# SOLUTIONS TO MECHANICAL BEHAVIOR 2nd d 7- 9

## Chapter 7

1. During a tension test the rate of straining was suddenly doubled. This caused the load (force) to rise by 1.2%. Assuming that the strain-rate dependence can be described by $\sigma = C\dot{\varepsilon}^m$, what is the value of $m$?

Solution: $m = \ln(\sigma_2/\sigma_1)/\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1) = \ln(1.012)/\ln 2 = 0.0017$

2. Two tension tests were made on the same alloy, but at different strain rates. Both curves were fitted to a power-law strain hardening expression of the form, $\sigma = K\varepsilon^n$. The results are summarized below. Assuming that the flow stress at constant strain can be approximated by $\sigma = C\dot{\varepsilon}^m$, determine the value of *m*.

| | Test A | Test B |
|---|---|---|
| strain rate ($s^{-1}$) | $2\times10^{-3}$ | $10^{-1}$ |
| strain-hardening exponent, n | 0.22 | 0.22 |
| constant, K (MPa) | 402 | 412 |

Solution: $m = (K_2/K_1)/\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1) = \ln(412/402)/\ln(10^{-1}/2\times10^{-3}) = .0063$

3. To achieve a weight saving in an automobile, replacement of a low-carbon steel with an HSLA steel is being considered. In laboratory tension tests at a strain rate of $10^{-3}$/s, the yield strengths of the HSLA steel and the low carbon steel were measured to be 400 MPa and 220 MPa respectively. The strain-rate exponents are $m = 0.005$ for the HSLA steel and $m = 0.015$ for the low carbon steel. What percent weight saving could be achieved if the substitution was made so that the forces were the same at the strain rates of $10^{+3}$, typical of crash conditions?

Solution: $(\sigma_{HSLA}/\sigma_{LC})_{@\text{high speed}} = 400\text{x}(10^6)^{0.005}/\ 220\text{x}(10^6)^{0.015} =$
$(400/220)(10^6)^{(0.005-0.015)} = 1.58$

4. The thickness of a cold-rolled sheet varies from 0.0322 to 0.0318 depending on where the measurement is made, so strip tensile specimens cut from the sheet show similar variation in cross section.

A. For a material with $n = 0.20$ and $m = 0$, what will be the thickness of the thicker regions when the thinner region necks?

B. Find the strains in the thicker region if $m = 0.50$ and $n = 0$ when the strain in the thinner region reaches

i. 0.5, ii. $\infty$

Solution: A. $f = 0.318/0.322 = 0.9876$.

$\varepsilon_a^{.2}\exp(-\varepsilon_a) = fn^n\exp(-n) = 0.987(.2)^{.2}\exp(-.2) = 0.586$, results in $\varepsilon_a = .1361$

B. $\exp(-\varepsilon_a/m) = 1 + f^{1/m}[\exp(-\varepsilon_b/m) - 1] = 1 + 0.986^{1/.5}[\exp(-\varepsilon_b/.5) - 1]$

i. for $\varepsilon_b = .5$, $\exp(-\varepsilon_a/.5) = 1 + 0.9722[\exp(-.5/.5) - 1] = 385$, $\varepsilon_a = -.5\ln(.385) = 0.477$.

ii. for $\varepsilon_b = \infty$, $\exp(-\varepsilon_a/.5) = 1 + 0.9722[\exp(-\infty/.5) - 1] = 1 - 0.9722 = 0.0278$,

5. Estimate the total elongation of a superplastic material if

A. $n = 0$, $m = 0.5$ and $f = 0.98$, B. $n = 0$, $f = 0.75$ and $m = 0.8$.

Solution: Assuming $\varepsilon_b = \infty$, $\exp(-\varepsilon_a/m) = 1 + f^{1/m}[-1] = 1 - f^{1/m}$

A. For $m = 0.5$ and $f = 0.98$, $\exp(-\varepsilon_a/m) = 1 - (.98)^2 = .0396$, $\varepsilon_a = -.5\ln(.0396) = 1.61$

$e_a = \exp(1.61) - 1 = 4$ or 400% elongation.

B. For $f = 0.75$ and $m = 0.8$, $\exp(-\varepsilon_a/m) = 1 - (.75)^{1.25} = 0.302$, $\varepsilon_a = -.8\ln(.302) = 0.958$

$e_a = \exp(0.958) - 1 = 1.606$ or 60.6 % elongation

6. In superplastic forming, it is often necessary to control the strain rate. Consider the forming of a hemispherical dome by clamping a sheet over a circular hole and bulging it with gas pressure.

