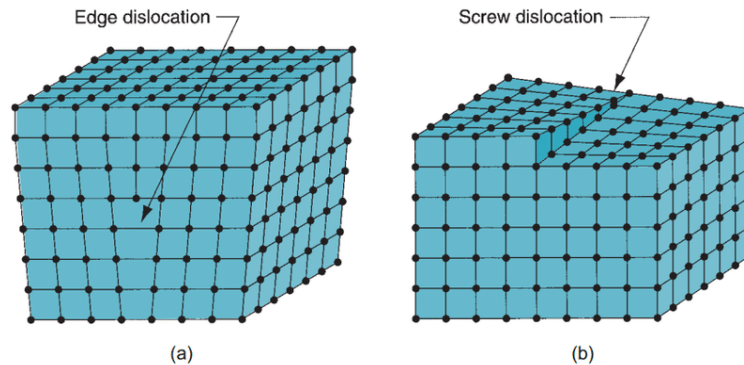
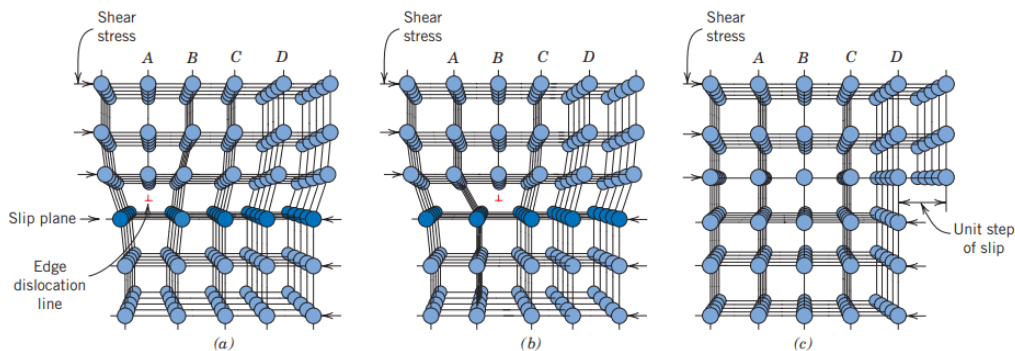


Types of Dislocation.

Edge and **screw** are the two fundamental dislocation types. In an edge dislocation, localized lattice distortion exists **along the end of an extra half-plane of atoms**, which also defines the dislocation line. A screw dislocation may be thought of as resulting from shear distortion; **its dislocation line passes through the center of a spiral, atomic plane ramp**.



Many dislocations in crystalline materials have both edge and screw components; these are **mixed dislocations**. Plastic deformation corresponds to the motion of large numbers of dislocations. An **edge** dislocation moves in response to a shear stress applied in a direction perpendicular to its line. Let the initial extra half-plane of atoms be plane A. When the shear stress is applied as indicated, plane A is forced to the right. If the applied shear stress is of sufficient magnitude, the interatomic bonds of plane B are severed along the shear plane, and the upper half of plane B becomes the extra half-plane as plane A links up with the bottom half of plane B.



This process is subsequently **repeated** for the other planes, such that the extra half-plane, by discrete steps, moves from left to right **by successive and repeated breaking of bonds and shifting by interatomic distances** of upper half-planes. Before and after the movement of a dislocation through some particular region of the

crystal, the atomic arrangement is ordered and perfect; it is only during the passage of the extra half-plane that the lattice structure is disrupted. Ultimately this extra half-plane may emerge from the right surface of the crystal, forming an edge that is one atomic distance wide. The process by which plastic deformation is produced by dislocation motion is termed slip; the crystallographic plane along which the dislocation line traverses is the slip plan. **Macroscopic plastic deformation simply corresponds to permanent deformation that results from the movement of dislocations**, in response to an applied shear stress, as represented.

The caterpillar forms a hump near its posterior end by pulling in its last pair of legs a unit leg distance. The **hump** is propelled forward by repeated lifting and shifting of leg pairs. When the hump reaches the anterior end, the entire caterpillar has moved forward by the leg separation distance.

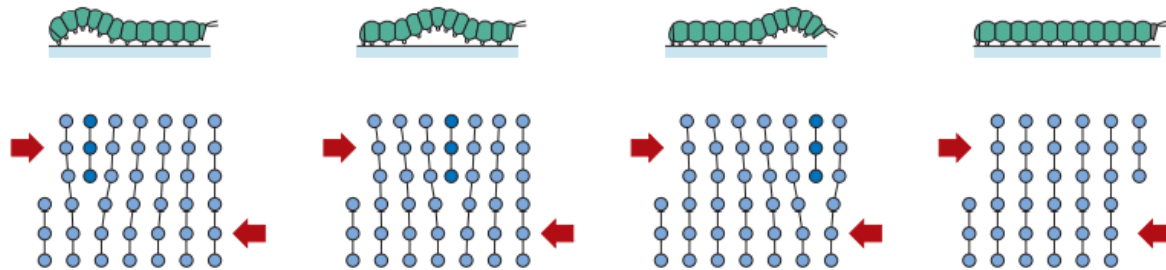


Figure. Representation of the analogy between caterpillar and dislocation motion

The motion of a **screw** dislocation in response to the applied shear stress is shown in Figure; the direction of movement is perpendicular to the stress direction. For an edge, motion is parallel to the shear stress. **However, the net plastic deformation for the motion of both dislocation types is the same.** The direction of motion of the mixed dislocation line is neither perpendicular nor parallel to the applied stress, but lies somewhere in between.

