MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
CAMBRIDGE, MASSACHUSETTS 02139

3.22 MECHANICAL PROPERTIES OF MATERIALS
PROBLEM SET 7

Due in 8 days from its assigned date

Reading
Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials* (John Wiley & Sons, Inc.) Chapter II.
Hull, D. and Bacon, D. J. *Dislocations*. (Butterworth Heinemann.) Chapters 1, 3 and 4.
Ashby, M.F., *Mechanical Behaviour of Materials* (Course Notes) Section 7.

1. At the ultimate tensile strength, the load $P = \sigma A$ is a maximum. Show that the criterion for necking of a tensile specimen can be written $d\sigma/d\varepsilon = \sigma$ (Considere's relationship). If the constitutive relation between stress and plastic strain can be expressed by $\sigma = 225 \cdot \varepsilon^{0.3}$ [MPa], determine the plastic strain at the onset of necking.

2. (Hertzberg 2.2) Consider the following face-centered-cubic dislocation reaction:
$$\vec{b}_1 \rightarrow \vec{b}_2 + \vec{b}_3$$
$$\frac{a}{2}[110] \rightarrow \frac{a}{6}[21\bar{1}] + \frac{a}{6}[121]$$
   a. Prove that the reaction will occur.
   b. What kind of dislocations are the $(a/6)\langle 121\rangle$?

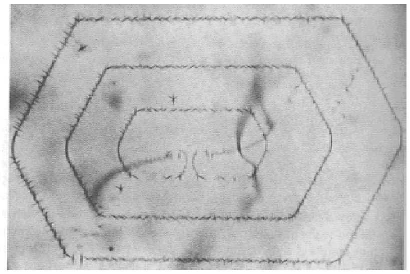
3. a. Why is it impossible to make a dislocation loop all of whose segments are pure screw dislocations?

   b. Give the specific indices of the two $\{111\}$ planes that contain the screw dislocation with the Burgers vector $(a/2)\langle\bar{1}01\rangle$ in a face-centered-cubic crystal where *a* is the lattice parameter of the fcc crystal.

4. (Hertzberg 2.4) Discuss the nature of the Peierls stress with regard to a dislocation and describe the role of the Peierls stress in determining the preferred slip place in a crystal and the yield-strength temperature dependence of the crystal.

5. Consider a ductile metal with Burgers vector $\vec{b} = 3$ angstroms.
   a. If a typical annealed metal is plastically deformed at a strain rate of 0.01 s^{-1}, what is the average velocity of a dislocation? Calculate the average velocity of dislocations if the metal has undergone significant deformation?
   b. Explain what happens to the overall dislocation density in general as a metal undergoes increasing plastic deformation.

6. (Hertzberg 2.5) Why do dislocation loops tend to be circular? Why, then, are they angular for silicon as shown in the figure below?



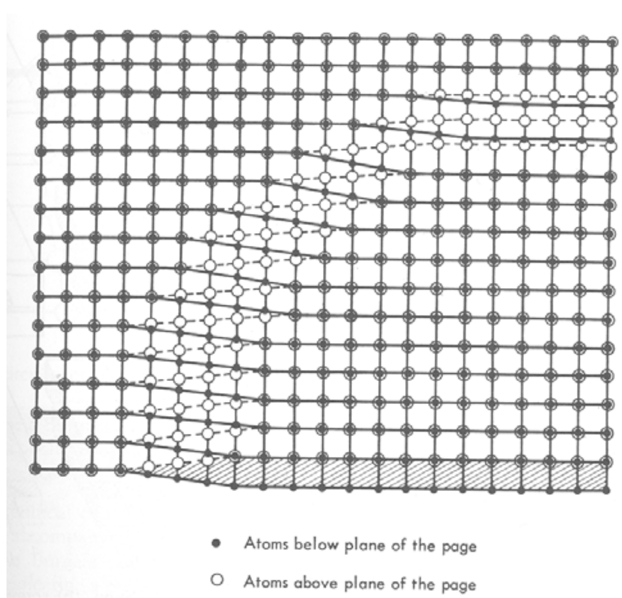
7. Substitutional solute atoms have a strain field about themselves, the sign of the strain depending on the size of the atom compared to a matrix atom. This strain field of a substitutional atom can interact with the stress field of an edge dislocation. Draw a schematic picture of an edge dislocation, and indicate the position around the dislocation where large and small substitutional atoms would be found. Where would interstitial atoms be found?

8. In rectangular coordinates, the stress field surrounding an edge dislocation is given by

$$\sigma_{xx} = -\frac{Gb}{2\pi(1-\nu)}\frac{y(3x^2+y^2)}{(x^2+y^2)^2}$$
$$\sigma_{yy} = \frac{Gb}{2\pi(1-\nu)}\frac{y(x^2-y^2)}{(x^2+y^2)^2} .$$
$$\sigma_{xy} = \frac{Gb}{2\pi(1-\nu)}\frac{x(x^2-y^2)}{(x^2+y^2)^2}$$
$$\sigma_{zz} = \nu(\sigma_{xx}+\sigma_{yy})$$

Plot the stress field along the positive y-axis. Explain why the theory breaks down at the extrema (y → 0, ∞).

9. Using the figure below, answer the following questions.
   a. What is the Burgers vector for the dislocation shown?
   b. Assuming that all atoms shown were all originally above (or below) each other, indicate the region of slipped material.
   c. Define the regions of the dislocation, whether screw, edge or mixed.



10. Explain why a second hardness measurement made adjacent to a previous measurement indicates a higher hardness.

11. At 20°C, an alloy yields at 150 MPa when strained at 0.03 s^{-1}. The same alloy yields at 145 MPa when the strain rate is decreased by a factor of ten and the temperature is kept the same. What test temperature would have to be used with a strain rate of 0.03 s^{-1} to reach a yield strength of 145 MPa? (Assume that the energy per bond is 500 kJ/mol.)

12. (Hertzberg 4.7) Maraging steels are relatively soft upon quenching from the austenitizing temperature range but strengthen greatly following exposure to a reheating treatment at intermediate temperature. Given that the carbon level of such steels is typically less that 0.03%, whereas the alloy contains additions of Ni, Mo, and Ti, speculate as to the probable strengthening mechanism that controls the strength of this class of alloys