A. Compare the levels of gas pressure needed to form a 2.0 in. dome with that to form a 20 in. dome if both are formed from sheets of the same thickness and at the same strain rate.

B. Describe (qualitatively) how the gas pressure should be varied during the forming to maintain a constant strain rate.

Solution: A. Since the stress is proportional to the pressure, and the needed pressure is proportional to 1/R, the pressure to form a 20 inch dome should be 1/10 the pressure to form a 2 inch dome.

B. Since $\rho$ decreases during forming, the pressure should increase to keep a constant stress (and therefore strain rate).

7. During a constant-load creep experiment on a polymer, the temperature was suddenly increased from 100 to 105°C. It was found that this increase of temperature caused the strain rate to increase by a factor of 1.8. What is the apparent activation energy for creep of the plastic?

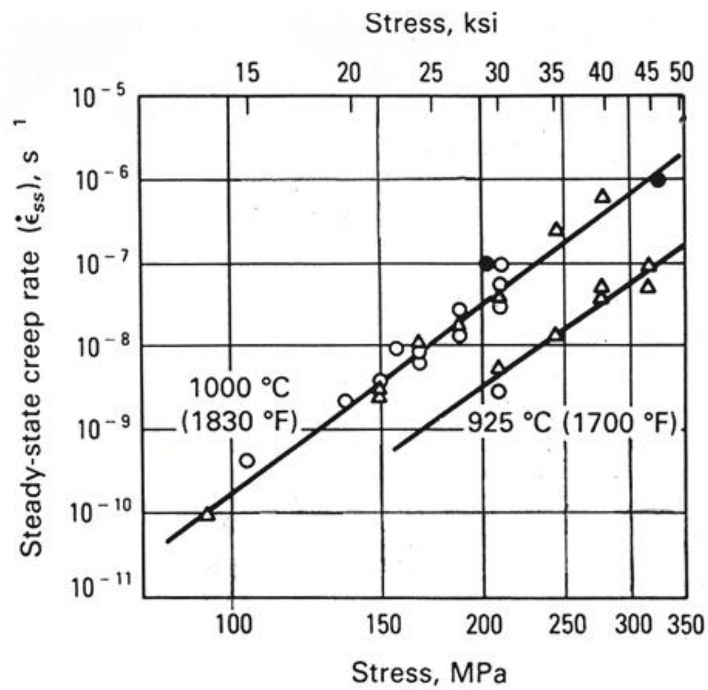
Solution: $\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1) = (-Q/R)(1/T_2 - 1/T_1)$, $Q = -R\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1)/(1/T_2 - 1/T_1) = -8.314\ln(1.8)/(1/373 - 1/378) = 138$ kJ/mole.

8. Figure 7.26 gives some data for the effect of stress and temperature on the strain rate of a nickel-base super-alloy single crystal. The strain rate is independent of strain in the region of this data. Determine as accurately as possible:

A. The activation energy, Q, in the temperature range 700 to 810°C.

B. The exponent, $m$, for 780°C.

Figure 7.26. The effects of stress and temperature on the strain rate of a nickel- base super-alloy single crystal.




Solution: A. $Q = -R\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1)/(1/T_2-1/T_1) = -8.314\ln(10)/(1/1273 - 1/1198) = 389$ kJ/mole

B. $m = \ln(\sigma_2/\sigma_1)/\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1) = \ln(350/100)/\ln(2\times10^{-6}/2\times10^{-10}) = 0.136$.

9. It has been suggested that $\dot{\varepsilon} = A\exp[-(Q-\sigma v)/RT] - A\exp[-(Q+\sigma v)/RT]$ is a better representation of the dependence of strain rate on temperature and stress than the Holloman-Zener approach. Using this equation, derive an expression for the dependence of stress on strain-rate at constant temperature if $\sigma v >> RT$.
solution: if $\sigma v >> RT$, $\dot{\varepsilon} = A\exp[-(Q+\sigma v)/RT]$, $\sigma v = RT[\ln(\dot{\varepsilon}/A)+Q]$, $\sigma = RT[\ln(\dot{\varepsilon}/A)+Q]/v$ or at a constant temperature $\sigma = m'\ln(\dot{\varepsilon}) + C$ where $m' = -RT[\ln(A)/v$ and $C = RTQ/v$. Note that this is equation 7.14.

