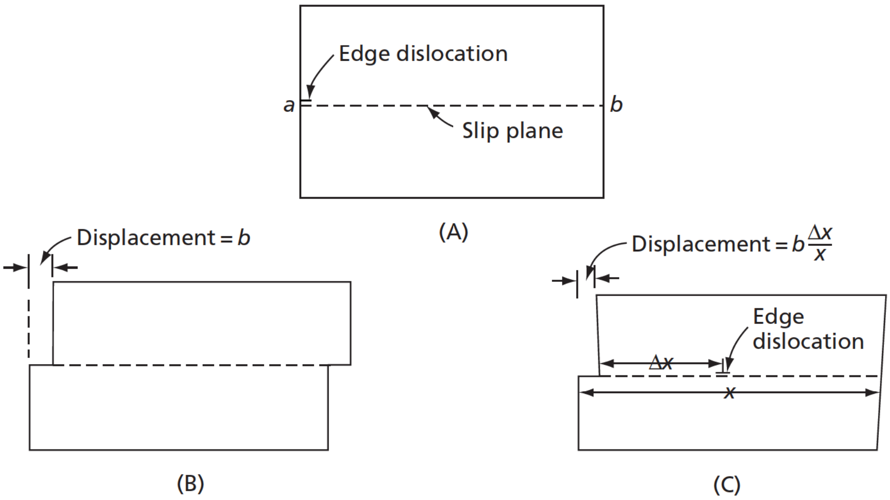


FIG. 5.36 The displacement of the two halves of a crystal is in proportion to the distance that the dislocation moves on its slip plane

since Az is the volume of the crystal. For the case where n edge dislocations of length l move through an average distance $\Delta\bar{x}$, this relation becomes

$$\Delta\gamma = \frac{bnl\Delta\bar{x}}{V} = \rho b\Delta\bar{x} \qquad \textbf{5.21}$$

where ρ, the dislocation density, is equal to nl/V. If, in a time interval Δt, the dislocations move through the average distance $\Delta\bar{x}$, we have

$$\frac{\Delta\gamma}{\Delta t} = \dot{\gamma} = \rho b\bar{v} \qquad \textbf{5.22}$$

where $\dot{\gamma}$ is the shear strain rate and $\bar{v}$ is the average dislocation velocity.

This expression, derived for the specific case of parallel edge dislocations, is a general relationship, and it is customary to consider that ρ represents the density of all the mobile dislocations in a metal whose average velocity is assumed to be $\bar{v}$. Furthermore, if $\dot{\varepsilon}$ is the tensile strain rate in a polycrystalline metal, a reasonable assumption is that

$$\dot{\varepsilon} = \frac{1}{2}\dot{\gamma} = \frac{1}{2}\rho b\bar{v} \qquad \textbf{5.23}$$

where the factor 1/2 is an approximate Schmid orientation factor.

PROBLEMS

5.1 If the shear vectors, τ, in Fig. 5.1, were moved from the top and bottom faces of the crystal and applied to the front and rear surfaces, with the forward vector pointing up and the rear one down, could any of the Frank-Read dislocation segments move as a result of this shearing stress? Explain.

5.2 (a) Again, with reference to Fig. 5.1, describe what might be expected to happen to the dislocation configuration of this crystal if a horizontal tensile stress were to be applied to the right and left faces of the crystal.

(b) What would be the effect on the dislocation configuration of Fig. 5.1 if the tensile stress in part (a) of this problem were to be changed to a compressive stress?

5.3 There are three slip systems on an fcc octahedral plane. Assume a 2 MPa tensile stress is applied along the [100] direction of a gold crystal, whose critical resolved shear stress is 0.91 MPa. Demonstrate quantitatively that measurable slip will not occur on any of the three slip systems in the (111) plane as a result of this applied stress.

