like sulfur and silicon are also controlled, but carbon is the primary element removed.

12. Ans: (d)

Sol: Carbon is the most important element controlling steel's physical properties. Its content determines hardness, strength, ductility, and tensile properties. Increasing carbon increases hardness and strength but reduces ductility and toughness. Other elements like silicon, manganese, and tungsten influence properties, but carbon is the primary controlling factor.

13. Ans: (b)

Sol: Adding large amounts of silicon to steel improves its refractory properties, meaning it can withstand high temperatures and resist oxidation. While small amounts of silicon also enhance strength and magnetic behavior, in large quantities the main effect is heat and oxidation resistance, making the steel suitable for high-temperature applications, like furnace parts and boiler components, rather than primarily improving mechanical or magnetic properties.

14. Ans: (a)

Sol: High-quality cutting tool steels have a fine grain structure, which improves hardness, toughness, wear resistance, and dimensional stability. Fine grains allow the steel to withstand high stresses and temperatures during cutting operations, providing better performance and longer tool life. Coarse grains, in contrast, reduce strength and make the steel more prone to failure.

15. Ans: (b)

Sol: Alloy steels are steels that contain small to moderate amounts of elements like nickel, tungsten, chromium, vanadium, or molybdenum to improve properties such as strength, hardness, toughness, and wear resistance. When these alloying elements are present in low percentages, the steel is still classified as alloy steel, not plain carbon, tool, or stainless steel.

16. Ans: (c)

Sol: High carbon tool steels are often alloyed with nickel to improve their toughness and resistance to shock. Nickel increases the steel's ability to absorb impact without cracking, making it suitable for tools subjected to sudden loads. Other elements like tungsten and chromium primarily improve hardness and wear resistance, while vanadium refines the grain structure.

17. Ans: (a)

Sol: Manganese (Mn) and Silicon (Si) are commonly added to steel as deoxidizers and purifiers. They remove oxygen and sulfur impurities during steelmaking, improving strength, ductility, and overall quality. Other alloying elements like vanadium, chromium, molybdenum, and nickel mainly enhance hardness, wear resistance, or corrosion resistance, rather than acting as cleaning agents.

18. Ans: (b)

Sol: Silicon is commonly added to steel to control its properties. It acts as a deoxidizer, removing oxygen during steelmaking, and improves strength, elasticity, and magnetic properties. While other elements like nickel or chromium enhance toughness or corrosion resistance, silicon is primarily used to refine the steel's structure and enhance overall performance.

19. Ans: (d)

Sol: High Speed Steel (HSS) is an alloy steel containing elements like tungsten, molybdenum, chromium, vanadium, and cobalt. These alloying elements give HSS its high hardness, wear resistance, and ability to retain hardness at high temperatures, making it ideal for cutting tools. It is not classified by carbon content alone but by its alloy composition.

20. Ans: (d)

Sol: Cast iron cannot be forged because it is brittle and has a high carbon content (2 – 4%), which makes it prone to cracking under compressive forces. In contrast, wrought iron, high-speed steel, and high-carbon steel can be forged, as they are malleable or ductile enough to withstand deformation under heat and pressure.

21. Ans: (a)

Sol: Reinforcing steel (rebar) used in R.C.C. structures is typically made from medium carbon steel. It offers a good balance of strength and ductility, allowing it to withstand tensile forces in concrete without breaking. Alloy steels, wrought iron, or tool steels are not commonly used for reinforcement due to cost or unsuitable mechanical properties.

22. Ans: (d)

Sol: Ordinary structural steel mainly contains carbon, silicon, and manganese. Carbon provides strength and hardness, silicon acts as a deoxidizer and slightly increases strength, while manganese improves toughness and wear resistance. Other elements like boron, sodium, fluorine, tungsten, or nickel are generally absent in standard structural steel.

23. Ans: (a)

Sol: Alloying carbon tool steel with tungsten and vanadium increases its hardness and wear resistance. Tungsten forms hard carbides that enhance hot hardness, making the steel suitable for cutting tools at high temperatures. Vanadium refines the grain structure and also forms hard carbides, further improving strength, toughness, and overall durability of the tool steel.

24. Ans: (b)

Sol: Manganese is added to steel to enhance its strength, hardness, and toughness, making it more resistant to shock and wear. It also acts as a deoxidizer and counteracts the harmful effects of sulfur, which can cause brittleness. Magnesium, phosphorus, and sulfur do not improve toughness and are either impurities or used in other alloys.

25. Ans: (c)

Sol: Malleable iron has nodular graphite in its structure, giving it high toughness and ductility. This allows it to withstand shocks and vibrations without cracking, unlike brittle materials. Chilled cast iron, white cast iron, and gray cast iron are either brittle or weak in tension, making them unsuitable for applications requiring shock resistance.