10. The stress-strain curve of a steel is represented by $\sigma = (1600\text{MPa})\varepsilon^{0.1}$. It is deformed to a strain of $\varepsilon = 0.1$ under adiabatic conditions. Estimate the temperature rise in the sample.
For iron, $\rho = 7.87$ kg/m$^2$, $C = 0.46$ J/g·°C, $E = 205$ GPa.
Solution: The mechanical energy expended per volume is $u = \int\sigma d\varepsilon = K\varepsilon^n/(n+1)$. $[\bar{1}12](1\bar{1}0)[01\bar{1}]$
$\Delta T = u//(\rho C) = (1/n)K\varepsilon^{n+1}/(\rho C) = 10(1600\text{MPa})(0.1)^{1.1}/[(7.87 \text{ kg/m}^2)(460\text{kJ/g}\cdot°\text{C})] = 0.35°$

11. Evaluate m for copper at room temperature from Figure 7.13.
Solution: $m = \ln(\sigma_2/\sigma_1)/\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1)$. Taking values at $\varepsilon = 1$, $\ln(550/400)/\ln(9500/.00014) = 0.0176$

12. The stress-strain curves for silver at several temperatures and strain rates are shown in Figure 7.27. Determine the strain-rate exponent, m for silver at 25°C
Solution: Taking values at $\varepsilon = 0.25$, $m = \ln(222/192)/\ln(2800/0.001) = 0.0098$ or 0.01.

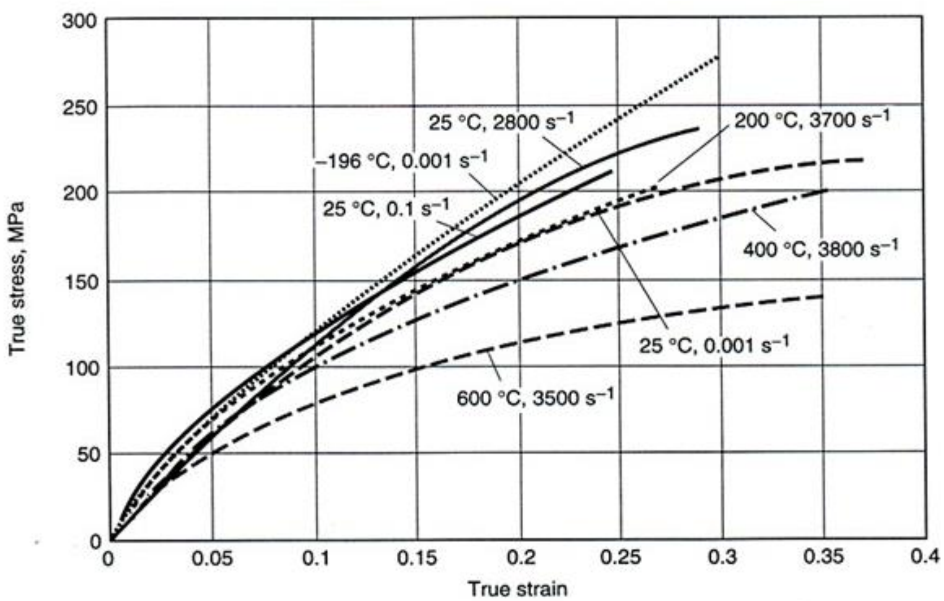



Figure 7.27. Stress-strain curves for silver (fcc). Note that at 25° the difference, Δs, between the stress-strain curves at different rates is proportional to the stress level. From G. T. Gray in *ASM Metals Handbook*, v. 8, 2000, p.472.

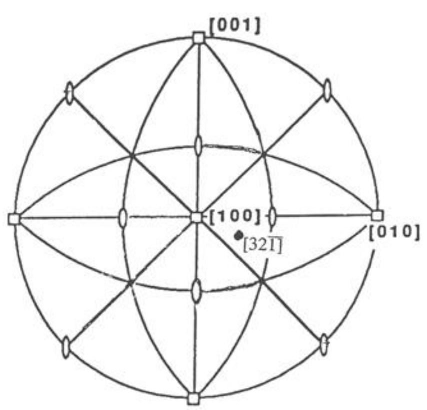
<u>Solution:</u> $m = \ln(\sigma_2/\sigma_1)/\ln(\dot{\varepsilon}_2/\dot{\varepsilon}_1) = \ln(225/192)/\ln(2800/0.001) = 0.011$

Chapter 8

1. If a single crystal of aluminum were stressed in uniaxial tension, with the tension applied along the $[0\bar{2}1]$direction, which slip system (or systems) would be most highly stressed?
Solution: By inspection, $[1\bar{1}0](1\bar{1}1)$ and $[\bar{1}\bar{1}0](1\bar{1}1)$. For both $m =$ $(5/6)/\sqrt{6} = 0.340$.