5.4 On a 100 standard projection of a cubic crystal (see Fig. 1.31), plot the (111) pole as well as the great circle corresponding to this plane. Mark the three $\langle 1\bar{1}0\rangle$ slip directions on the (111) great circle. Then plot the position of the [310] direction on the standard projection. If a tensile stress is applied along the [310] direction, what would be the magnitude of the Schmid factor (i.e., $\cos\theta\cos\phi$) for the $(111)[10\bar{1}]$ slip system with this stress axis orientation?

5.5 Deformation twins also form along the {111} planes of fcc crystals as a result of shear stresses. The twinning shear directions are $\langle 112\rangle$.

(a) Prove, using Eq. 5.4, that $[1\bar{2}1]$ and $[11\bar{2}]$ are directions that lie in the (111) plane.

(b) Determine the Schmid factors for the (111) $[\bar{2}11]$, (111) $[1\bar{2}1]$, and (111) $[11\bar{2}]$ twinning systems, if a tensile stress is applied along the [711] direction.

5.6 With the aid of Eq. 5.4, prove that the $(\bar{4}22)$ plane of a cubic crystal belongs to the zone whose axis is [111].

5.7 (a) Determine the angle between the [123] and [321] directions in a cubic crystal. Check Appendix A to see if your answer is correct. **(b)** Find a combination of two $\langle 321\rangle$ directions that make an angle of 85.90° with each other.

5.8 A 10 mm diameter cylindrical zinc single crystal has a longitudinal axis that makes an angle of 85° with the pole of the basal plane and a 7° angle with the closest $\langle 11\bar{2}0\rangle$ slip direction in the basal plane. If the critical resolved shear stress of zinc is 0.20 MPa, at what axial load should the crystal begin to deform by basal slip in:

(a) Newtons.

(b) Kilograms force.

5.9 With regard to slip in hcp crystals, answer the following:

(a) Would it be possible for rotational slip to occur with the pole of the $\{11\bar{2}2\}$ plane as an axis of rotation?

(b) Would bend gliding be possible with $(11\bar{2}2)$ $[\bar{1}\bar{1}23]$ slip? Explain.

5.10 (a) Would it be theoretically possible to deform a zinc crystal in compression if the stress axis is along its [0001] axis using only the three (0001) [1120] slip systems? Explain.

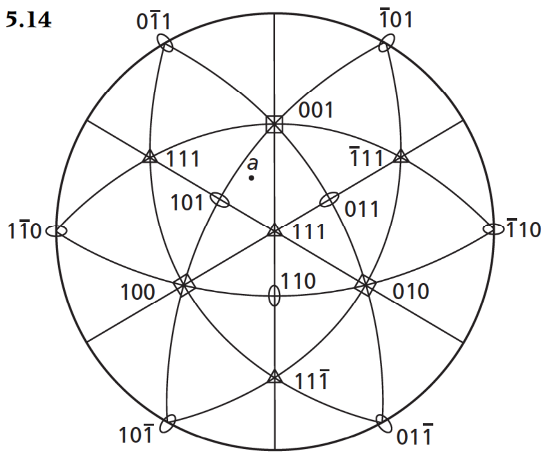
(b) If the $(11\bar{2}2)$ $[\bar{1}\bar{1}23]$ slip system were to operate could the crystal be deformed in the direction of its basal plane pole?

5.11 The total line length of the dislocations visible in a 4 cm by 4 cm TEM photograph of a metal foil, taken at a magnification of 20,000× is measured as 400 cm. The foil specimen imaged by this picture had a thickness of 300 nm. Determine the dislocation density in the specimen.

5.12 Identify the dislocation, in terms of its Burgers vector (using vector notation), that can cross slip between the (111) and $(1\bar{1}1)$ planes of an fcc crystal.

5.13 In some hcp metals, a dislocation with a $\frac{1}{3}\langle 11\bar{2}3\rangle$ Burgers vector has been observed to cross slip between the (0001), $\{10\bar{1}0\}$, and $\{10\bar{1}1\}$ planes. Identify the specific planes on which a dislocation with a $\frac{1}{3}[\bar{1}\bar{1}23]$ Burgers vector may move.

