chanical properties of FRP composites. Their uses, however, are generally limited to products that permit parallel layments.

Example 19

A rod contains 40 volume-percent glass fibers within a plastic matrix. The glass has an elastic modulus of 70,000 MPa; the plastic, 3,500 MPa. What fraction of a 700 N tensile load is carried by the glass?

Solution

Based on Eq. (18)

$(F_{gl}/0.4A) / (F_p/0.6A) = (70{,}000 \text{ MPa}/3500 \text{ MPa}) = 20$

$F_{gl} = 20(0.4/0.6)\, F_p = 13.3\, F_p$

$F_{gl}/(F_{gl} + F_p) = (13.3\, F_p)/(13.3\, F_p + F_p) = 93\%$

Example 20

An electric highline cable contains one cold-drawn steel wire and six annealed aluminum wires, all with a 2-mm diameter. (The steel provides the required strength; the aluminum, the conductivity.) Using the following data, a) calculate the resistivity and b) the elastic modulus of the composite wire.

Steel: $\rho = 17 \times 10^{-6}$ ohm • cm, $E = 205{,}000$ MPa

Aluminum: $\rho = 3 \times 10^{-6}$ ohm • cm, $E = 70{,}000$ MPa

Solution

a) From Eq. (20c)

$1/\rho_{\parallel} = (1/7)/(17 \times 10^{-6}\,\Omega \cdot \text{cm}) + (6/7)/(3 \times 10^{-6}\,\Omega \cdot \text{cm}) = 0.294 \times 10^{6}\,\Omega^{-1}\text{cm}^{-1}$

$\rho_{\parallel} = 3.4 \times 10^{-6}\,\Omega \cdot \text{cm}$

b) We must write a mixture rule for the elastic modulus of a composite in parallel. Let A be the area of one wire.

Since, $e_C = e_{Al} = e_{St}$, $[(F/A)/E]_C = [(F/A)/E]_{Al} = [(F/A)/E]_{St}$

Also, $F_C = F_{Al} + F_{St} = F_C(f_{Al}A_C/A_C)(E_{Al}/E_C) + F_C(f_{St}A_C/A_C)(E_{St}/E_C)$

Cancelling,

$E_C = f_{Al}E_{Al} + f_{St}E_{St} = (6/7)(70{,}000 \text{ MPa}) + (1/7)(205{,}000 \text{ MPa}) = 89{,}000 \text{ MPa}$

The apparent modulus will be lower because there will also be cable extension by the straightening of the cable wire.

Reference

Elements of Materials Science and Engineering, 6th Ed., L. Van Vlack, 1989, Addison-Wesley

Selected Symbols and Abbreviations

Symbol or Abbreviation	Description
amu	atomic mass unit
B	flux density
E	elastic modulus
e	engineering strain
E_f	Fermi energy level
E_g	energy gap
f	volume fraction
H	magnetic field
K_I	stress intensity factor
nm	nanometer
μ	carrier mobility
σ	conductivity
s	stress
SRI	Spalling Resistance Index
S_y	yield strength
Y	proportionality constant

Problems and Solutions

13-1. With a neutral atom,

(a) the atomic mass equals the mass of the neutrons plus the mass of the protons

(b) the atomic number equals the atomic mass

(c) the number of protons equals the atomic number

(d) the number of electrons equals the number of neutrons

Solution

Each step through the periodic table introduces an additional proton and electron to a neutral atom. The answer is (c).

Materials Engineering

13-2. All isotopes of a given element have

(a) the same number of protons

(b) the same number of neutrons

(c) equal numbers of protons and neutrons

(d) the same number of atomic mass units

Solution

The number of protons and electrons are fixed for an indivdual element. If the number of protons (and electrons) were varied, the chemical properties would be affected. The answer is (a).

13-3. Which of the following statements is *not* true?

(a) An anion has more electrons than protons.

(b) Energy is released when water is solidified to ice.

(c) Energy is required to remove an electron from a neutral atom.

(d) Energy is released, if a H_2 molecule is separated into two hydrogen atoms.

Solution

The H-to-H bond would have to be broken, thus requiring energy. The answer is (d).

13-4. Select the correct statement.

(a) Crystals possess long-range order.

(b) Within a crystal, like ions attract and unlike ions repel.

(c) A body-centered cubic metallic crystal (for example, iron) has nine atoms per unit cell.

(d) A face-centered cubic metallic crystal (for example, copper) has fourteen atoms per unit cell.

Solution

Unlike ions attract. Fcc metals possess four atoms per unit cell; bcc metals have two. The answer is (a).

13-5. The (110) plane of diamond contains all of the following directions *except*

(a) $[1\bar{1}1]$ (c) $[\bar{2}21]$

(b) [110] (d) $[1\bar{1}2]$

Solution

The (110) plane lies diagonally through the unit cell, parallel to the *c*-axis. The [110] direction is perpendicular to the *c*-axis. The answer is (b).

13-6. In a cubic crystal, a is the edge of a unit cell. The shortest repeat distance in the [111] direction of a body-centered cubic crystal is

(a) $a\sqrt{2}$ (c) $a\sqrt{3}/2$

(b) $2a$ (d) $a\sqrt{3}/4$

Solution

The [111] direction passes diagonally through the unit cell. That distance is $a\sqrt{3}$, which equals two repeat distances. The answer is (c).

13-7. The line of intersection between the (101) and (110) planes lies along what direction?

(a) $[11\bar{1}]$ (c) $[\bar{1}11]$

(b) [211] (d) [111]

Solution

$[\bar{1}11]$ lies in both planes. (This may be checked with a sketch or by verifying that both dot products are equal to zero.) The answer is (c).

13-8. All but which of the following data are required to calculate the density of aluminum in g/m^3?

(a) Avogadro's number, which is 0.6×10^{24}

(b) atomic number of Al, which is 13

(c) crystal structure of Al, which is face-centered cubic

(d) atomic mass of Al, which is 27 amu

Solution

The mass is determined from 27 amu per 0.6×10^{24} atoms. Each cell of four atoms has a volume of $\left(4R/\sqrt{2}\right)^3$. The answer is (b).

13-9. Being an fcc metal, the atomic packing factor of gold is

(a) $\left(4\pi R^3/3\right)/\left(4R/\sqrt{3}\right)^3$

(b) $4\left(4\pi R^3/3\right)/\left(4R/\sqrt{2}\right)^3$

(c) $4\left(4\pi R^3/3\right)/\left(R/\sqrt{2}\right)^3$

(d) $4\left(2R/\sqrt{2}\right)^3/\left(4\pi R^3/3\right)$

Solution

Assuming spherical atoms, there are four atoms of radius, R, per unit cell. The cube edge is $4R/\sqrt{2}$. The answer is (b).

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13-10. The lattice constant for a unit cell of fcc nickel is 0.3525 nm. Therefore, there are how many atoms/nm^2 on the (011) plane?