2. A single crystal of copper is loaded under a stress state such that $\sigma_2 = -\sigma_1$, $\sigma_3 = \tau_{23} = \tau_{31} = \tau_{12} = 0$. Here 1 = [100], 2 = [010] and 3 = [001]
A. When the stress $\sigma_1 = 6$ kPa, what is the shear stress, $\tau$, on the
i. $(111)[10\bar{1}]$slip system? ii. $(111)[1\bar{1}0]$ slip system? iii. $(111)[1\bar{1}0]$slip system?
B. On which of these systems would you expect slip to first occur as the applied stresses increased?
C. Assuming slip on that system, determine the ratios of the strains, $\varepsilon_2/\varepsilon_1$ and $\varepsilon_3/\varepsilon_1$.
Solution: A. i. $\tau = \sigma_1/\sqrt{6} + 0(\sigma_2) = 6/\sqrt{6} + 0 = 2.45$ kPa; ii. $\tau = \sigma_1/\sqrt{6} - \sigma_2/\sqrt{6} = 2\sigma_1/\sqrt{6} = 12//\sqrt{6} = 4.9$ kPa. .iii. $\tau = 0(\sigma_1) + \sigma_2/\sqrt{6} = -6/\sqrt{6} = -2.45$ kPa
B. ii
C. $\varepsilon_2/\varepsilon_1 = -1$, $\varepsilon_3/\varepsilon_1 = 0$.

3. A single crystal of aluminum was grown in the shape of a tensile bar with the $[32\bar{1}]$ direction aligned with the tensile axis.
A. Sketch a standard cubic projection with [100] at the center and [001] at the North Pole. Locate the $[32\bar{1}]$ direction on this projection.
B. Which of the {111}<110> slip system(s) would be most highly stressed when tension is applied along $[32\bar{1}]$? Show the slip plane normal(s) and the slip direction(s) of the system(s) on your plot.
C. What will be the ratio of the shear stress on the slip system to the tensile stress applied along $[32\bar{1}]$?
Solution: A.




B. $(111)[10\bar{1}]$
C. $\tau/\sigma = [3(1) + 2(1) - 1(1)][3(1) + 0 - 1(-1)]/[(3^2 + 2^2 + 1^2)\sqrt{6}] = 4\text{x}4/(14\sqrt{6}) = 0.466$.

4. An aluminum single crystal is subjected to a tensile stress of $\sigma_x = 250$ kPa parallel to x = [100] and a compressive stress, $\sigma_y = -50$ kPa parallel to y = [010] with $\sigma_z = \tau_{yx} = \tau_{zx} = \tau_{xy} = 0$. What is the shear stress on the (111) plane in the $[1\bar{1}0]$ direction?

Solution: $\tau = 250(1/\sqrt{6}) - 50(-1/\sqrt{6}) = 122$ kPa

5. Consider an aluminum single crystal that has been stretched in tension applied parallel to x = [100] ($\sigma_x = +250$kPa) and compressed parallel to y = [010] ($\sigma_y = -50$ kPa) with $\sigma_z = 0$ where z = [001]. Assume that slip occurred on the (111) in the $[1\bar{1}0]$ direction and only on that slip system. Also assume that the strains are small.

A. Calculate the ratios of resulting strain, $\varepsilon_y/\varepsilon_x$ and $\varepsilon_z/\varepsilon_x$.

B. If the crystal were strained until $\varepsilon_x = 0.0100$, what will the angle be between the tensile axis and [100]?

Solution: A. $\varepsilon_y/\varepsilon_x = -1$, $\varepsilon_z/\varepsilon_x = 0$

B. $\lambda_o = 45°$, $\sin\lambda = (1+e)\sin\lambda_o = 1.01/\sqrt{2} = 45.58°$, $\lambda - \lambda_o = 0.58°$

6. NaCl crystals slip on $\{110\}<1\bar{1}0>$ slip systems. There are six systems of this type. Consider a crystal subjected to uniaxial compression parallel to z = [110].

A. On which of the $\{110\}<1\bar{1}0>$ slip systems would the shear stress be the highest? i.e., on which of the systems would slip be expected?

B. Let the lateral directions be x = $[1\bar{1}0]$ and y = [001]. Determine the shape change that occurs as the crystal deforms on one of these systems by finding the ratios, $\varepsilon_y/\varepsilon_z$ and $\varepsilon_x/\varepsilon_z$. Describe the shape change in words. [Hint: Analyze one of the slip systems in your answer to (A). Be careful about signs.]

