Physical Metallurgy (I) Final exam (Chapter 4-6)

Department of materials science and engineering, National United University Jan. 10 2023 10:00 – 12:00

(A) Multiple-choice question (Select the correct answer from the list) (60%)

1. Which of following does not correct for screw dislocation? (a) It may be formed by a tensile stress (b) It belongs to one-dimensional defect (c) It can be found in crystalline materials (d) The dislocation line can be linear. (e) none of the above

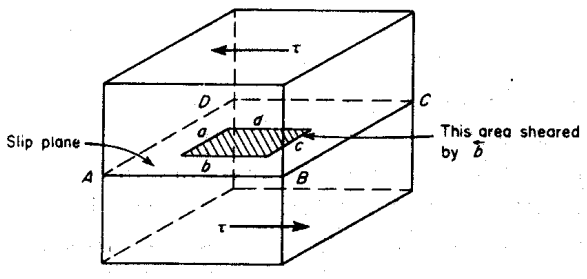
2. Two edge dislocations which are side by side at the same slip plane with opposite Burgers factor will (a) attract each other (b) release stress in grain (c) disappear finally (d) all of above (e) none of the above

3. Metal usually deforms plastically at stress ~1/10,000 of its theoretical strength. This is due to the presence of (a) vacancy (b) interstitial atom (c) dislocation (d) grain boundary (e) precipitates

4. During plastic deformation, dislocations move preferentially on (a) slip planes (b) twin planes (c) grain boundary (d) any planes (e) surface.

5. The total dislocation $\frac{1}{3}[\bar{1}\bar{1}20]$ on the (0001) plane of the hcp crystal can be dissociated into two Shockley partial dislocations. Which are the possible partial dislocations? (a) $\frac{1}{3}[0\bar{1}10]$, $\frac{1}{3}[\bar{1}010]$ (b) $\frac{1}{3}[10\bar{1}0]$, $\frac{1}{3}[1\bar{1}00]$ (c) $\frac{1}{3}[01\bar{1}0]$, $\frac{1}{3}[01\bar{1}0]$ (d) $\frac{1}{3}[01\bar{1}0]$, $\frac{1}{3}[\bar{1}100]$ (e) $\frac{1}{3}[0\bar{1}10]$, $\frac{1}{3}[\bar{1}100]$

6. The right figure shows the dislocation loop and applied shear stress. If the dislocation loop is expanding, which dislocation line is the positive edge dislocation? (a) line *a* (b) line *b* (c) line *c* (d) line *d* (e) none of the above.



7. Calculate the indices of the edge dislocation line which has $\vec{b} = \frac{1}{2}[1\bar{1}0]$ and lies in the (111) plane. (a) $[1\bar{2}1]$ (b) $[11\bar{2}]$ (c) $[\bar{2}11]$ (d) $[121]$ (e) $[112]$

8. Which of the following materials has the widest dislocation width (a) Ionic solids (b) Covalent solids (c) FCC metals (d) BCC metals (e) HCP metals

9. Force acts normal to the dislocations lines is proportional to (a) $\sqrt{b}$ (b) b (c) b^2 (d) b^3 (e) b^{-1}, where *b* is the Burgers vector.

10. Calculate the stored energy (J/m^3) in a copper crystal with a dislocation density of 10^{11} cm^{-2} and G= 48 GPa and a lattice constant a= 0.36 nm. (a) 1.5×10^3 (b) 1.5×10^4 (c) 1.5×10^5 (d) 1.5×10^6 (e) 1.5×10^7

11. When a tensile stress is applied along the $[010]$ direction of a single crystalline BCC iron, please calculate the solved shear stress along the $[\bar{1}11]$ direction on the (110) plane if the applied tensile stress is 97.9 MP. (a) 20 MPa (b) 40 MPa (c) 60 MPa (d) 80 MPa (e) 97.9 MPa.