(a) $(2/2 + 4/8)/(0.3525\ \text{nm})^2$

(b) $(1.5)/[(0.3525\ \text{nm})^2\sqrt{2}\,]$

(c) $2/(0.3525\ \text{nm})^2$

(d) $\sqrt{2}/(0.3525\ \text{nm})^2$

Solution

Within the unit cell, the (011) plane contains (2/2 + 4/4) atoms in an area of $a^2\sqrt{2}$. The answer is (d).

13-11. The lattice constant for a unit cell of bcc chromium is 0.288 nm. Therefore, there are how many atoms/nm in the [011] direction of chromium?

(a) $\sqrt{2}/(0.288 \text{ nm})$ (c) $1/(0.288 \text{ nm})$

(b) $2\sqrt{2}/(0.288 \text{ nm})$ (d) $1/(0.288 \text{ nm}\sqrt{2})$

Solution

In bcc atoms the [011] repeat distance is $a\sqrt{2}$. The answer is (d).

13-12. Ethylene is C_2H_4. To meet bonding requirements, how many bonds are present?

(a) 6 single (c) 1 double and 4 single

(b) 4 single and 2 double (d) 12 single

Solution

There is a double bond between the two carbons. Each hydrogen is held with a single bond. The answer is (c).

13-13. When comparing ethylene and vinyl chloride, each of the following statements is true, except

(a) they have the same molecular weight.

(b) they have the same bonding changes during polymerization.

(c) they have the same number of single bonds.

(d) they have the same number of atoms.

Solution

The two are equal except that one hydrogen is replaced with a chlorine.The answer is (a).

13-14. MgO is cubic. Every Mg^{2+} and O^{2-} ion has six neighbors. Their radii are r_{Mg} and R_O. Which of the following is *not* true?

(a) the lattice constant, a, equals $2(r_{Mg} + R_O)$

(b) there are eight ions per unit cell

(c) the body diagonal of the unit cell equals $a\sqrt{3}$

(d) the face diagonal of the unit cell is $4\ R_O$

Materials Engineering

Solution

The unlike ions make contact. The oxygen anions avoid contact. The face diagonal is $2(r_{Mg} + R_O)\sqrt{2}$. The answer is (d).

13-15. Each of the following groups of plastics is thermoplastic, *except*

(a) polyvinyl chloride (PVC) and a polyvinyl acetate

(b) phenolics, melamine, and epoxy

(c) polyethylene, polypropylene, and polystyrene

(d) acrylic (Lucite) and polyamide (Nylon)

Solution

Thermoplastic materials are polymerized but soften for molding at elevated temperatures. The polymeric molecules are linear. Thus they include the ethylene-type compounds that are bifunctional (two reaction sites per mer).

Thermosetting materials develop three-dimensional structures that become rigid during processing. For example, phenol is trifunctional and thus forms a network structure. Reheating does not soften them. The answer is (b).

13-16. Gold is fcc and has a density of 19.3 g/cm^3. Its atomic mass is 197 amu. Its atomic radius, R, may be calculated using which of the following?

(a) $19.3\ \text{g/cm}^3 = (197)(0.602 \times 10^{24}) / \left[\left(4R/\sqrt{2}\right)^3\right]$

(b) $19.3\ \text{g/cm}^3 = 2\,(197/0.602 \times 10^{24}) / \left[\left(4R/\sqrt{2}\right)^3\right]$

(c) $19.3\ \text{g/cm}^3 = 4\,(197/0.602 \times 10^{24}) / \left[\left(4R/\sqrt{2}\right)^3\right]$

(d) $19.3\ \text{g/cm}^3 = 6\,(197)(0.602 \times 10^{24}) / \left[\left(4R/\sqrt{2}\right)^3\right]$

Solution

Density is mass/volume. The mass per fcc unit cell is 4 Au(197 g/0.602 × 10^{24} Au). The volume per fcc unit cell of a metal is (face diagonal / $\sqrt{2}$)^3 or ($4R$ / $\sqrt{2}$)^3. The answer is (c).

13-17. X-ray diffraction shows that sodium is bcc and has an atomic radius of 0.186 nm. Its density is 0.97 g/cm^3 (= 0.97 Mg/m^3). From which of the following can one calculate its atomic mass?

(a) $0.97\ \text{Mg/m}^3 = [4(\text{amu}_{\text{Na}})/0.602 \times 10^{24}] / [4R/\sqrt{3}]^{1/3}$

(b) $0.97\ \text{Mg/m}^3 = [(\text{amu}_{\text{Na}})/0.602 \times 10^{24}] / [4R/\sqrt{3}]^{1/3}$

(c) $0.97\ \text{Mg/m}^3 = [(\text{amu}_{\text{Na}})/0.602 \times 10^{24}] / [4R/\sqrt{3}]^3$

(d) $0.97\ \text{Mg/m}^3 = [2(\text{amu}_{\text{Na}})/0.602 \times 10^{24}] / [4R/\sqrt{3}]^3$

Solution

Density is mass/volume. With 2 Na per cell, the mass per unit cell is (2Na)[g/(0.6 × 10^{24} Na)]. Volume per bcc unit cell is (body diagonal / $\sqrt{3}$)^3 or ($4R$ / $\sqrt{3}$)^3. The answer is (d).

13-18. How is the distance between adjacent (111) planes in fcc aluminum related to the distance between adjacent (110) planes?

(a) the same

(b) greater than

(c) (1+1+1)/(1+1+0) times as great

(d) (1+1+0)/(1+1+1) times as great

Solution

Make a sketch. There are three (111) interplanar spacings per cube body diagonal in an fcc metal unit cell. There are four (110) interplanar spacings per face diagonal in an fcc metal unit cell. The answer is (b).

13-19. How does the distance compare between adjacent (100) planes in bcc tungsten and between adjacent (110) planes.

(a) (100) distance is the same

(b) (100) distance is greater

(c) (100) distance is (1+0+0)/(1+1+0) times as great

(d) (100) distance is less

Solution

Make a sketch. There are two (100) interplanar spacings per cube edge in an bcc metal unit cell. There are two (110) interplanar spacings per face diagonal in an bcc metal unit cell. The answer is (d).

13-20. The repeat distance in the [011] direction of nickel (fcc) is 0.2492 nm. Therefore, the atomic radius is how many nm?

(a) $(0.2492)(\sqrt{2})$

(b) $(0.2492/2)/(\sqrt{3})$

(c) $(0.2492)/\sqrt{2})$

(d) 0.1246

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Solution

In fcc metals, the atoms have contact in the <110> directions. Therefore, the repeat distance is $2R$. The answer is (d).

13-21. The repeat distance in the [110] direction of iron (bcc metal) is 0.4052 nm. The atomic radius is how many nm?