5.14



(a) The above diagram shows a 111 standard projection of an fcc crystal in which the standard stereographic triangles are outlined. Assuming that the point, *a*, in the figure represents the orientation of the tensile stress axis, indicate on a copy of this diagram the path that the crystal axis should follow during tensile deformation of the crystal.

(b) Give the Miller indices of the final stress axis orientation.

5.15 Now consider that the point, *a*, represents the stress axis during compressive deformation. Show the path on the stereographic projection that this axis will follow and identify its end orientation.

5.16 For the case of tensile deformation considered in Problem 5.14, determine the indices of the primary, conjugate, and cross-slip slip systems as well as that of the critical plane.

5.17 Johnston and Gilman have reported that in a grown LiF crystal that has been subjected to a constant stress of 1100 gm/mm^2 (10.8 MPa), the dislocation velocity at 249.1 K was 6×10^{-3} cm/s (6×10^{-5} m/s) and at 227.3 K the velocity was 10^{-6} cm/s (10^{-8} m/s). They also observed that their data suggested an Arrhenius relationship between the dislocation velocity and the absolute temperature so that one might write $\nu = A \exp(-Q/RT)$, where ν is the dislocation velocity, A is a constant of proportionality, Q an effective activation energy in J/mol, R the international gas constant (8.314 J/mol·K) and T is in K. Use the velocity vs. temperature data of Johnston and Gilman, given above, to determine Q and A for their LiF crystal, stressed at 1100 gm/mm^2. Note that Q may be obtained using the relation

$$\ln v_1 - \ln v_2 = Q/R(1/T_2 - 1/T_1)$$

Once Q has been determined, A may be obtained by substitution back into the Arrhenius equation.

5.18 (a) Johnston and Gilman also observed that, at a constant temperature, the dislocation velocity obeyed a power law. Assuming that the dislocation velocity exponent, m, is 16.5 and that the stress, D, for a velocity of 1 cm/s is 5.30 MPa, determine the stress in MPa needed to obtain a velocity that is 5 times greater.

(b) Also give your answer in psi.

5.19 A typical cross-head speed in a tensile testing machine is 0.2 in./min.

(a) What is the nominal engineering strain rate imposed by this cross-head speed on a typical engineering tensile specimen with a 2 inch gage length?

(b) Estimate the dislocation velocity that would be obtained at this strain rate in an iron specimen with a dislocation density of 10^{10} cm/cm^3. Assume that the Burgers vector of iron is 0.248 nm.

(c) If in a very slow tensile test a strain-rate of 10^{-7} s^{-1} is used, what dislocation velocity would be expected in the above iron specimen?

5.20 Necking in a tensile specimen begins at an engineering strain of 0.20. The corresponding engineering stress at this point is 1000 MPa. Determine the work hardening rate at the beginning of necking.

5.21 A tensile test was made on a specimen that had a cylindrical gage section with a diameter of 10 mm and a length of 40 mm. After fracture the total length of the gage section was found to be 50 mm, the reduction in area 90 percent, and the load at fracture 1000 N. Compute:

(a) The specimen elongation.

(b) The engineering fracture stress.

(c) The true fracture stress, ignoring the correction for triaxiality at the neck.

(d) The true strain at the neck.

5.22 The Hollomon equation

$$\sigma_t = k\epsilon_t^m$$

where k and m are constants, is capable of roughly approximating the shape of some stress-strain curves.

(a) Assume $k = 750$ MPa and $m = 0.6$. If the true stress at the point of maximum load is 552 MPa, what is the true strain at the maximum load?

(b) Compare m with ϵ_t at the maximum load.

(c) Prove that in general $m = \epsilon_t$ at the maximum load.

5.23 The slope, m, of the curve drawn through the data points in Fig. 5.35 is approximately equal to $2.55 \times 10^{-4} \frac{\text{kg}}{\text{mm}^2} \cdot \text{cm}$. Compute the increase in the dislocation density that would correspond to an increase in flow stress from 588 to 784 MPa (use the titanium data of Jones and Conrad).