26. Ans: (d)

Sol: Invar steel is a special nickel-iron alloy known for its extremely low coefficient of thermal expansion (almost zero). This property ensures that its length remains nearly constant with temperature changes, making it ideal for precision measuring instruments, tapes, and gauges. Other steels like stainless or cobalt steels do not have this near-zero expansion property.

27. Ans: (d)

Sol: Brass is an alloy made of copper and zinc, with varying zinc content to adjust strength, ductility, and corrosion resistance. It is commonly used in plumbing fittings, musical instruments, and decorative items. Copper and tin form bronze, while other elements like chromium, carbon, or aluminium are not part of standard brass.

28. Ans: (c)

Sol: Babbitt metal is a soft, low-friction alloy, usually composed of tin, lead, copper, and antimony, used primarily for lining sleeve (journal) bearings. Its conformability and embedability allow it to accommodate small misalignments and trap dirt particles, reducing wear. It is not used in ball or roller bearings, which require harder materials.

29. Ans: (d)

Sol: Steels are classified by their alloying element content. Low alloy steels have less than 4%, medium alloy steels have 4–10%, and high alloy steels contain more than 10% alloying elements. High alloy steels, such as stainless steel and tool steels, offer enhanced hardness, corrosion resistance, and heat resistance for demanding applications.

30. Ans: (b)

Sol: The two most important copper-based alloys are brass and bronze. Brass is an alloy of copper and zinc, offering ductility, corrosion resistance, and machinability, while bronze is an alloy of copper and tin, valued for strength, wear resistance, and corrosion resistance. Other alloys like Monel or cupronickel are more specialized.

31. Ans: (e)

Sol: Gun metal is an alloy of copper, tin, and zinc, usually containing around 85% copper, 5–10% tin, and 5–10% zinc. Sometimes small amounts of lead or phosphorus are added to improve machinability and strength. It is widely used for bearings, gears, valves, and marine components due to its strength and corrosion resistance.

32. Ans: (b)

Sol: Carbon is the key element in steel that determines whether it can be hardened by heating and quenching. Higher carbon content increases the steel's hardness and strength after quenching by forming martensite. Other elements like vanadium or tungsten influence hardness or wear resistance, but without sufficient carbon, steel cannot be effectively hardened.

33. Ans: (c)

Sol: Gun metal is primarily a copper-based alloy. Tin and zinc are added in smaller amounts to improve strength, corrosion resistance, and wear resistance. Copper forms the base metal, giving the alloy its characteristic properties, while tin and zinc enhance mechanical performance and durability for applications like bearings, gears, and valves.

34. Ans: (c)

Sol: A small amount of sulfur in pig iron can increase ductility by improving the flow of molten iron during casting, making it easier to shape. However, excess sulfur can cause brittleness (hot shortness). So controlled sulfur content can actually enhance ductility in cast iron.

35. Ans: (d)

Sol: In cemented carbide tools, hard particles like tungsten carbide (WC) are held together by a metallic binder. Cobalt is used as the binder because it provides toughness and impact resistance, preventing the brittle carbide grains from breaking during cutting. Iron, chromium, or nickel are not suitable for effectively binding carbide particles.

36. Ans: (a)

Sol: Adding chromium and nickel to steel greatly improves its corrosion resistance, forming what is known as stainless steel. Chromium develops a protective oxide layer that prevents rust, while nickel enhances toughness and resistance to acids and marine environments. Tungsten and sulfur do not provide significant corrosion resistance in steel.

37 Ans: (a)

Sol: Red hardness is the ability of steel to retain hardness at high temperatures, important for cutting tools. Tungsten (W) forms hard carbides that maintain hardness under heat, while vanadium (V) refines the grain structure and forms additional carbides, enhancing hot hardness and wear resistance. Other elements mainly improve strength or corrosion resistance, not red hardness.

38. Ans: (a)

Sol: Lead is widely used in storage batteries (lead-acid batteries) because it is corrosion-resistant, dense, and has excellent electrochemical properties. The lead plates act as electrodes, while sulfuric acid serves as the electrolyte. Lead is not typically used in transformers or switch gears.

39. Ans: (b)

Sol: Machine tool beds are made of gray cast iron because it has excellent vibration-damping capacity, good compressive strength, wear resistance, and is easily machinable. These properties help maintain accuracy and stability during machining operations. Wrought iron, mild steel, and pig iron lack sufficient damping and are less suitable for tool beds.

40. Ans: (c)

Sol: Magnesium alloys are known for their low density, making them very light, which is why they are widely used in aerospace, automotive, and portable equipment. While magnesium alloys are relatively easy to machine, their light weight is their most significant property. They are generally non-magnetic but can be prone to corrosion if not properly protected.

