3.032 Problem Set 6
Fall 2006
Due: 11/22/06 to Room 8-235; no lecture on 11/22/06

1. When engineers decided that, indeed, dislocations must exist in crystalline materials, several new questions emerged.

   (a) For example, experimentally it is known that crystalline materials that have been cold worked (mechanically deformed at temperatures much lower than melting temperatures) exhibit compressive/tensile yield stress σ_y that increases as the dislocation density ρ increases. The more deformation, the more dislocations, the higher the yield stress. However, we learned that the theoretical shear strength of a material with NO dislocations is orders of magnitude greater than the the shear strength of a well-annealed material that has some dislocations (10^2/cm^2). Explain how both of these things can be true.

   (b) Others have shown that, theoretically, dislocation density increases with the square root of strain:

   $$\frac{\rho}{\sqrt{\varepsilon}} = C \qquad (1)$$

   where C is a constant particular to the crystalline material. In addition, others have shown that, experimentally, shear strength τ of materials such as single crystal and polycrystalline Cu varies linearly with ρ:

   From these findings for $\varepsilon(\rho)$ and $\tau(\rho)$, find the strain hardening (aka work hardening) exponent n that would be expected solely from cold working of a crystalline material. [Adapted from Hosford, 2005]

2. Your boss at NewAlloys, Inc. has asked you to investigate a new nickel alloy with several weight percent of other metals to provide strengthening. You decide to perform a Brinell hardness test with a 10 mm-diameter tungsten carbide sphere and 1000 kgf force. You measure an average indentation diameter of 2.85 mm.

   (a) Estimate the tensile strength of this alloy, using linear interpolation if necessary.

   (b) Your colleague has performed additional indentation tests using much probes of much smaller diameter and lower applied forces, and her data features much larger scatter (variation from measurement to measurement) than yours. Describe two possible reasons why this might occur.

(c) Sketch a quantitative stress-strain diagram for this alloy out to a strain of 0.4%. State any assumptions you make and include any references you consulted to produce this diagram.

3. The extent of strain hardening of materials is important from a processing perspective, when a desired level of permanent deformation is required to make a part.

   (a) Estimate the strain hardening exponent n for the uniaxial tensile test in Example 3.5 of Meyers and Chawla (p. 131-132).

   (b) Prove that true strain ε_t is *always* smaller than engineering strain ε_e.

   (c) Given this proof, why does the true strain data extend far to the right of the engineering strain data in Figure E3.5.2 of Meyers and Chawla (p. 133)? Think about what is directly measured and what is inferred in a uniaxial tensile test.

4. As the chief materials scientist at Strengthened Metalworks, Inc. you are developing a model to predict the amount of precipitate strengthening (aka precipitate hardening) in a material which includes precipitates shaped as rods rather than spheres. You first attempt is a 2-D model in which a dislocation cuts through a rectangular precipitate with side lengths L and $2r$, and random orientation θ, as shown in Fig. 2.

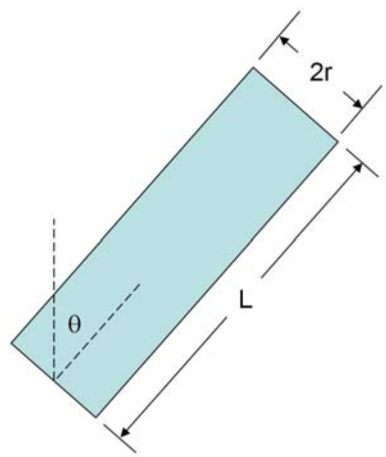

Figure 2: 2-D model of an alloy containing precipitates that will induce strengthening.

Develop an expression for the shear stress τ required for a dislocation to move through this 2-D material. Your model should consider details such as:

- The chance of a dislocation encountering a precipitate (assume a volume fraction f for the precipitated second phase).
- The distance a dislocation must travel through the precipitate as a function of θ, and the average distance for the case where θ is random (as it is here).
- The increase in surface area when a dislocation with Burgers vector $\mathbf{b}$ cuts through a precipitate (assume the energetic cost of creating a new surface is γ [J/m]). The actual type of dislocation is not important.
- The limits of the expression when L and $2r$ are approximately equal, and also when one is much larger than the other.

Your answer will likely be in the form of $\tau = F(r, L, \gamma, f, \mathbf{b})$. Feel free to make any assumptions necessary, but be sure to clearly state and justify them.