(a) $(0.4052)(\sqrt{2})$

(b) 0.2026

(c) $[(0.4052)/(\sqrt{2})][(\sqrt{3})/4]$

(d) 0.4052

Solution

In a bcc metal, the repeat distance in the [110] is $a\sqrt{2}$. And the atoms have contact in the <111> directions. Make a sketch. The answer is (c).

13-22. The average molecular mass of PVC molecules in a plastic is 50,000 amu. How many mers in each? (Atomic masses are from Table 13-1.)

(a) 50,000/[2(12) + 3(1) + 35.5]

(b) (50,000) [2(12) + 3(1) + 35.5]

(c) 50,000/[2(12) + 2(1) + 2(35.5)]

(d) 50,000 (24 + 2 + 71)

Solution

Polyvinyl chloride (PVC) resembles polyethylene (PE) except that one of the four hydrogens is replaced by a chlorine, $-(C_2H_3Cl)-$ vs $-(C_2H_4)-$. The mass of each mer is [2(12) + 3(1) + 35.5 amu]. The answer is (a).

13-23. Styrene resembles vinyl chloride, C_2H_3Cl, except that the chlorine is replaced by a benzene ring. The mass of each mer is

(a) 8(12) + 9(1) amu

(b) 26 + 78 amu

(c) 27 + 6(12) + 6(1) amu

(d) 2(12) + 3(1) + 77 amu

Solution

Benzene is C_6H_6; however, in styrene, one hydrogen is absent at the connection to the C_2H_3- base. The answer is (d).

13-24. The $<1\bar{1}0>$ family of directions in a cubic crystal include all but which of the following? (An overbar is a negative coefficient):

(a) [110] (c) [101}

(b) $[0\bar{1}1]$ (d) $[1\bar{1}1]$

Solution

Since a cubic crystal has interchangeable *x*–, *y*–, and *z*– axes, the <110> family includes all directions with permutations of 1, 1, and 0 (either + or –). (This is not necessarily true for non-cubic crystals.) The answer is (d).

13-25. The {112} family of planes in a cubic crystal includes all but which of the following directions?

(a) (212) (c) $(1\bar{1}2)$

(b) (211) (d) (121)

Solution

Since a cubic crystal has interchangeable x–, y–, and z– axes, the {112} family includes all planes with index permutations of 1, 1, and 2 (either + or –). (This is not necessarily true for non-cubic crystals.) The answer is (a).

13-26. Crystal imperfections include all but which of the following?

(a) dislocations
(b) displaced atoms
(c) interstitials
(d) dispersions

Solutions

(b) and (c) involve individual atoms (point imperfections). (a) is a lineal imperfection. Boundaries result from a two-dimensional mismatch of crystal structures. The answer is (d).

13-27. A dislocation may be described as a

(a) displaced atom
(b) shift in the lattice constant
(c) a slip plane
(d) linear imperfection

Professional Engineering Exam

Solutions

There are two types of dislocations: 1) An edge dislocation may be described as an edge of a missing half-plane of atoms; 2) A screw dislocation is the core of a helix. The answer is (d).

13-28. A grain within a microstructure is

(a) a particle the size of a grain of sand
(b) the nucleus of solidification
(c) a particle the size of a grain of rice
(d) an individual crystal

Solution

Unless special efforts are made to grow single crystals, many crystals are nucleated and grow until they encounter neighboring crystals. Each grain is individually oriented. The answer is (d).

13-29. Which of the following does *not* apply to a typical brass?

(a) an alloy of copper and zinc
(b) a single-phase alloy
(c) an interstitial alloy of copper and zinc
(d) a substitutional solid solution

Solution

Zinc is sufficiently near copper in size and electrical behavior to proxy for copper in the crystal structure. It is too big for the interstices. The answer is (c).

13-30. Which of the following is a crystalline material having long-range order?

(a) a plate glass window

(b) a super-cooled syrup

(c) a pendant on a chandelier

(d) a random solid solution of copper in silver

Solution

Some glass products are called "crystal" because they can be shaped to give refracted colors, as do transparent gem crystals. Actually, glasses are amorphous, supercooled liquids. The answer is (d).

13-31. Sterling silver, as normally sold,

(a) is pure silver

(b) is a supersaturated solid solution of 7.5% copper in silver

(c) is 24-carat silver

(d) has higher conductivity than pure silver

Solution

The 7.5% copper replaces silver atoms. If it is cooled rapidly, the copper is retained in solid solution. The copper atoms interfere with electron movements within the silver. The answer is (b).

13-32. Atomic diffusion in solids matches all but which one of the following generalities?

(a) Diffusion is faster in fcc metals than in bcc metals.

(b) Smaller atoms diffuse faster than do larger atoms.

(c) Diffusion is faster at elevated temperatures.

(d) Diffusion flux is proportional to the concentration gradient.

Solution

Fcc metals have a higher packing factor than do bcc metals; therefore, with other factors equal, diffusion is reduced. The answer is (a).

13-33. Grain growth involves all but which of the following?

(a) reduced growth rates with increased time

(b) an increase in grain boundary area per unit volume

(c) atom movements across grain boundaries

(d) a decrease in the number of grains per unit volume

Solution

As the grains grow, their volume increases by the third power. Their surface area increases by the square. The answer is (b).

13-34. Imperfections within metallic crystal structures may be any but which one of the following?

(a) lattice vacancies and extra interstitial atoms

(b) displacements of atoms to interstitial sites (Frenkel defects)

(c) linear defects or slippage dislocations caused by shear

(d) ion pairs missing in ionic crystals (Schottky imperfections)

Solutions

Metallic crystals are not ionic and do not have discrete ions. The answer is (d).

13-35. All but which of the following statements about solid solutions are correct?

(a) In metallic solid solutions, larger solute atoms occupy the interstitial space among solvent atoms in the lattice sites.

(b) Solid solutions may result from the substitution of one atomic species for another, provided radii and electronic structures are compatible.

(c) Defect structures exist in solid solutions of ionic compounds when there are differences in the oxidation state of the solute and solvent ions, because vacancies are required to maintain an overall charge balance.

(d) Order-to-disorder transitions that occur at increased temperatures in solid solutions result from thermal agitation that dislodges atoms from their preferred neighbors.

Solution

The interstitial sites are smaller than the atoms in metals. The answer is (a).

13-36. In ferrous oxide, $Fe_{1-x}O$, two percent of the cation sites are vacant. What is the Fe^{3+}/Fe^{2+} ratio?

(a) 2/98 (c) 0.04/0.96

(b) 0.04/0.94 (d) 0.06/0.94

Solution

To balance the charge, each missing Fe^{2+} ion must be compensated by two Fe^{3+} ions. Therefore, out of 100 cation sites, two are vacant, four are Fe^{3+}, and thus 94 are Fe^{2+}. The answer is (b).