41. Ans: (a)

Sol: Cutting speed in machining depends on the material's hardness and machinability. Aluminum is soft, ductile, and easy to cut, allowing high cutting speeds with HSS tools. Harder materials like cast iron, mild steel, and wrought iron are more abrasive, so lower speeds are necessary to prevent tool wear, overheating, and poor surface finish.

42. Ans: (c)

Sol: Carbide tips are fixed to cutting tool shanks by sintering, a powder metallurgy process where carbide particles are pressed and fused under high heat and pressure to form a solid tip. This method produces a strong, durable, and heat-resistant bond. Brazing is used in some tools, but sintering is common for high-performance, integral carbide-tipped tools.

43. Ans: (d)

Sol: Sulphur in cast iron is generally considered an impurity because it has several harmful effects:

- Promotes oxidation during melting and casting
- Reduces fluidity, making casting difficult
- Increases brittleness, especially hot shortness, reducing toughness

44. Ans: (a)

Sol:

Element	**Effect on Steel /Alloy**	**Reason**
Manganese	Ductility	Improves toughness and ductility, counteracts brittleness
Silicon	Hardenability	Increases hardness and strength, especially in heat treated steel
Lead	Machinability	Provides lubrication, improving ease of cutting and machining
Tungsten	High temperature strength	Maintains hardness at high temperatures (red hardness)

45. Ans: (d)

Sol: Alloying metals improves the properties of a base metal. It can increase tensile strength by adding elements like chromium or nickel, enhance fatigue resistance with vanadium or molybdenum, and improve corrosion resistance by adding chromium and nickel. Therefore, alloying serves multiple purposes, making metals stronger, tougher, and more durable.

46. Ans: (a)

Sol:

- The main alloying element in stainless steel is chromium, usually in the range of 10–20%. Chromium forms a thin, protective oxide layer on the steel surface, giving it corrosion resistance.
- Nickel and molybdenum are added in smaller amounts to improve toughness, ductility, and resistance to specific environments, but chromium is the primary element responsible for stainless properties.

47. Ans: (a)

Sol: Metallic glasses are metal alloys that have an amorphous (non-crystalline) structure, like glass, but retain metallic properties such as strength, toughness, and electrical conductivity. They combine the hardness and corrosion resistance of metals with the disorder and unique properties of glass, making them useful in specialized engineering applications.

48. Ans: (b)

Sol: Ferritizers are alloying elements that promote the formation of ferrite in steel, giving it a body-centered cubic (BCC) structure. Chromium (Cr) and Aluminium (Al) are common ferritizers. In contrast, elements like Ni, Mn, and Co stabilize austenite, while interstitial elements such as C, N, and S affect hardenability but do not form ferrite.

49. Ans: (c)

Sol: Austenizers are elements that stabilize the austenite phase (FCC structure) in steel. Nickel (Ni) and Cobalt (Co) are common austenitizing elements, allowing steel to retain austenite at higher temperatures.

Other elements like V, Al, Si, S, Mo, and W either stabilize ferrite or affect hardenability, but do not promote austenite formation.

50. Ans: (a)

Sol: High-Speed Steel (HSS) is a high-carbon, high-alloy steel specifically designed for cutting tools that operate at high speeds and temperatures.

Its primary alloying elements are: Tungsten (W), which improves hot hardness; Cobalt

(Co), which enhances red hardness; Vanadium (V), which refines the grain structure and increases wear resistance; and Molybdenum (Mo), which boosts strength and toughness.

Other elements such as aluminum, copper, sulfur, or phosphorus are either minor additives or impurities and do not significantly contribute to the high-speed steel's cutting performance.

51. Ans: (c)

Sol: Nichrome is a nickel-chromium alloy commonly used in heating elements due to its high electrical resistance and oxidation resistance. Its typical composition is approximately 65% nickel, 15% chromium, and 20% iron. The nickel provides corrosion resistance and ductility, chromium gives oxidation resistance, and iron adds strength and stability at high temperatures.

52. Ans: (b)

Sol: Phosphor bronze is a copper-based alloy containing tin (Sn) and a small amount of phosphorus (P). Tin improves strength, corrosion resistance, and wear resistance, while phosphorus increases hardness, stiffness, and fatigue resistance. This makes phosphor bronze suitable for springs, bearings, gears, and marine applications, providing durability and reliability.

53. Ans: (a)

Sol: Duplex stainless steels are dual-phase alloys with roughly equal amounts of ferrite and austenite, combining high strength and excellent corrosion resistance. Chromium (20–30%) improves corrosion and oxidation resistance, nickel (~5%) stabilizes austenite, and low carbon (0.03%) prevents sensitization and carbide precipitation, making duplex alloys ideal for chemical, marine, and high-stress applications.