Solution: A. $(0\bar{1}1)[1\bar{1}0]$, $[0\bar{1}1](1\bar{1}0)$, $[\bar{1}01](101)$ and $(\bar{1}01)[101]$.

B. Assuming $(0\bar{1}1)[011]$, $\varepsilon_x = [1\bar{1}0]\bullet[0\bar{1}1][1\bar{1}0][011] = (1/2)(-1/2) = -1/4$

$\varepsilon_y = [001]\bullet[0\bar{1}1][001]\bullet[011] = (1/\sqrt{2})(1/\sqrt{2}) = 1/2$,

$\varepsilon_z = [110]\bullet[0\bar{1}1][110]\bullet[011] = (-1/\sqrt{2})(1/\sqrt{2}) = -1/4$;

Conclusion: $\varepsilon_y/\varepsilon_z = -2$, $\varepsilon_x/\varepsilon_z = 1$. As the crystal is compressed, in the z direction, it contracts in the x direction and expands in the y direction.

7. Predict the R-value for a sheet of a hcp metal with (0001) parallel to the rolling plane and $[10\bar{1}0]$ parallel to the rolling direction.

Solution: For tension applied perpendicular to the c-axis, all deformation by slip should produce no thinning. Therefore the R value ought to be infinite. Of course it isn't in real sheets because of misalignment from the ideal texture.

8. Determine the number of independent slip systems for crystals with each of the combinations of slip systems listed below. [The simplest way to do this is to determine how many of the strains $\varepsilon_1$, $\varepsilon_2$, $\gamma_{23}$, $\gamma_{31}$ and $\gamma_{12}$ can be independently imposed on the crystal.]

A. Cubic crystal that deforms by {100}<011> slip.

B. Cubic crystal that deforms by slip on {100}<011> and {100}<001> systems.

C. Cubic crystal that deforms by $\{110\} < \bar{1}10 >$ slip.

D. Hcp crystal that deforms by slip on $(0001)<11\bar{2}0>$ and $\{10\bar{1}0\}<11\bar{2}0>$systems.
Solution: A. $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0$ because either λ or φ are 90° for all of the slip systems. Slip can accommodate $\gamma_{23}$, $\gamma_{31}$ and $\gamma_{12}$. Therefore 3 independent slip systems.
B. Same conclusion as A (3 independent slip systems.)
C. $\varepsilon_1$and $\varepsilon_2$ can be independently imposed on the crystal, but $\gamma_{23}$, $\gamma_{31} = \gamma_{12}$= 0 for all of the slip systems, so there are only 2 independent slip systems.
D. $\varepsilon_3$ = 0. All other strain components can be satisfied so there are 4 independent slip systems.

9. A tetragonal crystal slips on {011}<111> systems. How many of the strains, $\varepsilon_x$, $\varepsilon_y$, $\varepsilon_z$, $\gamma_{yz}$, $\gamma_{zx}$, $\gamma_{xy}$, can be accommodated? [Note that in a tetragonal crystal the {011} family does not include (110) or $(\bar{1}10)$.]

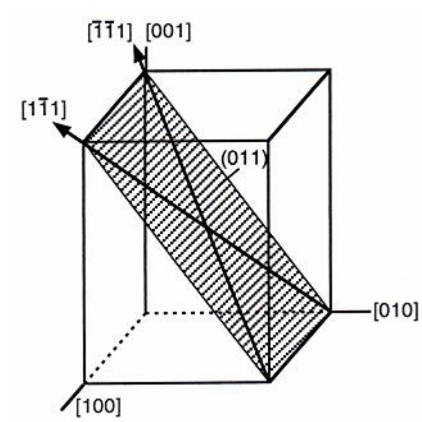



Figure 8.17. A tetragonal crystal with {011}<111> slip systems.

Solution: Shear on the (110) plane can be geometrically simulated by simultaneous slip on (011) and $(01\bar{1})$and shear on th$(\bar{1}10)$ plane can be geometrically simulated by simultaneous slip on$(\bar{1}01)$ and $(01\bar{1})$ so there are 5 independent slip systems. All of the strains can be accommodated.

