Engineering Materials

1. The crystal structure of copper is face-centered cubic. The density of copper at room temperature is 8.94 g/cm^3 and the atomic weight of copper is 63.5. Answer the following questions. The Avogadro number is 6.02 x 10^{23}. 21.3$^{1/3}$ can be approximated as 2.77 and 2$^{1/2}$ as 1.41.

    (1) Find the number and mass of atoms per unit lattice of copper crystal.

    (2) Find the lattice constant of copper crystal at room temperature.

    (3) Draw a cross-sectional view of a face-centered cubic crystal cut in the (100), (110), and (111) planes for a unit lattice.

    (4) Find the center-to-center distance of the nearest neighbor atoms in a copper crystal at room temperature.

    (5) Find the number of atoms per unit area in the (100) plane of a copper crystal at room temperature.

2. Answer the following questions about the structure and defects of solids.

    (1) Assume that the interatomic potential energy $V_{(r)}$ is given by the following equation as a function of the interatomic distance r (m, n are constants). Show the variation of $V_{(r)}$ and the force acting between the two atoms in a schematic diagram with r on the horizontal axis. Also, explain the relationship between $V_{(r)}$ and a) distance between nearest neighbor atoms, b) Young's modulus, and c) melting point.

$$V_{(r)} = -\frac{m}{r} + \frac{n}{r^{10}}$$

    (2) In the body-centered cubic and face-centered cubic structures, give one Miller indices for a crystallographic plane where the atoms are most tightly packed, and answer how many of those planes are crystallographically equivalent to each other. If the lattice constant is 0.3 nm, find the number density of atoms [/m^2] on that face.

    (3) If atoms are assumed to be rigid spheres in a hexagonal close-packed lattice, find the axial ratio c/a. (Note that a and c are the lattice constants of the unit cell as shown in Fig. 1.

    (4) Imperfections of crystal structure are generally classified into a) point defects, b) line defects, and c) planar defects based on their morphology. For each, give one specific name of the defect and explain its structure and effect on the properties of the material.
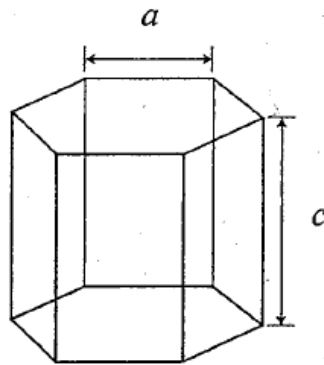
a

c

Fig. 1

3. Answer the following questions about face-centered-cubic (fcc) crystal with the lattice constant a.

(1) Draw the unit cell.

(2) Consider the hard-sphere model. Obtain the atomic radius R using a.

(3) There are two different types of interstitial sites in fcc.

    a) Give the names of the two interstitial sites.

    b) Obtain all the coordinates of the interstitial sites in the unit cell referring to Fig. 2.

    c) Obtain the largest radius of the hard-sphere that fits into interstitial sites

(4) The slip motion of dislocations causes plastic deformation of metals. It occurs more readily along with certain crystal directions on certain planes than along with others. These combinations are called a slip system.

    a) Show a predominant slip system using Miller indices.

    b) Explain the reason why the slip system is predominant.

    c) Draw one of the slip planes in a blank cube and show all the slip directions on the slip plane using arrows.
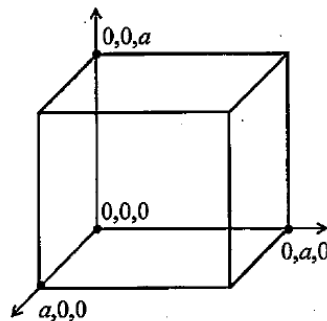

0,0,a

0,0,0

0,a,0

a,0,0

Fig. 2

4. Answer the following questions concerning mechanical properties of carbon steel.

(1) Uniaxial tensile test was performed on a round bar specimen made of carbon steel. The diameter and the length of the gauge section of the specimen were 14 mm and 50 mm, respectively. When a tensile load of 50 kN was applied to the specimen, elastic elongation of the gauge section was 0.077 mm. Obtain Young's modulus of this material.

(2) The initial dislocation density and the yield stress of a steel were 1.0×10^5 mm/mm^3 and 0.40 GPa, respectively. Cold-rolling was applied to the steel and the yield stress of the steel increased to 0.90 GPa. Estimate the dislocation density of the cold-rolled steel when the modulus of rigidity is 80 GPa and length of the Burgers vector is 2.5×10^{-7} mm.

(3) The yield stress of a steel decreased from 0.60 GPa to 0.40 GPa when its average grain size was changed from 1.0×10^{-3} mm to 9.0×10^{-3} mm. Estimate the yield stress when the average grain size is 8.1×10^{-2} mm. Neglect the changes of other variables.

5. Answer the following questions about plastic deformation of metals.

(1) Explain Peierls stress and describe the reason why the Peierls stress is smaller than the theoretical critical shear stress of a perfect crystal.