13-37. A solid solution of MgO and FeO contains 25 atomic percent Mg^{2+} and 25 atomic percent Fe^{2+}. What is the weight fraction of MgO? (Mg: 24; Fe: 56; and O: 16 amu)

(a) 40/(40 + 72) (c) 25/(25 + 25)

(b) 24/(24 + 56), or 4/80 (d) (25 + 25)/(50 + 50)

Solution

Using a computational basis of four atoms, (1 Mg^{2+} + 1 O^{2-}) + (1 Fe^{2+} + 1 O^{2-}) = (24 +16) + (56 + 16) = (40 + 72)
The answer is (a).

13-38. The boundary between two metal grains provides all but which of the following?

(a) an impediment to dislocation movements

(b) a basis for an increase in the elastic modulus

(c) a site for the nucleation of a new phase

(d) interference to slip

Solution

The elastic strains between atoms along the boundary follow the same relationships as the strains among atoms within the grains. The answer is (b).

13-39. If five percent copper is added to silver,

(a) the hardness is decreased

(b) the strength is decreased

(c) the thermal conductivity is decreased

(d) the electrical resistivity is decreased

Solution

Solid solution increases strength (solution hardening). It also decreases conductivity (and increases resistivity). Sterling silver is 92.5 Ag – 7.5 Cu. The answer is (c).

13-40. An interstitial site in fcc iron is at the center of the edge of the unit cell. The radius, R, of an iron atom is 0.127 nm. What is the diameter, d, of the interstitial site?

(a) 2(0.127)

(b) $(0.127)\sqrt{2} - (0.127)$

(c) $(\sqrt{2} - 1)(2)(0.127)$

(d) $[4(0.127)/\sqrt{3}] - 2(0.127)$

Solution

The face diagonal of an fcc metal is $4R$; therefore, the edge of the unit cell is $2R(\sqrt{2})$, and also $(2R + d)$. The answer is (c).

13-41. Stoichiometric zinc oxide is ZnO. Normally a few Zn^+ ions are present. In order to maintain a neutral charge, that presence of Zn^+ in the crystal could be accomodated by any but which of the following?

(a) interstitial zinc ions
(b) anion vacancies
(c) cation vacancies
(d) the introduction of Zn^{3+} ions

Solution

Charges can be balanced by (Zn^+F^- for $Zn^{2+}O^{2-}$), by (Zn^+Zn^{3+} for 2 Zn^{2+}), by an anion vacancy ($Zn^+Zn^+O^{2-}$ for 2 Zn^+O^{2-}) but not by a cation vacancy. The cation interstitial ($Zn^+Zn_i^+$ for 1 Zn^{2+}) is the principal adjustment in pure zinc oxide. The answer is (c).

13-42. All but which of the following statements about diffusion and grain growth are correct?

(a) Atoms can diffuse both within grains and across grain (crystal) boundaries.

(b) The activation energy for diffusion through solids is inversely proportional to the atomic packing factor of the lattice.

(c) Grain growth results from local diffusion and minimizes total grain boundary area. Large grains grow at the expense of small ones, and grain boundaries move toward their centers of curvature.

(d) Net diffusion requires an activation energy and is irreversible. Its rate increases exponentially with temperature. It follows the diffusion equation where flux equals the product of diffusivity and the concentration gradient.

Solution

When atoms are moved from one site to another, bonds are broken and reconstituted. During transition, an activation energy is required to distort the lattice. Small solute atoms, low melting-point solvents, and lower atomic packing factors in a lattice all require a lower activation energy. Hence activation energy for diffusion is *directly* proportional to the packing factor. The answer is (b).

13-43. Refer to the accompanying Mg–Zn phase diagram, Fig. 13-43. Select an alloy of composition C (71 Mg – 29 Zn) and raise it to 575 °C so that only liquid is present. Change the composition to 60 Mg – 40 Zn by adding zinc. When this new liquid is cooled, what will be the first solid to separate?

(a) a solid intermetallic compound

(b) a mixture of solid intermetallic compound and solid eutectic C (71 Mg – 29 Zn)

(c) a solid eutectic C (71 Mg – 29 Zn)

(d) a solid solution containing less than 1% intermetallic compound dissolved in Mg

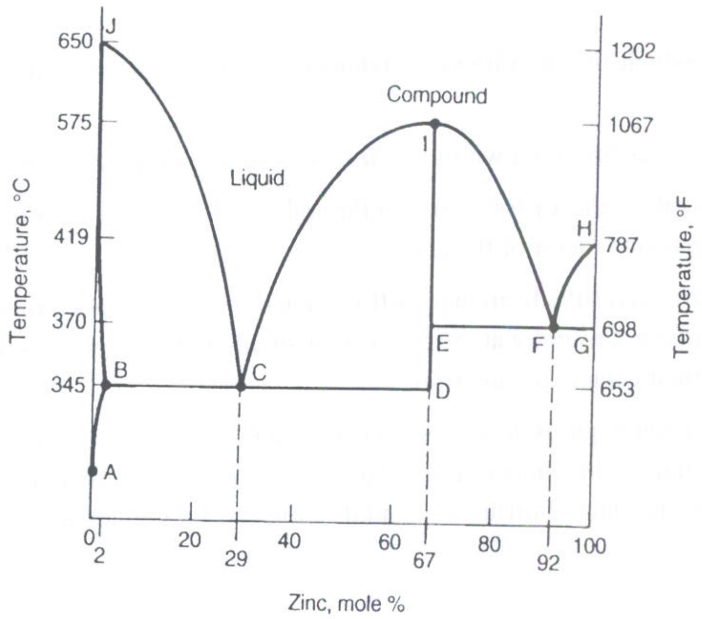

Fig. 13-43. Magnesium-Zinc phase diagram.

Solution

On cooling, curve CI is encountered at approximately 420 °C (790 °F). That curve is the solubility limit of Zn in that liquid. Zinc in excess of the solubility limit separates as the intermetallic compound, $MgZn_2$, which is plotted as the vertical line EI. The answer is (a).

13-44. Refer to the accompanying Mg–Zn phase diagram. Which of the following compounds is present?

(a) Mg_3Zn_2 (c) MgZn

(b) Mg_2Zn_3 (d) $MgZn_2$

Solution

A 67 Zn to 33 Mg atom ratio is 2-to-1; therefore, $MgZn_2$. The answer is (d).

13-45. Refer to Fig. 13-45, a schematic sketch of the Fe–Fe_3C phase diagram. All but which of the following statements are true?

(a) A eutectoid reaction occurs at location C, 727 °C (1340 °F).

(b) The eutectic composition is 99.2 weight-percent Fe and 0.8 weight-percent C.

(c) A peritectic reaction occurs at K, 1500 °C (2732 °F).

(d) A eutectic reaction occurs at G, 1130 °C (2202 °F).

(e) The eutectoid composition is 0.8 weight-percent C.

Solution

The eutectic composition is that of a low melting liquid saturated with two solids. The 0.8 weight-percent composition is a solid, not a liquid, at 727 °C. The answer is (b).