10. A. Consider an fcc single crystal extended in uniaxial tension parallel to [321]. Will the Schmid factor, m = cosλcosφ for the most highly stressed slip system increase, decrease or remain constant as the crystal is extended?
B. Consider an hcp single crystal that slips easily only on $(0001)<11\bar{2}0>$ slip systems. If an hcp crystal is extended in uniaxial tension in a direction oriented 45° from the c-axis and 45° from the most favored $<11\bar{2}0>$ slip direction, will the Schmid factor, m = cosλcosφ for the most highly stressed slip system increase, decrease or remain constant?
Solution: A. Reference to Figures 8.6 and 8.11 shows that it will decrease.
B.The Schmid factor, m = cosλcosφ = cosλsinλ, decreases as λ decreases.

11. Consider a sheet of an fcc metal that has a {110}<001> texture. That is, a {110} plane is parallel to the plane of the sheet and a <001> direction is parallel to the prior rolling direction.
A. Predict the value of $R_o$ (the strain ratio measured in a rolling direction tension test).

Hint: Let x, y, and z be the rolling, transverse and sheet normal directions. Assign specific indices [hkl] to the rolling and sheet normal directions. Find the specific indices of the transverse direction, y. Then sketch a standard cubic projection showing these directions. (It is convenient to choose x, y and z so that they lie in the hemisphere of the projection.) For uniaxial tension along x, determine which slip systems will be active, and assume an equal shear strain, $\gamma_i$, on each. For each system, calculate the resulting strains, $\varepsilon_x$, $\varepsilon_y$, and $\varepsilon_z$ in terms of $\gamma_i$ and sum these over all slip systems. Assume equal amounts of slip on all the equally favored slip systems. Now predict the strain ratio $R_o$.

B. Predict $R_{90}$.

Solution: A. Let [110] be the sheet normal and $[1\bar{1}0]$ be the width direction. For tension along [001], the slip on the $(1\bar{1}\bar{1})$ and $(11\bar{1})$ planes causes no strain in the [110] direction (thickness) and slip on the (111) and $(1\bar{1}\bar{1})$ planes causes no strain in the $[1\bar{1}0]$ direction (width direction). With equal slip on all systems, R = 1.

B. For tension in the $[1\bar{1}0]$ direction, the favored slip systems $(1\bar{1}\bar{1})[0\bar{1}1]$, $(1\bar{1}1)[0\bar{1}1]$, $(1\bar{1}\bar{1})[101]$ and $(1\bar{1}1)[10\bar{1}]$. None of these cause any strain in the [110] thickness direction so the R-value is 0.

12. For a unit elongation along a <110> direction in a bcc metal, determine the ratio of the amount of slip required for axially symmetric flow to that required plane strain.

Solution: For axially symmetric flow, the amount of slip in the two slip directions normal to the tensile axis must be one half of the slip in the two directions causing the elongation. Therefore the total amount of slip must be 3/2 as much as for plane strain.

13. Predict the ratio of the flow stress for a copper wire with a <111> texture to that of one with a <100> texture at the same tensile strain. Assume power-law hardening with n = 0.30.

Solution: Assume $\tau = C\gamma^n$. Then $\tau_2/\tau_1 = (\gamma_2/\gamma_1)^n = (m_2/m_1)^n$. Since $\sigma = m\gamma$, $\sigma_2/\sigma_1 = m_2\gamma_2/m\gamma_1$, so $\sigma_2/\sigma_1 = (m_2/m_1)^{n+1}$ Substituting $(m_2/m_1) = 3/2$ and $n = 0.3$. $\sigma_2/\sigma_1 = (3/2)^{1.3} =$

Chapter 9

1.A crystal of aluminum contains $10^{12}$ meters of dislocation per $m^3$.
A. Calculate the total amount of energy associated with dislocations per $m^3$. Assume that half of the dislocations are edges and half are screws.
B. If all of this energy could be released as heat, what would be the temperature rise?
Data for aluminum: atomic diameter = 0.286 nm, crystal structure = fcc, density = 2.70 $Mg/m^3$, atomic mass = 27 g/mole, C = 0.215 cal/g.°C, G = 70 GPa, $\upsilon = 0.3$
Solution: A. $E_L = Gb^2/4\pi)\ln(r_1/r_o)$.
Taking $r_1 = (1/2)10^{-6}$ m and $r_o = (1/4)(.286\text{x}10^{-9})$m,
$\ln(r_1/r_o) = 7.47$ is about $2\pi$ so $E_L = Gb^2/2$
$E_V = 0.5\text{x}10^{12}(Gb^2/2) + 0.5\text{x}10^{12}(Gb^2/2)/(1\text{-u}) =$
$0.5\text{x}10^{12}(Gb^2/2)[1+1/(1\text{-u})] = 13.9 \text{ x}10^3 J/m^3$.
B. $\Delta T = E_V/(\rho C) = 13.9\text{x}10^3 J/m^3/[(2.7\text{x}10^6 \text{ g/m}^3)(0.215)(4.18J/g°C)] =$
$5.7 \text{ x}10^{-3}$°C

2. Calculate the average spacing between dislocations in a 1/2° tilt boundary in aluminum. See Figure 9.15 and look up any required data.
Solution: $\theta$ (radians) = $b/d$ so $d = b/\theta = 0.246\text{x}10^{-9}\text{m}/(.5\pi/180) = 32.8 \text{ x}10^{-6}\text{m} = 32.8\mu\text{m}$.

