CHAPTER 7
DISLOCATIONS and STRENGTHENING MECHANISMS
SOLUTIONS to ASSIGNED PROBLEMS

Assigned (and graded): 7.5, 7.17, 7.33

Suggested: 7.9, 7.11, 7.18, 7.30, 7.32

7.5 **(a)** Define a slip system.
(b) Do all metals have the same slip system? Why or why not?

a) A slip system is the combination of a crystallographic plane, and, within that plane, the direction along which dislocation motion (or slip) occurs.
b) All metals do not have the same slip system. The reason for this is that for most metals, the slip system will consist of the most densely packed crystallographic plane, and within that plane the most closely packed direction. This plane and direction will vary from crystal structure to crystal structure. Some metals, like Ti, Zr, Hf, and Zn (all hexagonal) have fewer active slip systems than cubic material.

2 points for recognizing that a slip system involves both a plane and a direction. 3 points for explaining that close-packed planes (and directions) vary with crystal structure. **5 points total**.

7.17 Briefly explain why HCP metals are typically more brittle than FCC and BCC metals.

Hexagonal close packed metals are typically more brittle than FCC and BCC metals because there are fewer slip systems in HCP.

3 points for making reference to fewer slip systems in HCP metals.

7.33 Briefly explain why some metals (e.g., lead and tin) do not strain harden when deformed at room temperature.

Metals such as lead and tin do not strain harden at room temperature because their recrystallization temperatures lie below room temperature (see Table 7.2 in the text). A new set of strain-free grains is continuously nucleated during deformation.

2 points for mentioning that $T_{recryst}$ of these metals < 300 K .

10 points for this assignment

Answers to suggested problems:

7.9 Explain the difference between resolved shear stress and critical resolved shear stress.

Resolved shear stress is the shear component of an applied tensile (or compressive) stress resolved along a slip plane that is other than perpendicular or parallel to the stress axis. **The critical resolved shear stress** is the value of resolved shear stress at which yielding begins; it is a property of the material.

7.11 Consider a metal single crystal oriented such that the normal to the slip plane and the slip direction are at angles of 43.1° and 47.9°, respectively, with the tensile axis. If the critical resolved shear stress is 20.7 MPa (3000 psi), will an applied stress of 45 MPa (6500 psi) cause the single crystal to yield? If not, what stress will be necessary?

This problem calls for us to determine whether or not a metal single crystal having a specific orientation and of given critical resolved shear stress will yield. We are given that ϕ = 43.1°, λ = 47.9°, and that the values of the critical resolved shear stress and applied tensile stress are 20.7 MPa (3000 psi) and 45 MPa (6500 psi), respectively. From Equation (7.1)

$$\tau_R = \sigma \cos \phi \cos \lambda = (45 \text{ MPa})(\cos 43.1°)(\cos 47.9°) = \mathbf{22.0 \text{ MPa}} \ (3181 \text{ psi})$$

Since the resolved shear stress (22 MPa) is greater than the critical resolved shear stress (20.7 MPa), the single crystal will yield (that is, plastic deformation will occur).

7.18 Describe in your own words the three strengthening mechanisms discussed in this chapter (i.e., grain size reduction, solid solution strengthening, and strain hardening). Be sure to explain how dislocations are involved in each of the strengthening techniques.

Grain size reduction: dislocations are pinned by grain boundaries because additional energy is required for them to change glide plane from one grain to another. The grain boundary itself is a disordered region in which close-packed planes and directions (slip systems) are not well defined.

Solid solution strengthening: The presence of a solute atom introduces local lattice strains which can interact with the strain fields near dislocation cores. Solute atoms smaller than the solvent (and the associated tensile strain field) will tend to diffuse to the compressive strain region above the slip plane in order to reduce the overall lattice strain. Larger solute atoms (and their associated compressive strain fields) will tend to diffuse to the region just below the slip plane in order to partially cancel the dislocations' tensile strain field. Since movement of the dislocation away from the solute atom would then result in an increase of the overall lattice strain, dislocations become pinned by the impurity.

Strain hardening results in an increase in dislocation density, as a result of mechanisms such as Frank-Reed sources. On the average, more dislocations with the same sign are produced which results in a repulsive force between dislocations. As the dislocation density increases, the average distance between them decreases and the magnitude of the repulsive force increases, thereby making it more difficult for any given dislocation to move under the action of an applied stress. Thus, since dislocation movement is hindered, the material becomes stronger.

7.30 Briefly cite the differences between recovery and recrystallization processes.

For recovery, there is some relief of internal strain energy by dislocation motion; however, there are virtually no changes in either the grain structure or mechanical characteristics. During recrystallization, on the other hand, a new set of <u>strain-free</u> grains forms, and the material becomes softer and more ductile.

7.32 Explain the differences in grain structure for a metal that has been cold worked and one that has been cold worked and then recrystallized.

During cold-working, the grain structure of the metal has been distorted to accommodate the deformation and the grains are stressed, that is, in a high energy state. Recrystallization produces grains that are equiaxed, smaller, and of lower stress than the parent grains.