13-46. Refer to Fig. 13-45, the Fe–Fe_3C phase diagram. Pearlite contains ferrite (α) and carbide (Fe_3C). The weight fraction of carbide in pearlite is

(a) 0.8% (c) CD/BD

(b) BC/CD (d) BC/BD

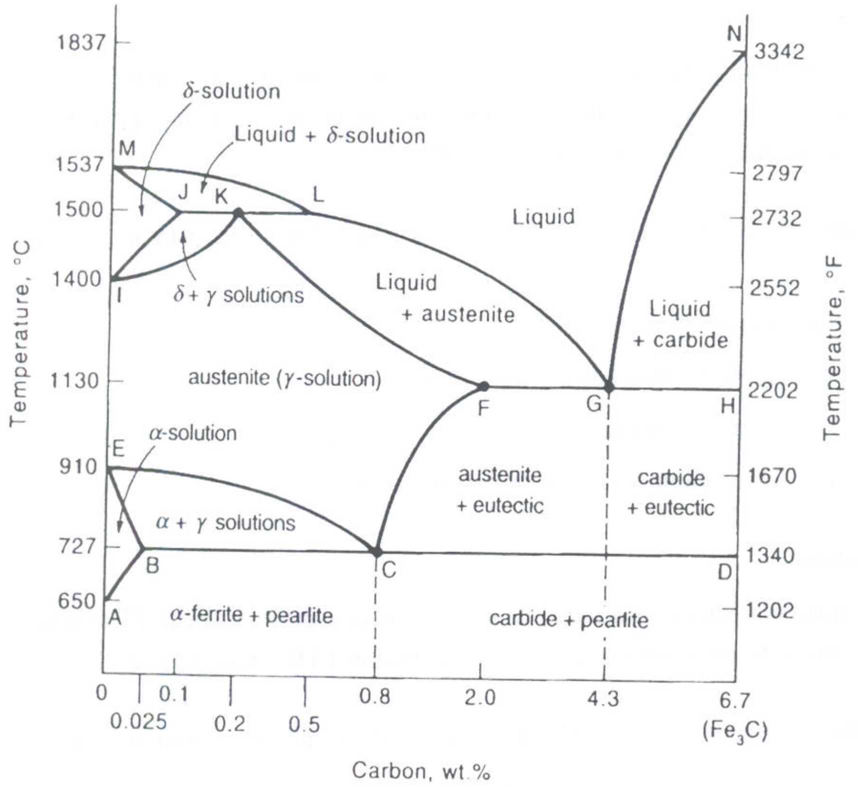

Fig. 13-45. Iron-Iron Carbide phase diagram (schematic)

Solution

The (ferrite + carbide) area extends across the lower part of the phase diagram from nil carbon to 6.7 carbon. At the left side there is no Fe_3C; at the right side there is only carbide (Fe_3C contains 6.7% carbon). The amount of carbide between the two extremes may be determined by linear interpolation. The answer is (d).

Materials Engineering

13-47. Consider the Ag–Cu phase diagram (Fig. 13-11 of the text). Silver-copper alloys can contain *approximately* half liquid and half solid at all but which of the following situations?

(a) 40 Ag – 60 Cu at 781 °C (c) 20 Ag – 80 Cu at 910 °C

(b) 81 Ag – 19 Cu at 781 °C (d) 50 Ag – 50 Cu at 779 °C

Solution

The eutectic temperature is 780 °C (1445 °F). That is the lowest temperature at which liquid can exist with equilibrium. At 779 °C there are approximately equal amounts of α and β, the two solid solutions. The answer is (d).

13-48. Refer to the Ag–Cu phase diagram previously cited. Which of the following statements is wrong?

(a) The solubility limit of copper in the liquid at 900 °C is approximately 62%.

(b) The solubility limit of silver in β at 700 °C is approximately 5%.

(c) The solubility limit of silver in β at 900 °C is approximately 7%.

(d) The solubility limit of copper in β at 800 °C is approximately 92%.

Solution

The curves of a phase diagram are solubility limits for the phases within the single-phase regions. Since copper is the solvent for the β structure, β has no upper limit of copper solubility (other than 100%). The answer is (d).

13-49. Other factors being equal, diffusion flux is facilitated by all but which of the following?

(a) smaller grain sizes

(b) smaller solute (diffusing) atoms

(c) lower concentration gradients

(d) lower melting solvent (host structure)

Solution

The diffusion flux is proportional to the concentration gradient. (The other choices cited reduce the activation energy needed for diffusion.) The answer is (c).

13-50. Consider copper. All but which of the following statements are applicable for grain growth?

(a) Atoms jump the boundary from large grains to small grains.

(b) Grain size varies inversely with boundary area.

(c) Grain growth occurs because the boundary atoms possess higher energy than interior atoms.

(d) Grain growth occurs because larger grains have less boundary area.

Solution

Boundary atoms possess higher energy. Therefore, the boundary is reduced and the grain size is increased at temperatures where the atoms can move. The net movement of the atoms is to the larger grains (with less boundary area). The answer is (a).

13-51. When equilibrated, single-phase microstructures may possess which of the following variations in the grains?

(a) size and composition

(b) conductivity and size

(c) density and shape

(d) shape and orientation

Solution

Size, shape, and orientation are variables in single-phase microstructures. The answer is (d).

13-52. A phase diagram can provide answers for all but which of the following questions?

(a) What are the directions of the planes at a given temperature?

(b) What phases are present at a given temperature?

(c) What are the phase compositions at a given temerpature?

(d) How much of each phase is present at a given temperature?

Solution

Phase diagrams can not be used to predict crystalline properties. The answer is (a).

13-53. In the Ag–Cu system (Fig. 13-11 of the text), three equilibrated phases may be present at

(a) 930 °C (c) 830 °C

(b) 880 °C (d) 780 °C

Solution

Above the eutectic temperature, $(\alpha + L)$ can be present concurrently, as can $(L + \beta)$, but not $(\alpha + \beta)$. Below the eutectic temperature, $(\alpha + \beta)$ may be present, but no liquid. As the eutectic temperature is passed during cooling or heating, all three phases may coexist. The answer is (d).

13-54. The microstructures of multiphase materials may involve all but which of the following variables?

(a) phase shape and phase density

(b) phase amounts and distribution

(c) phase quantities and shape

(d) phase composition and shape

Solution

Microstructure is a geometric characterization. Density is independent of size, shape, and location. The answer is (a).

13-55. During heating, a 72 Ag – 28 Cu alloy (Fig. 13-11 of text) may have any but which one of the following equilibrium relationships?

(a) ~25% β at 600 °C, where β contains ~2% Ag

(b) less than 50% β (95 Cu – 5 Ag) at 700 °C

(c) ~74% α (93 Ag – 7 Cu) at 750 °C

(d) α (26% Cu) and β (32% Cu) at 800 °C

Solution

At 800 °C, a 72 Ag – 28 Cu alloy is fully liquid, which therefore has 72–28 composition. The answer is (d).