Chapter 6

Powder Metallurgy

01. Ans: (c)

Sol: These ceramic materials exhibit strong piezoelectric properties, meaning they generate electric charge when mechanically stressed. Because of this behavior, they are widely used in applications such as sensors, actuators, ultrasonic transducers, and vibration control devices in engineering and electronics.

02. Ans: (d)

Sol: Conditioning and mixing of metal powders include preliminary heat treatment to improve powder properties, pulverisation and screening to obtain uniform particle size, and blending or mixing to ensure homogeneity. All these steps are essential in powder metallurgy to achieve consistent composition and desired material properties.

03. Ans: (b)

Sol: Compaction of metal powders is the process of pressing metal powders into a desired shape using a die or mold. This may be done at room temperature or with the application of heat. The aim is to increase density and strength before the sintering process.

04. Ans: (a)

Sol: During sintering, the primary activity is the bonding or adhesion of adjacent powder particles due to atomic diffusion at elevated temperatures. Other effects like densification and pore reduction may occur, but adhesion is the fundamental and defining process.

05. Ans: (c)

Sol: Spark sintering is a hot pressure shaping technique in which metallic powders are electrically heated by the production of sparks (or pulsed current) inside a graphite die for a short time while pressure is applied. This method enables rapid heating, effective bonding, and high densification of powders.

06. Ans: (b)

Sol: Cermets are composite materials produced by powder metallurgy using a combination of ceramic powders and metallic powders. This combination provides the hardness and wear resistance of ceramics along with the toughness and ductility of metals.

07. Ans: (a)

Sol: In powder metallurgy, the typical sequence is:

- Blending – mixing metal powders uniformly.

- Compacting – pressing powders into the desired shape.
- Sintering – heating compacted powders to bond particles.
- Sizing/finishing – final machining or sizing for precise dimensions.

08. Ans: (b)

Sol: Powder metallurgy allows precise control of powder composition and compaction, which enables accurate control over the density and porosity of the final product. Casting is less precise in this regard. PM is ideal for small to medium-sized components with uniform properties rather than very large or highly variable-thickness parts.

09. Ans: (b)

Sol: In powder metallurgy, sintering involves heating the compacted metal powders to a temperature below their melting point but high enough to cause atomic diffusion, particle bonding, densification, and strengthening.

Other processes like blending, pre-sintering, or briquetting occur at much lower temperatures.

10. Ans: ($\leq$ 2.5)

Sol: Ratios above 2.5 make uniform compaction difficult, leading to density variations, cracks, or warping during sintering. Maintaining $L/D \leq 2.5$ ensures better dimensional accuracy and structural integrity of the part.

11. Ans: (b)

Sol: In powder metallurgy, sintering is often carried out in an inert atmosphere (like argon or nitrogen) to prevent oxidation of the metal powders while allowing particle bonding. This ensures the integrity and properties of the sintered part. Reducing atmospheres are used for specific metals, but in general, inert atmospheres are preferred.

12. Ans: (a)

Sol: In powder metallurgy, the rate of production mainly depends on how quickly the metal powder can flow into the die during the compaction process. Good flow ensures rapid and uniform filling, reducing cycle time.

Other factors like green strength, apparent density, and compressibility affect part quality, but production rate is governed primarily by powder flowability.

13. Ans: (c)

Sol: Powder metallurgy is widely used to produce hard materials like tungsten carbide tool bits, which are difficult to manufacture by conventional melting or casting due to their high melting points and hardness. PM allows precise shaping, uniform density, and high hardness, making it ideal for cutting tools and wear-resistant components.

14. Ans: (b)

Sol: Bakelite is a thermosetting plastic, not a ceramic material. Ceramics are typically inorganic, non-metallic materials like glass, clay, and aluminium oxide, which can withstand high temperatures and are brittle.

Bakelite, on the other hand, is an organic polymer, used for electrical insulators and molded products.

15. Ans: (d)

Sol: In powder metallurgy, solvents (or lubricants/binders) are often added in the form of low boiling liquids. These help in mixing, compacting, and shaping the powders and evaporate easily during sintering without leaving harmful residues.

Oils or resins are used differently, not as primary solvents in PM.

16. Ans: (d)

Sol: Sintering in powder metallurgy heats the compacted powder below its melting point, causing atomic diffusion. This bonds particles together, increases density, and significantly improves the strength and hardness of the final component, making it suitable for practical applications.

17. Ans: (c, d)

Sol: In powder metallurgy, statements (c) and (d) are incorrect.

Infiltration is the process of filling the pores of a sintered part with a molten metal, usually of lower melting point, to increase density and strength—not with oil or other liquids.

Impregnation, on the other hand, involves introducing lubricants, oils, or resins into the porous structure to improve properties like corrosion resistance or lubrication, not placing a metal slug.

Statements (a) and (b) are correct: low apparent density indicates a large fraction of unfilled space in loose powder, and green strength is the strength of a compact immediately after pressing, before sintering.