12. Determine the resolved shear stress on $(\bar{1}11)[101]$ slip system in an copper single crystal, assuming applied stress of 20 MPa in the $[324]$ direction. (a) -16 MPa (b) -6 MPa (c) 6 MPa (d) 16 MPa (e) 10 MPa

13. Which crystal structure usually has small temperature dependence on critical resolved shear stress? (a) BCC (b) FCC (c) HCP (d) rhombohedral (e) diamond

14. The slip systems in a BCC crystal is (a) 3 (b) 6 (c) 12 (d) 24 (e) 48

15. On deformation of a FCC crystal, the primary and conjugated slip systems are $(111)[1\bar{1}0]$ and $(1\bar{1}\bar{1})[101]$, respectively, then the tensile stress axis eventually reaches the (a) $[11\bar{1}]$ (b) $[112]$ (c) $[121]$ (d) $[211]$ (e) $[2\bar{1}1]$ direction.

16. On deformation of a BCC crystal, the primary system is $(\bar{1}01)[1\bar{1}1]$, then the cross-slip systems can be (a) $(110)[1\bar{1}1]$ (b) $(\bar{1}01)[111]$ (c) $(0\bar{1}1)[111]$ (d) $(\bar{1}01)[\bar{1}1\bar{1}]$ (e) $(101)[1\bar{1}1]$.

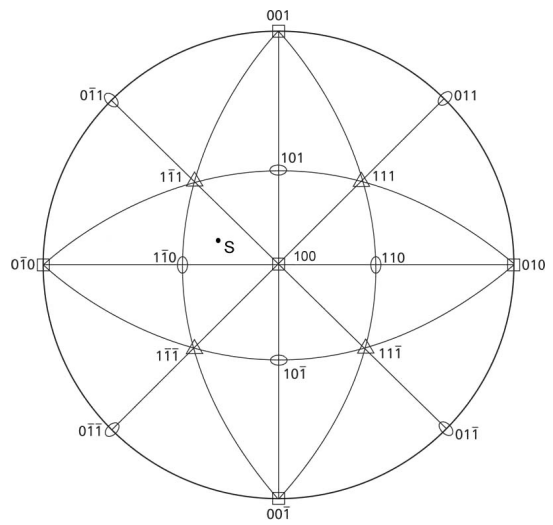
17. A partial dislocation with **b**=$\frac{1}{6}[2\bar{1}\bar{1}]$ tries to move from the (111) plane to the $(11\bar{1})$ plane, its Burgers vector should dissociate to (a)

$\frac{1}{6}[12\bar{1}]$ and $\frac{1}{6}[110]$ (b) $\frac{1}{6}[1\bar{2}\bar{1}]$ and $\frac{1}{6}[110]$ (c) $\frac{1}{6}[\bar{1}21]$ and $\frac{1}{6}[1\bar{1}0]$ (d) $\frac{1}{6}[1\bar{1}2]$ and $\frac{1}{6}[101]$ (e) $\frac{1}{6}[1\bar{2}1]$ and $\frac{1}{6}[10\bar{1}]$.

18. The total dislocation $\frac{1}{2}[10\bar{1}]$ on the (111) plane of the FCC crystal can be dissociated into two $\frac{1}{6}[2\bar{1}\bar{1}]$ and $\frac{1}{6}[11\bar{2}]$ partial dislocations.

    If they cross-slip to the $(\bar{1}\bar{1}1)$ plane, which is the stair-rod dislocation? (a) $\frac{1}{6}[101]$ (b) $\frac{1}{6}[110]$ (c) $\frac{1}{6}[011]$ (d) $\frac{1}{6}[1\bar{1}0]$ (e) $\frac{1}{6}[10\bar{1}]$.

19. In the stereographic projection on the right, assuming that point **S** represents the orientation of the tensile stress axis exerted on an FCC crystal, indicate the primary slip system. (a) $(1\bar{1}1)[10\bar{1}]$ (b) $(1\bar{1}1)[110]$ (c) $(1\bar{1}\bar{1})[101]$ (d) $(11\bar{1})[101]$ (e) $(111)[1\bar{1}0]$.



20. According to previous Problem, what is the conjugate slip system? (a) $(1\bar{1}1)[10\bar{1}]$ (b) $(1\bar{1}1)[110]$ (c) $(1\bar{1}\bar{1})[101]$ (d) $(11\bar{1})[101]$ (e) $(111)[1\bar{1}0]$.