3. On which {110} planes of bcc iron can a dislocation with a Burgers vector $(a/2)[11\bar{1}]$move?
Solution: (101), (011) and $(1\bar{1}0)$. These three planes contain the $[11\bar{1}]$direction.

4. A single crystal of aluminum was stretched in tension. Early in the test the specimen was removed from the testing machine and examined at high magnification (Figure 9.27). The distance between slip lines was found to be 100 μm and the average offset at each slip line was approximately 500 nm. Assume for simplicity that both the slip direction and the slip plane normal are oriented at 45° to the tensile axis.

A. On the average, how many dislocations must have emerged from the crystal at each observable slip line?
B. Find the shear strain on the slip system, calculated over the whole crystal.
C. Find the tensile strain (measured along the tensile axis) must have occurred? (i.e.,

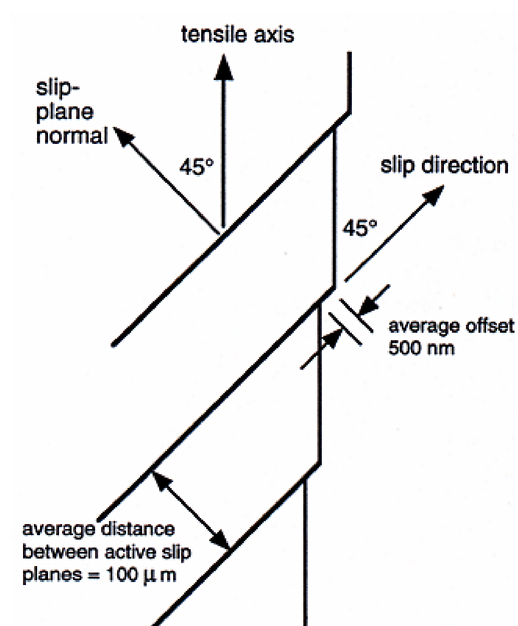



Figure 9.27. Profile of a crystal surface showing offsets caused by slip.

What was the % elongation when the test was stopped?)

Solution: A. For aluminum, $b$ = 0.286nm, so number of dislocations = 500nm/0.286nm = 1750 dislocations.

B. $\gamma$ = 500nm/100x$10^3$ nm = 0.005

C. $\varepsilon$ = (1/2)$\gamma$ = .0025

5. Consider the reactions between parallel dislocations given below. In each case write the Burgers vector of the product dislocation and determine whether the reaction is energetically favorable.

A. (a/2)$[1\bar{1}0]$+ (a/2)[110] $\rightarrow$

B. (a/2)[101] + (a/2)$[01\bar{1}]$ $\rightarrow$

C. (a/2)$[1\bar{1}0]$+ (a/2)[101] $\rightarrow$

Solution: A. (a/2)[$[1\bar{1}0]$+ (a/2)[110] $\rightarrow$ a[100]; $a^2/2 + a^2/2 = a^2$ energetically neutral

B. (a/2)[101] + (a/2)$[01\bar{1}]$ $\rightarrow$ (a/2)[110]; $a^2/2 + a^2/2 > a^2/2$ energetically favorable

C. (a/2)$[1\bar{1}0]$+ (a/2)[101] $\rightarrow$ (a/2)$[2\bar{1}1]$: $a^2/2 + a^2/2 < (3/2)a^2$ energetically unfavorable

6. Consider the dislocation dissociation reaction (a/2)[110] $\rightarrow$ (a/6)$[21\bar{1}]$ + (a/6)[121] in an fcc crystal. Assume that the energy/length of a dislocation is given by $E_L = Gb^2$ and neglect any dependence of the energy on the edge vs. screw nature of the dislocation. Assume that this reaction occurs and the partial dislocations move very far apart. Neglect the energy associated with the stacking fault between the partial dislocations.

A) Express the total decrease in energy/length of the original (a/2)[110] dislocation in terms of a and G.

B) On which {111} must these dislocations lie?