13-56. During cooling, a (20 Ag – 80 Cu) alloy (Fig. 13-11 of text) has all but which one of the following equilibrium situations?

(a) the first solid forms at 980 °C

(b) the first solid contains 5% Ag

(c) the second solid appears at 780 °C

(d) the last liquid contains 32% Cu

Solution

During equilibrium cooling, the final liquid for this alloy does not disappear until the eutectic temperature is reached at 780 °C. At that temperature, the liquid composition is 72 Ag – 28 Cu. The answer is (d).

13-57. Add copper to 100 g of silver at 781 °C (Fig. 13-11 of text). Assume equilibrium. Which statement is correct?

(a) Liquid first appears with the addition of exactly 9 g of copper.

(b) The last α disappears when approximately 39 g of copper has been added.

(c) The solubility limit of copper in solid silver (α) is 28% copper.

(d) β first appears with the addition of 92 g of copper.

Solution

All α disappears on the right side of the (α + L) field, where the composition is 72 Ag – 28 Cu, or (100 g Ag – 39 g Cu). The answer is (b).

13-58. The valence band model used to explain conduction is consistent with all but which one of the following statements?

(a) Each valence band may contain up to $2n$ electrons per n atoms; each pair of electrons (with opposite spins) possesses a discretely different energy level (state) in the energy band.

(b) Conduction occurs when an electron remains in its existing state, or energy level, within the band.

(c) The Fermi energy level, E_f, is essentially temperature independent and is the energy at which 50% of the available energy states are occupied.

(d) A conduction band lies at the next higher set of energy levels above those of the valence band.

Solution

For an electron to conduct charge, it must be energized to move toward the positive pole. This means that it must be raised out of its occupied state to a higher vacant state. Both semiconductors and insulators have filled valence bands. For them to conduct, an electron from the valence band must be energized across an energy gap. The gap is small enough in a semiconductor so that a usable number enter the upper conduction band. The band gap is too great in an insulator for measurable numbers of electrons to enter the conduction band. The answer is (b).

13-59. Silicon becomes an extrinsic semiconductor—with electrons as the majority carrier—when doped with

(a) germanium

(b) boron

(c) antimony

(d) aluminum

Solution

Group III elements have a shortage of an electron compared to Si and Ge. As examples, B and Al readily accept an electron from the valence band, thereby leaving an electron hole. These are positive in response, and they become the majority charge carriers. The silicon becomes p-type.

Group V elements have an extra electron per atom, which can be donated to the conduction band of silicon (or Ge). These electrons serve as the majority carriers. Being negative, the semiconductor is n-type. The answer is (c).

13-60. All but which one of the following statements about ferromagnetism are correct?

(a) The high magnetic susceptibility of ferromagnetic materials disappears below the Curie temperature.

(b) Domains are randomly oriented when unmagnetized. On magnetization, domains oriented with the external field grow at the expense of those not so aligned.

(c) Above the Curie temperature (770 °C for iron) ferromagnetic domains disappear, and the material becomes paramagnetic.

(d) Impurities, inclusions, dislocations, and grain boundaries interfere with movements of domain boundaries and add to the permanency of a magnet.

Solution

Thermal agitation overcomes spontaneous magnetism at elevated temperatures, vanishing completely at the Curie temperature. Atomic magnetism occurs mainly from unbalanced electron spins in the 3*d* orbitals. The answer is (a).

13-61. Which of the following compounds would more likely serve as an intrinsic semiconductor?

(a) SbP (c) SiB

(b) AlB (d) InP

Solution

A III-V compound averages four valence electrons per atom, completely filling two energy bands. InP is a III-V compound. The answer is (d).

13-62. In metals, conductivity is reduced when electrons are scattered by all but which one of the following?

(a) dislocations

(b) long range order

(c) solute atoms

(d) increased thermal vibrations of the atoms

Solution

Structural disorder in metals scatters electrons and decreases the electrical conductivity. The answer is (b).

13-63. All but which one of the following statements regarding intrinsic semiconductors is generally true?

(a) The number of negative carriers equals the number of electron holes.

(b) The numbers of electrons in the conduction band equals the number of positive carriers.

(c) Heavier Group IV semiconductors have smaller energy gaps.

(d) The number of carriers is a direct function of the melting point of the semiconductor.

Solution

There are equal numbers of positive and negative carriers in an intrinsic semiconductor. They increase in number with application temperature (not with melting temperature). The answer is (d).

13-64. Metals are good thermal conductors because

(a) thermons partially fill the valence band

(b) thermons jump the energy gap into the conduction band

(c) metals are thermally dense

(d) electrons transfer thermal energy

Solution

Thermal energy is transferred through solids by elastic waves (phonons) and by delocalized electrons, as they are in metals. The answer is (d).

13-65. Electrical conduction can occur by all but which one of the following?

(a) cation diffusion to the negative electrode

(b) anion transfer to the positive electrode

(c) anion vacancy diffusion to the negative electrode

(d) electron holes carried to the positive electrode

Solution

Cations, electron holes, and anion vacancies are all positive carriers that migrate toward the negative electrode. The answer is (d).

13-66. All but which one of the following statements regarding extrinsic semiconducting silicon is true?

(a) The number of n-type carriers equals the number of p-type carriers in extrinsic silicon.

(b) Group III elements accept electrons from the valence band of silicon.

(c) Electrons are donated to the conduction band in n-type silicon.

(d) The Fermi energy is raised by Group V elements in extrinsic silicon.

Solution

Group III elements accept electrons from the valence band of silicon to produce electron holes and p-type majority carriers. Group V elements donate electrons to the conduction band of silicon to produce n-type majority carriers. Thus, the symmetry across the energy gap does not hold, and the Fermi energy level is shifted. The answer is (a).

13-67. Which one of the following statements is *incorrect* at 0 °K?

(a) The valence and conduction bands of an intrinsic semiconductor overlap.

(b) Insulators have a wide energy gap.

(c) Insulators have a filled valence band.

(d) Metals have empty states in the valence band.

Solution

Semiconductors have a narrow energy gap; insulators have a wide energy gap. The answer is (a).

13-68. Which of the following does *not* contribute to the permanence of a magnet?

(a) cold working (c) minor phases

(b) grain growth (d) crystal anisotropy

Solution

The movement of domain boundaries (Bloch walls) is resisted by structural imperfections and variations. The answer is (b).

13-69. Which of the following statements is correct?

(a) Silicon (E_g = 1.1 eV) has a greater intrinsic conductivity than does germanium (E_g = 0.7 eV).

(b) Electrons are the majority carriers in boron-doped silicon.

(c) Semiconductivity is proportional to the product of the number and the mobility of carriers.

(d) Semiconductivity increases linearly with temperature.