21. Which of the following is most strongly associated with strength of metals? (a) vacancy concentration (b) density of dislocations (c) surface tension of grain boundary (d) atomic packing factor (e) number of slip systems

22. The relationships between engineering stress (σ_e), true stress (σ_t), true strain (ε_t) and engineering strain (ε_e) is (a) $\sigma_t=\sigma_e(1+\varepsilon_e)$ (b) $\sigma_e=\sigma_t\ (1+\varepsilon_e)$ (c) $\sigma_t = \sigma_e\ (1+\varepsilon_t)$ (d) $\sigma_e = \sigma_t\ (1+\varepsilon_t)$ (e) none of the above

23. For the following stacking sequences found in FCC metals, cite the type of planar defect that exists: …ABCBACBA … (a) a subgrain boundary (b) a twin boundary (c) a domain wall (d) an intrinsic stacking fault (e) an extrinsic stacking fault

24. Which of the following statement is support about the strain hardening effect (a) oversaturated solid solution (b) precipitations (c) deformation (d) diffusion (e) none of the above

25. In FCC crystals, it is much easier for the dynamic recovery to occur for a crystal (a) with small stacking fault energy (b) with dislocations that are easier to do cross-slip (c) with high surface energy (d) with small dislocation density (e) none of the above

26. Grain boundary is a (a) zero-dimensional (b) one-dimensional (c) two-dimensional (d) three-dimensional (e) four-dimensional defect.

27. The orientation mismatch of crystals for a small-angle boundary is less than (a) 5^o (b) 15^o (c) 30^o (d) 60^o (e) 90^o

28. The grain-boundary energy between the first phases is 0.78 J/m^2. What is the minimum surface energy between first and second phases to avoid a continuous network along the grain edges of the first phase? (a) 0.15 (b) 0.30 (c) 0.45 (d) 0.60 (e) 0.75 J/m^2

29. What relationship is discussed at Hall-Petch equation? (a) hardness-cooling rate (b) phase transformation-temperature (c) strength-grain size (d) hardness-dislocation (e) strength-vacancy

30. Which strengthening mechanism can improve both the strength and ductility? (a) precipitation hardening (b) solution hardening (c) work hardening (d) grain refinement (e) none of the above

(B) Multiple-choice question (Select the wrong answer from the list and correct it) (40%)

31. Which of the following statement is not true? (a) The slip plane is usually the closest plane in crystals. (b) Unit dislocations tend to have lowest energy when their Burgers vector extends along a close-packed direction. (c) In general, the lowest-energy dislocations have the greatest mobility. (d) When a total dislocation breaks down into a pair of partials, the strain energy of the lattice is increased. (e) In extended dislocation, the separation between the two partials represents equilibrium between the repulsive energy of the dislocations and the surface energy of the fault.

32. Dislocation climb is an important mechanism in the creep of metals. Which of the following statement about climb is not true? (a) Climb is an atom-by atom procedure movement (b) Slip is a result of normal stress whereas climb is a result of shear stress. (c) Positive climb will be promoted by a compressive stress component perpendicular to the extra plane. (d) Climb is very dependent on temperature. (e) In positive climb, vacancies move through the lattice toward the dislocation.

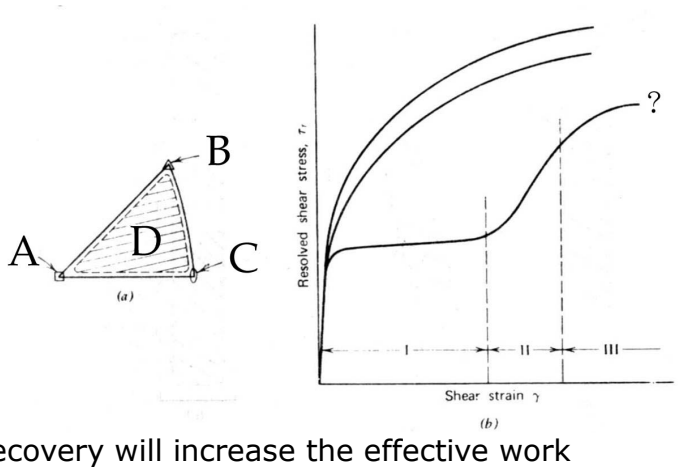
33. Real dislocations contain kinks and jogs, both of them are sudden deviations from a straight line. As you might know, which of the following statement is not true? (a) The step of a kink lies in the slip plane of a dislocation (b) The step of a jog is normal to the slip plane of a dislocation (c) kinks and jogs can be generated by heat (d) Kinks could be easily removed (e) The jog in the edge dislocation is immobile by slip