Solution: A. $\Delta U = Ga^2/2 - 2G(a^2/6) = G(a^2/6)$

B. $(1\bar{1}1)$ (This has dot products of zero with both $[21\bar{1}]$ and[121])

7. A dislocation in an fcc crystal with a Burgers vector, b = (a/2)[011], dissociates on the $(1\bar{1}1)$ plane into two partial dislocations of the (a/6)<211> type.

A) Give the specific indices of the two (a/6)<211> partial dislocations.

B) Onto what other plane of the {111} family could the b = (a/2)[011] dislocation have dissociated?

C) Give the specific indices of the two (a/6)<211> partials that would be formed if the (a/2)[011] dislocation had dissociated on the plane in B.

Solution: A. (a/2)[011] $\rightarrow$(a/6)[121] + (a/6)$[\bar{1}12]$ (Both of these have zero dot products with $[1\bar{1}1]$)

B. $(11\bar{1})$

C. (a/2)[011] $\rightarrow$ (a/6)[112] + (a/6)$[\bar{1}12]$

8. Consider a circular dislocation loop of diameter, d, in a crystal under a shear stress, $\tau$. The region inside the circle has slipped relative to the material outside the circle. The presence of this dislocation increases the energy of the crystal by the dislocation energy/length times the length of the dislocation. The slip that occurs because of the formation of the dislocation under the stress, $\tau$, lowers the energy of the system by $\tau$Ab. ($\tau$A is the shear force and b is the distance the force works through.) If the diameter of the loop is small, the energy will be reduced if the loop shrinks. If the loop is large enough, the loop will spontaneously expand. Find the diameter of critical size loop in terms of $b$, $G$, and $\tau$. For simplicity take $E_L = Gb^2$.

Solution: The total energy caused by the loop is $U = \pi DGb^2 - \pi(D^2/4)tb$. The critical size corresponds to $dU/dD = 0 = \pi Gb^2 - \pi(D/2)tb$. Solving for $D$, $D = 2Gb/\tau$.

9. Referring to Figure 9.23, find the ratio of the wrong second nearest neighbors across a stacking fault to the number across a twin boundary. If the surface energies are proportional to the number of wrong second nearest neighbors, what is $\gamma_{SF}/\gamma_{TB}$?

Solution: Across a stacking fault (ABCBCA)there are two sets of wrong second nearest neighbors. Across a twin boundary (ABCBA) there is one set ofwrong second nearest neighbors. Therefore $\gamma_{SF}/\gamma_{TB} = 2$.

10. Using the values of $\gamma_{SF}$ from Table I and equation 9.21, make an approximate calculation of the equilibrium separation, $r$, of two partial dislocations resulting from dissociation of screw dislocation in aluminum and in silver. Express the separation in terms of atom diameters. The shear modulus of aluminum is 70 GPa and that of silver is 75 GPa. The atom diameters of Al and Ag are 0.286 and 0.289 nm

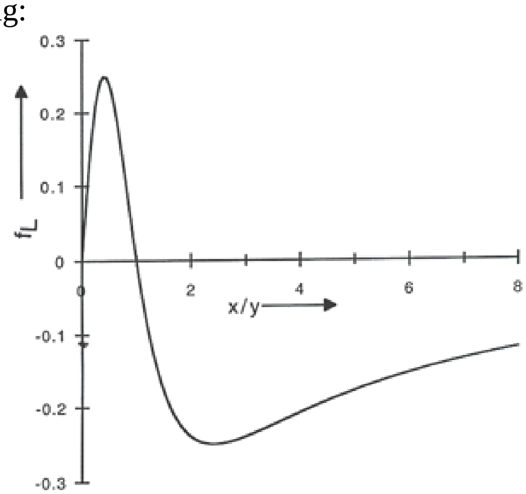
Solution: Taking $r = Ga^2/(24\pi\gamma)$

for aluminum $r = (70x10^9)(0.286\ x10^{-9})^2/(24\pi 166x10^{-3}) = 0.476$ nm

for silver, $r = (75x10^9)(0.289\ x10^{-9})^2/(24\pi 16x10^{-3}) = 5.2$nm

11. Plot the variation with x of the force, $f_L$, on an edge dislocation caused by another edge dislocation at a fixed level of y according to equation 9.19. Let the units of $f_L$ be arbitrary.

Solution: With y = 1 equation 9.19 becomes $f_L = Ax[(x^2 - 1]/[(x^2 + 1]^2$, where A is a constant. Plotting:




Note that for x<y the dislocations attract, for x>y the dislocations rep