Solution

Semiconductivity is proportional to $e^{-E_g/2kT}$, and equals $nq\mu$ [Eq. (5) and (6) of the text]. The greater semiconductivity at higher temperature comes from the exponential increase in the number of carriers, and not from their mobility. Electron (and hole) mobilities decrease slightly with increased temperature because of thermal scattering. The answer is (c).

13-70. Nonmetallic solids may lose transparency by all but which one of the following:

(a) light scattering at pore surfaces

(b) light refraction at phase boundaries

(c) by containing only a single phase

(d) the inclusion of higher index particles

Solution

Internal boundaries reflect and refract light. Imperfections within a phase absorb light. The answer is (c).

13-71. All but which one of the following statements about strain hardening is correct?

(a) Strain hardening is produced by cold working.

(b) Strain hardening is relieved during annealing above the recrystallization temperature.

(c) With more strain hardening, more time-temperature exposure is required for relief.

(d) Strain hardening is relieved during recrystallization. Recrystallization produces less strained and more ordered structures.

Solution

As the temperature is increased, the atoms gain additional energy and can relocate, eliminating the strain energy that accompanies dislocations. *Less time* is required at higher temperatures. *Less time* is also required for a highly cold-worked material because there is additional stored energy present. The answer is (c).

13-72. Which process is used for the high-temperature shaping of many materials?

(a) reduction
(b) recrystallization
(c) polymerization
(d) extrusion

Solution

Reduction and polymerization involve chemical reactions. Tempering and recrystallization involve reheating but no shape change. The answer is (d).

13-73. All but which one of the following processes strengthens metals?

(a) precipitation processes which produce submicroscopic particles during a low-temperature heat treatment

(b) increasing the carbon content of low-carbon steels

(c) annealing above the recrystallization temperature

(d) mechanical deformation below the recrystallization temperature (cold working)

Solution

Strength and hardness are increased at the expense of ductility and toughness (opposite of brittleness). The increase is facilitated by microstructures that interfere with dislocation movements. These include a high density of dislocations from plastic deformation, and the presence of many fine, hard particles. Annealing removes dislocations and permits the agglomeration of particles into fewer large particles. The answer is (c).

13-74. All but which one of the following statements about the austenite-martensite-bainite transformations is correct?

(a) Pearlite is a stable lamellar mixture consisting of bcc ferrite (α) plus carbide (Fe_3C). It forms through eutectoid decomposition during slow cooling of austenite. Most alloying elements in steel retard this transformation.

(b) Martensite has a body-centered structure of iron that is tetragonal and is supersaturated with carbon. It forms by shear during the rapid quenching of austenite (fcc iron).

(c) Tempering of martensite is accomplished by reheating martensite to precipitate fine particles of carbide within a ferrite matrix, thus producing a tough strong structure.

(d) Bainite and tempered martensite have distinctly different microstructures.

Solution

The production of tempered martensite is indicated in (c) above. Bainite is formed by isothermally decomposing austenite directly to a microstructure of fine carbide partcles within a ferrite matrix. Although the processing differs, the resulting microstructure and properties are nearly identical. The answer is (d).

13-75. Steel can be strengthened by all but which one of the following practices?

(a) annealing

(b) quenching and tempering

(c) age or precipitation hardening

(d) work hardening

Solution

Annealing removes the hardness that was introduced by cold work. Quenched and tempered steels are harder with higher carbon contents, because more hard carbide particles are present. Alloying elements perform several hardening functions: They solution-harden the ferrite matrix; they slow down grain growth; and they delay the formation of pearlite, thus permitting more martensite with slower cooling rates (in turn, more tempered martensite may be realized farther below the quenched surface). The answer is (a).

13-76. Residual stresses can produce any but which one of the following?

(a) warpage

(b) distortion in machined metal parts

(c) cracking of glass

(d) reduced melting temperatures

Solution

Stresses will relax below the melting temperature. Tensile stresses facilitate the cracking of brittle materials; compression limits cracking. The answer is (d).

13-77. The reaction ($\gamma \rightarrow \alpha + Fe_3C$) is most rapid at

(a) the eutectoid temperature

(b) 10 °C above the eutectoid temperature

(c) the eutectic temperature

(d) 100 °C below the eutectoid temperature

Solution

The reaction occurs only below the eutectoid temperature. The answer is (d).

13-78. If 1080 steel (0.80 wt.% carbon) is annealed by very slow cooling from 800 °C to ambient temperature, its microstructure will consist almost entirely of

(a) bainite
(c) martensite
(b) austenite
(d) pearlite

Solution

With equilibrium at 800 °C a 1080 steel is fully austenitic. During slow cooling past the eutectoid temperature to ambient, austenite decomposes to pearlite (ferrite plus lamellar carbides). Rapid cooling (quenching) yields metastable martensite. On tempering, the martensite yields fine particles of carbide in a ferrite matrix. The answer is (d).

13-79. Grain growth, which reduces boundary area, may be expected to

(a) decrease the thermal conductivity of ceramics

(b) increase the hardness of a solid

(c) decrease the creep rate of a metal

(d) increase the recrystallization rate

Solution

While grain boundaries interfere with slip at low temperatures, they facilitate creep at elevated temperatures. The answer is (c).

13-80. Crystallization from a liquid is slowest for

(a) soda-lime glasses

(b) pure silica glasses

(c) metallic alloys, such as iron with additions of C, P, or Si

(d) pure metals

Solution

Both silica glass and crystallized silica have the same strong Si-O bonds. Therefore, only a very small (long-range) energy change is available to drive the crystallization process. Na^+ and Ca^{2+} ions modify the silica network to permit easier atom rearrangements and crystallization. The answer is (b).

13-81. Crystallization from a liquid is fastest for

(a) soda-lime glasses

(b) pure silica glasses

(c) metallic alloys, such as iron with additions of C, P, or Si

(d) pure metals

Solution

All first-neighbor bonds are identical in pure metals. Therefore only nearest neighbor relocations are necessary. The answer is (d).

13-82. Rapid cooling can produce which one of the following in a material such as sterling silver?

(a) homogenization

(b) phase separation

(c) grain boundary contraction

(d) supersaturation

Solution

The processing step of rapid cooling, such as quenching, retains the structures that existed at higher temperatures, even though a solubility limit is exceeded. The answer is (d).

13-83. Martensite, which may be obtained in steel, is a

(a) supersaturated solid solution of carbon in iron

(b) supercooled iron carbide, Fe_3C

(c) undercooled fcc structure of austenite

(d) superconductor with zero resistivity at low temperatures

Solution

Martensite is a transition phase between austenite and ferrite, which retains carbon interstitially. Given an opportunity, the carbon separates as Fe_3C. The answer is (a).

13-84. Alloying elements produce all but which one of the following effects in steels?

(a) They alter the number of atoms in a unit cell of austenite.

(b) They increase the depth of hardening in quenched steel.

(c) They increase the hardness of ferrite in pearlite.

