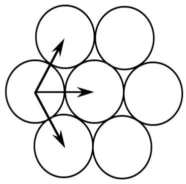
Material Science

Homework set 4 Solution

1. The arrows indicate three different $\langle 11\bar{2}0 \rangle$-type directions.



2. In order for the dislocation to move in its slip system, a shear force acting in the slip direction must be produced by the applied force. This resolved shear force F_r is given by

$$F_r = F\cos\lambda$$

If we divide the equation by the area of the slip plane, $A = A_0/\cos\phi$, we obtain the following equation known as **Schmid's law**:

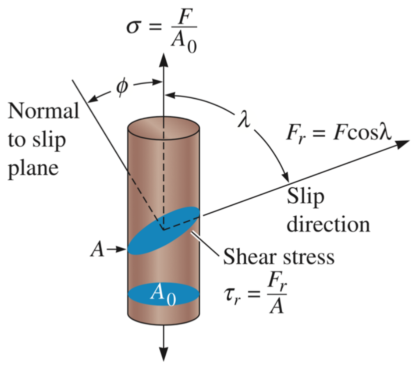
$$\tau_r = \sigma\cos\phi\cos\lambda$$

where

$$\tau_r = \frac{F_r}{A} = \text{resolved shear } \textit{stress} \text{ in the slip direction}$$

and

$$\sigma = \frac{F}{A_0} = \text{normal } \textit{stress} \text{ applied to the cylinder}$$



3. $$\phi = \cos^{-1}\left[\frac{(1)(1) + (1)(1) + (0)(1)}{\sqrt{\left[(1)^2 + (1)^2 + (0)^2\right]\left[(1)^2 + (1)^2 + (1)^2\right]}}\right] = \cos^{-1}\left(\frac{2}{\sqrt{6}}\right) = 35.3^\circ$$

$$\lambda_{[110]-[\bar{1}10]} = \cos^{-1}\left[\frac{(1)(-1)+(1)(1)+(0)(0)}{\sqrt{(1)^2+(1)^2+(0)^2}\sqrt{(-1)^2+(1)^2+(0)^2}}\right] = \cos^{-1}(0) = 90^\circ$$

$$\sigma_y = \frac{\tau_{crss}}{(\cos\phi\,\cos\lambda)} = \frac{2.2\,MPa}{\cos(35.3^\circ)\cos(0^\circ)} = \frac{2.2}{(0.816)(0)} = \infty$$

which means that slip will not occur on this $(111)-[\bar{1}10]$ slip system.

$$\lambda_{[110]-[10\bar{1}]} = \cos^{-1}\left[\frac{(1)(1) + (1)(0) + (0)(-1)}{\sqrt{\left[(1)^2 + (1)^2 + (0)^2\right]\left[(1)^2 + (0)^2 + (-1)^2\right]}}\right] = \cos^{-1}\left(\frac{1}{2}\right) = 60^\circ$$

$$\sigma_y = \frac{\tau_{crss}}{(\cos\phi\,\cos\lambda)} = \frac{2.2\text{ MPa}}{\cos(35.3^\circ)\cos(60^\circ)} = \frac{2.2\text{ MPa}}{(0.816)(0.500)} = 5.39\text{ MPa}$$

$$\lambda_{[110]-[0\bar{1}1]} = \cos^{-1}\left[\frac{(1)(0)+(1)(-1)+(0)(1)}{\sqrt{(1)^2+(1)^2+(0)^2}\sqrt{(0)^2+(-1)^2+(1)^2}}\right] = \cos^{-1}\left(\frac{-1}{2}\right) = 120^\circ$$

which means that slip will not occur on this $(111)-[0\bar{1}1]$ slip system. It is right to change slip direction to reversed.

4. (1)Perhaps the easiest way to solve for σ_0 and k_y in Equation 9.7 is to pick two values each of σ_y and $d^{-1/2}$ from Figure 9.15, and then solve two simultaneous equations, which may be created. For example

$d^{-1/2}$ (mm)$^{-1/2}$	σ_y (MPa)
4	75
12	175

The two equations are thus

$$75 = \sigma_0 + 4k_y$$

$$175 = \sigma_0 + 12k_y$$

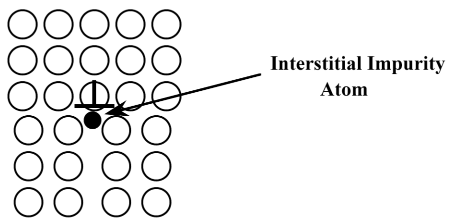
Solution of these equations yield the values of

$$k_y = 12.5 \text{ MPa (mm)}^{1/2} \quad ; \quad \sigma_0 = 25 \text{ MPa}$$

(b)When $d = 2.0 \times 10^{-3}$ mm, $d^{-1/2} = 31.6$ mm$^{-1/2}$, and, using Equation 9.7,

$$\sigma_y = \sigma_0 + k_y d^{-1/2} = (25) + (12.5)(31.6) = 420 \text{MPa}$$

5. Below is shown an edge dislocation and where an interstitial impurity atom would be located. Compressive lattice strains are introduced by the impurity atom. There will be a net reduction in lattice strain energy when these lattice strains partially cancel tensile strains associated with the edge dislocation; such tensile strains exist just below the bottom of the extra half-plane of atoms.



6. Small-angle grain boundaries are not as effective in interfering with the slip process as are high-angle grain boundaries because there is not as much crystallographic misalignment in the grain boundary region for small-angle, and therefore not as much change in slip direction.

7. Solid-solution strengthening, Strain hardening (or Cold work), Grain refining, and Precipitation hardening

8. (a)
   (1) The driving force for recrystallization is the difference in internal energy between the strained and unstrained material.
   (2) The driving force for grain growth is the reduction in grain boundary energy as the total grain boundary area decreases.

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