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EGR 221 Materials Science
Assignment 7, Fall 2015

1) Define a slip system. What defines a slip plan and a slip direction within a crystal? What is the main slip system in a BCC crystal?

ANS: A slip system is composed of a slip plane and slip direction. The slip planes are the planes within a crystal with highest atomic planar density and slip directions are directions in the crystal with highest atomic linear density. The dislocations move across the slip planes in the slip direction.
In BCC, the {110} family of planes and the <111> family of directions form the slip system.

2) Define/describe the differences between resolved shear stress and critical resolved shear stress.

ANS: Resolved shear stress is determined on mechanical analysis – it is the result of resolving the applied forces into a shear force acting on an internal plane.
Critical resolved shear stress is a material property. It is the amount of shear stress on a slip system required to cause a dislocation in that material to slip.

3) Consider a metal with a single crystal oriented such that the normal to the slip plane is 30° and the angle to the slip direction is 65°, with respect to the tensile axis (the loading direction). If the critical resolved shear stress is 21 MPa, what applied normal stress is required to cause the single crystal to yield?

ANS: See attachment.

4) Repeat problem 3, but with a differently oriented crystal. A single crystal oriented such that the normal to the slip plane is 45° and the angle to the slip direction is 45°, with respect to the tensile axis (the loading direction). If the critical resolved shear stress is 21MPa, what applied normal stress is required to cause the single crystal to yield?
ANS: See attachment.

5) Are single crystal metals (and alloys) isotropic with regards to yield strength? Are polycrystalline metals (and alloys) isotropic with regards to yield strength? Explain.

ANS: Single crystal metals are anisotropic with respect to yield strength. This is because the resolved shear stress on the slip system will depend upon how the crystal is oriented with respect to the loading condition. Therefore, depending upon orientation, the metal may be stronger or less strong (it will take more or less applied load to cause a dislocation to slip).
Polycrystalline metals are isotropic with respect to yield strength. This is because with a large number of crystals (grains), the directional dependence of a single grain's strength is average out.

6) Briefly explain why high angle grain boundaries are more effective at preventing dislocation slip than low angle grain boundaries.

ANS: because the resolved shear stress in the new grain's slip system will be lower if the new grain is oriented substantially different than the original grain's slip system – thus requiring greater applied force to cause the dislocation to continue to slip. With low angle boundaries, the resolved shear stress in the new grain's slip system will be nearly the same as the original grains.

7) Briefly explain why FCC materials tend to be more ductile than BCC materials.
ANS: Because FCC has the same or more slip systems than BCC (actually, both have 12 slip systems) but FCC has more "efficient" slip systems – i.e. they have greater planar density and therefore, it is easier for dislocations to slip.

8) Does increasing the dislocation density (in other words, more dislocations per volume) increase strength, decrease strength of have no effect on strength of an alloy? Explain.
ANS: increasing dislocation density results in greater strength because dislocations become tangled with each other and do not move so freely. The more dislocations, the more they become tangled.

9) Briefly describe one way to increase dislocation density and one way to decrease dislocation density.
ANS: dislocation density can be increased by cold working (plastic deformation). It can be decreased by certain heat treatments.

10) Why would metals behave as brittle materials if they have no dislocations?
ANS: dislocation slip, which is plastic deformation, absorbs energy before the material fractures. Without dislocations, there can be little plastic deformation, and hence, little energy absorbed before fracturing. Therefore, the material will be brittle.

11) Explain what each of the following strengthening mechanisms are and explain how dislocations are involved with each:

a. Grain size reduction
ANS: smaller grains result in more grain boundaries. Dislocations interact with grain boundaries (become "tangled" or "pinned") and do not move easily. Macroscopically, this manifests itself as increased strength.

b. Solid-solution strengthening
ANS: Lattice strains are produced by substitutional and interstitial impurities. The lattice strains interact with lattice strains produced by dislocations. This is like a magnet – the strains interact and help hold the dislocation in place (preventing slipping).

c. Strain hardening
ANS: strain hardening increases the dislocation density, making it more difficult for dislocations to slip (they become tangled with each other).

Given: Single crystal metal
Normal to slip plane to the load axis (ϕ) is 30°
Angle from loading axis to slip direction (λ) is 50°

$\tau_{CRSS} = 21 \text{ MPa}$ (mat'l property)

FIND: σ_{axial} to cause dislocation slip (i.e. yielding)

SOLN:

$$\tau_{RSS} = \sigma_{axial} \cos\phi \cos\lambda$$

Slip will occur when $\tau_{RSS} \geq \tau_{CRSS}$

Let $\tau_{RSS} = \tau_{CRSS} = 21 \text{ MPa}$, solve for σ_{axial}

$$21 \text{ MPa} = \sigma_{axial} \cos 30^\circ \cos 65^\circ$$

$$\sigma_{axial} = \frac{21 \text{ MPa}}{\cos 30^\circ \cdot \cos 65^\circ} = \underline{\underline{57.4 \text{ MPa}}}$$

Given: repeat previous problem but with $\phi = 45°$ & $\lambda = 45°$

$$\sigma_{axial} = \frac{\tau_{RSS}}{\cos\phi \cos\lambda}$$

Let $\tau_{RSS} = \tau_{CRSS} = 21$ MPa (given)

$$\sigma_{axial} = \frac{21 \text{ MPa}}{\cos 45° \cos 45°} = \underline{\underline{42 \text{ MPa}}}$$

NOTE: when $\phi = 45°$ & $\lambda = 45°$ the resolved shear stress is maximized.

Therefore, it takes less applied load (σ_{axial}) to cause plastic deformation (aka yielding, aka dislocation slip). So the slip system w/ $\phi = 30°$ & $\lambda = 65°$ required greater applied stress (57.4 MPa) than the $\phi = 450$ $\lambda = 45°$ system (42 MPa).