(2) Explain the mechanism of work hardening.

(3) High purity lead can be highly deformed without work hardening at ambient temperature. Explain the reason of the phenomenon from the viewpoint of microstructure change during the deformation.

(4) Explain the influence of grain boundary on the creep deformation, and give an example of the grain boundary controlling methods to suppress the creep deformation.

6. Answer the following questions about evaluation methods of the strength of metallic materials.

(1) Briefly describe the fatigue test method and explain the definition of fatigue limit using schematic figures.

(2) Briefly describe the creep test method, and explain the relationship between creep rate and time using schematic figures.

(3) Briefly describe the impact test method and explain how to determine the ductile-brittle transition temperature using schematic figures.

7. Answer the following questions. Use figures and equations if necessary.

    (1)   Show the one-dimensional diffusion equation under non-steady state defined as Fick's second law, and show the unit of the diffusion coefficient.

    (2)   Explain peritectic reaction and peritectoid reaction.

    (3)   Explain isothermal transformation and draw a typical time temperature transformation diagram.

    (4)   Explain recovery and recrystallization.

    (5)   Explain age hardening and over aging.

    (6)   Explain diffusion creep and give two diffusion paths.

8. Answer the following questions. Use figures and equations if necessary.

    (1)   Explain the temperature dependence of the diffusion coefficient of atoms in solids.

    (2)   Explain interstitial solid solution and substitutional solid solution.

    (3)   Explain quenching and tempering of steel.

    (4)   Describe the relationship between work hardening and recovery processes and dislocations.

    (5)   Explain the Guinier-Preston zone.

    (6)   Explain the Paris equation for fatigue crack growth rate.

9. Answer the following questions about the phase diagram of Pb-Sn alloys shown in Fig. 3.

    (1)   Alloys with a different composition of C_1, C_2 and C_3 are gradually cooled from 350°C to room temperature. Explain the microstructures at points i, j, k, l and m using schematics.

    (2)   Explain Gibbs phase rule, and write the degrees of freedom at the phase of the point k.

    (3)   A Pb-Sn alloy with a Sn concentration of 30 wt% is slowly cooled from 350°C to 250°C. Give the compositions and ratio of formed phases after this thermal treatment.
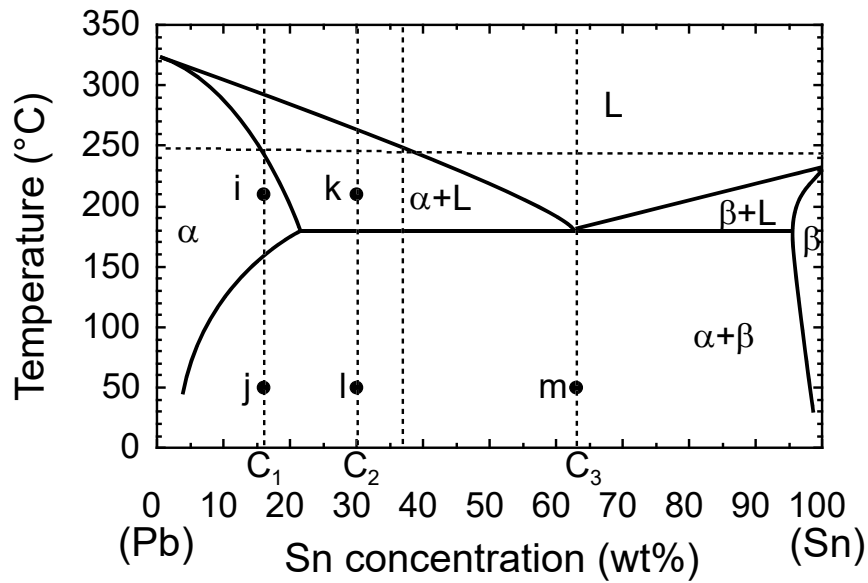
Fig. 3

10. Consider that one side of a Fe plate is exposed to carburizing environment and that the other side is exposed to decarburizing environment, at 973 K. Here, it is assumed that the steady state of carbon diffusion is achieved and that the concentrations of carbon at the depth of 5×10^{-3} and 1×10^{-2} m from the carburizing environment are 1.2 and 0.8 kg/m^3, respectively. The carbon concentration just beneath the decarburizing surface is assumed to be 0. The diffusion coefficient of carbon in Fe at 973 K is 3×10^{-11} m^2/s. Use gas constant $R = 8.31 \, J(mol \cdot K)$, $e = 2.72$; ln2 = 0.693; ln10 = 2.30, if necessarily. Answer the following questions.

(1) Obtain the carbon flux through the Fe plate.

(2) Obtain the carbon concentration at the depth of 1×10^{-3} m from the surface of the carburizing side.

(3) Obtain the thickness of the Fe plate.

(4) Obtain the activation energy for diffusion of carbon when the frequency factor is 6.0×10^{-7} m^2/s.

(5) Obtain the temperature where the diffusion coefficient is the half of that at 973 K.