(d) They retard the decomposition of austenite.

Solution

Alloying elements can dissolve substitutionally in austenite which remains fcc. The answer is (a).

13-85. Hardenability may be defined as

(a) resistance to indentation

(b) the hardness attained for a specified cooling rate

(c) another measure of strength

(d) rate of increased hardness

Solution

Hardenability may be described as the ability, or the ease, by which martensitic hardness is obtained at various cooling rates (as located on an end-quenched, or Jominy, test). The answer is (b).

13-86. Hardenability tests are used for steel alloys. Why not for copper alloys?

(a) The copper-rich phase is stable at all temperatures below the melting temperature.

(b) Copper alloys never are as hard as any of the steels.

(c) Copper-rich phases are fcc.

(d) Copper alloys form substitutional and not interstitial phases.

Solution

Hardenability is the result of phase transitions which produce new structures. The answer is (a).

13-87. The linear portion of the stress-strain diagram of steel is known as the

(a) irreversible range
(b) secant modulus
(c) modulus of elasticity
(d) elastic range

Solution

The ratio of stress-to-strain is defined as the elastic modulus. The answer is (d).

13-88. The ultimate (tensile) strength of a material is calculated from

(a) the applied force divided by the true area at fracture

(b) the applied force times the true area at fracture

(c) the tensile force at the initiation of slip

(d) the applied force and the original area

Solution

$S_u = F/A_o$. The answer is (d).

13-89. All but which one of the following statements about slip are correct?

(a) Slip occurs most readily along crystal planes that are least densely populated

(b) Slip, or shear along crystal planes, results in an irreversible plastic deformation or permanent set.

(c) Ease of slippage is directly related to the number of low energy slip planes within the lattice structure.

(d) Slip is impeded by solution hardening, with odd-sized solute atoms serving as anchor points around which slippage does not occur.

Solution

Slip occurs most readily in directions that have the shortest steps, and along planes that are farthest apart. The latter are automatically the planes that are most densely populated. The answer is (a).

13-90. When a metal is cold worked more severely, all but which one of the following generally occur?

(a) the recrystallization temperature decreases

(b) the tensile strength increases

(c) grains become equiaxed

(d) slip and/or twinning occur

Solution

Cold working—such as rolling, forging, drawing, or extrusion—deforms the material at temperatures below the recrystallization temperature. Strain hardening occurs, increasing both the yield and ultimate strength. Internal strains and minute cracks are introduced as slip or twinning occur. Ductility, elongation and the recrystallization temperature are decreased. A preferred grain orientation is introduced in the direction of elongation, and the grains are flattened. The answer is (c).

13-91. All but which one of the following statements about steel are correct?

(a) Abrasion resistance of ultra-high strength steels may be obtained by increasing the hardness to 225–400 Brinell at the expense of some ductility.

(b) Steels used in reinforced concrete construction have yield strengths in tension of 230 – 525 MPa.

(c) Intergranular corrosion of Cr-Ni stainless steels is reduced if the steel is stabilized with niobium (columbium), titanium, or tantalum to form carbides, avoiding the depletion of chromium along grain boundaries.

(d) Yield strengths of commercially available heat-treated alloy steels do not exceed 1400 MPa.

Solution

Dozens of steels are available with yield strengths over 1575 MPa. Any steel with a yield strength over 1120 MPa is considered to be an ultra-high strength steel. The answer is (d).

13-92. All but which one of the following statements about the rusting of iron are correct?

(a) Contact with water and oxygen are required for rusting to occur.

(b) Halides aggravate rusting, a process which involves electrochemical oxidation-reduction reactions.

(c) Contact with a more electropositive metal restricts rusting.

(d) Corrosion occurs in oxygen-rich areas.

Solution

Since oxygen is required for rust formation, oxygen-depleted areas become the anode and are corroded. This may lead to pitting, particularly if rust or other corrosion products are accumulated locally to prevent the access of oxygen. Iron and other metals may be protected from corrosion by the presence of a more electropositive metal such as magnesium or zinc. This is the reason for coating steel with zinc to produce galvanized sheet. The answer is (d).

13-93. All but which one of the following statements about mechanical and thermal failure is true?

(a) Creep is time-dependent, plastic deformation that accelerates at increased temperatures. Stress rupture is the failure following creep.

(b) Ductile fracture is characterized by significant amounts of energy absorption and plastic deformation (evidenced by elongation and reduction in cross-sectional area).

(c) Fatigue failure from cyclic stresses is frequency-dependent.

(d) Brittle fracture occurs with little plastic deformation and relatively small energy absorption.

Solution

Although fatigue strength is not sensitive to temperature or loading rates, it is very sensitive to surface imperfections from which cracks originate and propagate. The answer is (c).

13-94. The stress intensity factor is calculated from

(a) yield stress and crack depth

(b) applied stress and crack depth

(c) tensile stress and strain rate

(d) crack depth and strain rate

Solution

The stress intensity factor is proportional to the applied stress and the square root of the crack depth. The answer is (b).

13-95. Service failure from applied loads can occur in all but which one of the following cases?

(a) cyclic loading, tension to compression

(b) glide normal to the slip plane

(c) cyclic loading, low tension to higher tension

(d) Stage 2 creep

Solution

Glide occurs parallel to the slip plane. The answer is (b).

13-96. Brittle failure becomes more common when

(a) the endurance limit is increased

(b) the glass-transition temperature is decreased

(c) the critical stress intensity factor is increased

(d) the ductility-transition temperature is increased

Solution

Brittleness exists below T_{dt}. The answer is (d).

13-97. Where applicable, all but which one of the following procedures may reduce corrosion?

(a) avoidance of bimetallic contacts

(b) sacrificial anodes

(c) aeration of feed water

(d) impressed voltages

Solution

Corrosion commonly occurs in the combined presence of oxygen and water. Protection may be obtained by making a cathode out of the critical part or avoiding air. The answer is (c).

13-98. A fiber-reinforced rod contains 50 volume-percent glass fibers (E = 70 GPa, S_y = 700 MPa) and 50 volume-percent plastic (E = 7 GPa). The glass carries what part of a 5000 N tensile load?

(a) [(7,000 MPa)(0.5)] / [70,000 MPa)(0.5)] = 0.1; $F_g = (0.1)(5{,}000\text{ N}) = 500\text{ N}$

(b) [(70,000)(0.5) + 7,000(0.5)] = 5000/x; $x = 0.0002$

(c) $[(F_g/0.5A)/(F_p/0.5A)] = (70/7) = 10;\quad F_g/(F_p + F_g) = 10F_p/(10F_p + F_p) = 0.91$

(d) (70)/[70 + 2(7)] = 0.83

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Solution

With equal strains, $(s_g/s_p) = E_g/E_p = 10$. Likewise with equal areas, $F_g = 10F_p$, and $F_g/(F_g + F_p)$ = 10/(10 + 1). The answer is (c).