34. Which of the following statement is not true? (a) When a curvature appears in the dislocation line, it has the mixed edge and screw character. (b) The burgers vector of a curved dislocation has the same direction and magnitude. (c) A dislocation loop cannot end in the interior of a perfect crystal. (d) A pure edge dislocation must end on the surface of a perfect single crystal. (e) A square closed dislocation loop consists of positive edge, right-hand screw, negative edge, and left-hand screw dislocations on a slip plane.

35. Which of the following statement is not true? (a) The Frank-Read source is a dislocation generator (b) Rotational slip is normally associated with slip planes containing multiple slip directions (c) Bending deformation is possible with only one set of slip systems (d) Homogeneous nucleation of the dislocation requires extremely high stresses (e) If dislocations are not formed by Frank-Read sources, then they must be nucleated homogeneously.

36. Choose the wrong statement (a) There are 12 slip systems in FCC crystals (b) If c/a > 1.633, then the slip plane for hcp crystals is usually the basal plane (c) Slip occurs first on that slip system having the highest shear stress along its slip direction. (d) FCC and HCP materials are closed-packed so they are ductile (e) At least 5 independent slip systems are necessary to make a polycrystalline material ductile.

37. The orientation of the tensile axis direction is shown in the right figure by four points A, B, C and D on the standard triangle. Choose the wrong statement (a) In orientation A, the crystal has several active slip systems (b) Orientation B show considerable work hardening as soon as the yield stress is exceeded and plastic flow begins. (c) Orientation C shows easy glide at stage I. (d) In orientation D, the crystals have only one active slip system at stage I. (e) The stress-strain cure with a question mark is orientation D.



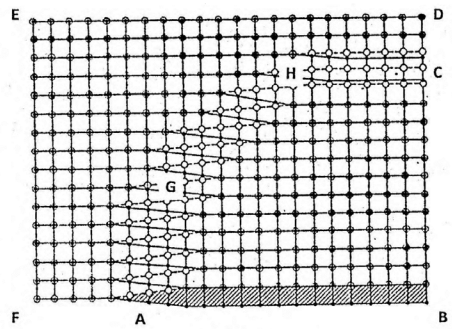
38. Which of the following statement about dynamic recovery is not true? (a) Dynamic recovery will increase the effective work hardening rate. (b) At elevated temperature, the effects of dynamic recovery become stronger. (c) Dynamic recovery occurs most strongly in metals of high stacking fault energy. (d) Pure metals have stronger dynamic recovery than alloys. (e) Stronger dynamic recovery has tendency to form cells with a low internal dislocation density and boundaries composed of dislocation tangles.

39. Which of the following statement is not true? (a) Grain boundaries are planar crystal defects. (b) At low temperatures, cracks run along the grain boundaries rather than pass through the grain interior. (c) Etching can reveal the presence of grain boundaries on metal surface. (d) The driving force for grain boundary movement is the reduction of the surface energy of the grain boundaries. (e) Grain boundary is one kind of crystal defects. The presence of grain boundary will increase the free energy of the system.

40. Grain boundary strengthening is an important mechanism to enhance the mechanical properties of metallic alloys. Which of the following statement is correct related to the grain boundary strengthening? (a) The smaller the grain size the less defect density and better mechanical property. (b) The grain boundaries act as pinning points that will impede the propagation of dislocations and result in lower mechanical properties. (c) Grain boundary strengthening is also known as the Hall-Petch strengthening. (d) The Hall–Petch relation predicts that as the grain size decreases the yield strength increases. (e) The grain size of metallic alloys cannot be changed by aging treatment.

(C) Answer the following questions (50%)

41. (12 points) The figure illustrates the core structure of curved dislocation line AGHC on the slip plane BDEF when there is a shear stress applied on the Top surface upward also another one at the bottom surface downward, where the circles represent the atomic plane just above the slip plane, and the small dots represent the atoms just below, (a) What are the type of dislocation AG, GH, and HC? (3%) Also, indicate the Burgers vectors and the motion of the three sections AG, GH, and HC, (3%) (b) Assuming that all atoms shown were all originally above (or below) each other, indicate the region of slipped material. (2%) (c) Can this dislocation line AGHG cross-slip to another slip plane? Yes or No? Justify your answer. (2%) (d) If there is a perfect dislocation which can slip on (0001) plane and $(\bar{1}100)$ plane of one HCP single crystal, please calculate the Burgers vector of this dislocation. (2%)



42. (10 points) Fig. 1 shows a (111) slip plane of FCC crystal containing an edge dislocation. (a) Write down the Burgers vector of the dislocation. (2%) (b) What is the direction of $[u_1v_1w_1]$. (2%) (c) Describe the position of the dislocation including direction of the dislocation line and the Burgers vector in Fig. 1. (2%) (d) In fcc metals, the dislocations are usually dissociated into an extended dislocation, containing two partial dislocations and a stacking fault. Fig. 2 shows an extended dislocation in FCC lattice. Describe the position of the partial dislocation including the direction of dislocation line and Burgers vectors. (4%)

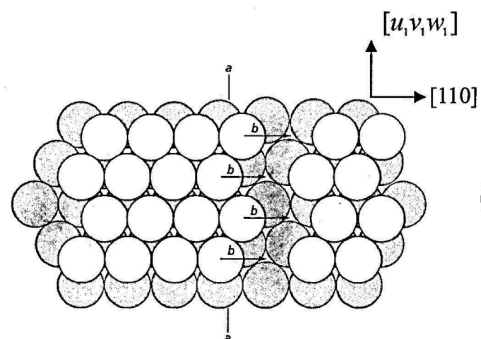


Fig. 1

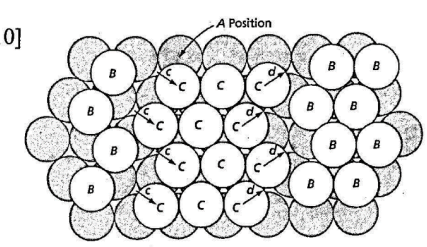
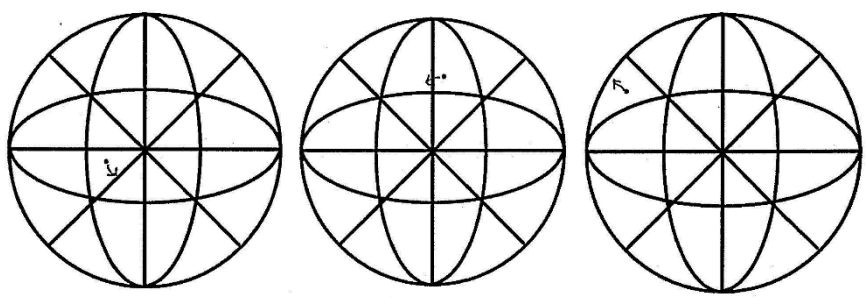


Fig. 2

43. (9 points) Three different metal crystals, all of which are cubic (either FCC or BCC) are strained, and the orientation of the crystal is tracked. Each of them is strained in compression. In the stereographic projections below, the results of these tests are shown. (a) Identify whether you think the crystal is FCC or BCC (3%), and (b) explain briefly why in each case (6%).



44. (10 points) (a) Please draw an engineering stress-strain curve and a true stress-strain curve for a polycrystalline metal. (2%) (b) Write down the Considere's Criterion and to address the importance of this criterion. (2%) (c) A typical cross-head speed in a tensile testing machine is 5 mm/min. What is the nominal engineering strain rate imposed by this cross-head speed on a typical engineering tensile specimen with a 50 mm gage length? (2%) (d) Estimate the dislocation velocity that would be obtained at this strain rate in an iron specimen with a dislocation density of 10^{14} m/m^3. Assume that the Burgers vector of iron is 0.248 nm. (2%) (e) lf in a very slow tensile test a strain-rate of 10^{-7} sec^{-1} is used, what dislocation velocity would be expected in the above iron specimen? (2%)

45. (9 points) (a) The iron containing small quantities of sulfur will become brittle at high temperature. Please explain the reason in detail. (6%) (b) How to avoid "hot short" in steel? (3%)