All metals and alloys contain some **dislocations that were introduced during solidification**, during plastic deformation, and as a consequence of thermal stresses that result from rapid cooling. **The number of dislocations, or dislocation density in a material, is expressed as the total dislocation length per unit volume or, equivalently, the number of dislocations that intersect a unit area of a random section.**

SLIP SYSTEMS

Dislocations do not move with the **same degree of ease** on all crystallographic planes of atoms and in all crystallographic directions. Ordinarily there is a **preferred plane**, and in that plane there are **specific directions** along which dislocation motion occurs. This plane is called the **Slip Plane**; it follows that the direction of movement is called the **slip direction**. This combination of the slip plane and the slip direction is termed the **slip system**. The slip system depends on the crystal structure of the metal and is such that the atomic distortion that accompanies the motion of a dislocation is a minimum.

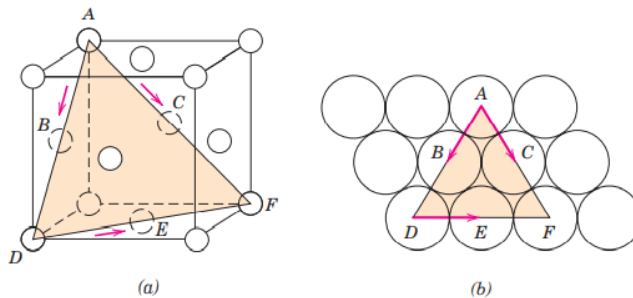


Figure 7.6 (a) A $\{111\}$ $\langle 110 \rangle$ slip system shown within an FCC unit cell. (b) The (111) plane from (a) and three $\langle 110 \rangle$ slip directions (as indicated by arrows) within that plane constitute possible slip systems.

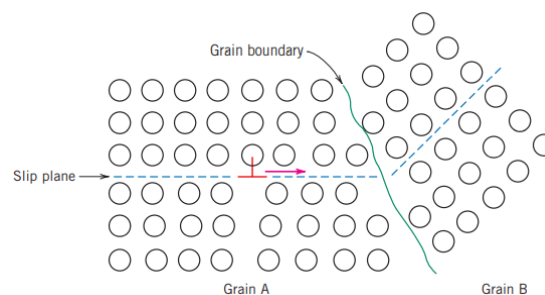
Mechanisms of Strengthening in Metals

Metallurgical and materials engineers are often called on to design alloys having high strengths yet some ductility and toughness; ordinarily, ductility is sacrificed when an alloy is strengthened. Several hardening techniques are at the disposal of an engineer, and frequently alloy selection depends on the capacity of a material to be tailored with the mechanical characteristics required for a particular application. Important to the understanding of strengthening mechanisms is the relation between dislocation motion and mechanical behavior of metals. Because macroscopic plastic deformation corresponds to the motion of large numbers of dislocations, the ability of a metal to plastically deform depends on the ability of dislocations to move. Because hardness and strength (both yield and tensile) are related to the ease with which plastic deformation can be made to occur, by reducing the mobility of dislocations, the mechanical strength may be enhanced; that is, greater mechanical forces will be required to initiate plastic deformation.

In contrast, the more unconstrained the dislocation motion, the greater is the facility with which a metal may deform, and the softer and weaker it becomes. Virtually all strengthening techniques rely on this simple principle: Restricting or hindering dislocation motion renders a material harder and stronger. The present discussion is confined to strengthening mechanisms for single-phase metals by grain size reduction, solid-solution alloying, and strain hardening. Deformation and strengthening of multiphase alloys are more complicated, involving concepts beyond the scope of the present discussion.

1-Strengthening by Grain Size Reduction

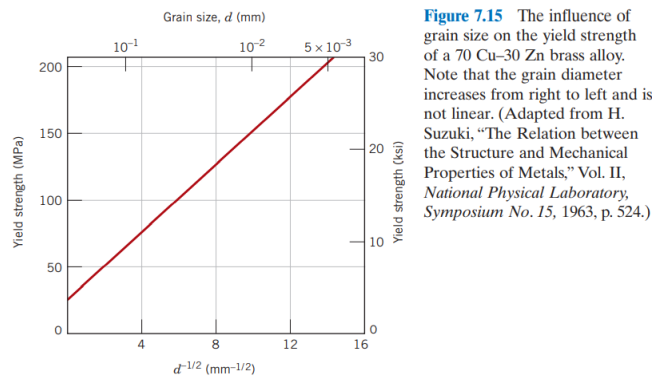
The size of the grains, or average grain diameter, in a polycrystalline metal influences the mechanical properties. Adjacent grains normally have different crystallographic orientations and, of course, a common grain boundary, as indicated in Figure 7.14. During plastic deformation, slip or dislocation motion must take place across this common boundary—say, from grain A to grain B in the figure.



The grain boundary acts as a barrier to dislocation motion for two reasons:

1. Because the two grains are of **different orientations**, a dislocation passing into grain B will have to change its direction of motion; this becomes more difficult as the crystallographic **misorientation** increases.
2. The atomic **disorder** within a grain boundary region will result in a **discontinuity of slip planes** from one grain into the other.

A fine-grained material (one that has small grains) is harder and stronger than one that is coarse grained, because the former has a greater total grain boundary area to impede dislocation motion. It should also be mentioned that grain size reduction improves not only strength, but also the **toughness** of many alloys.



2- Solid-Solution Strengthening

Another technique to strengthen and harden metals is **alloying with impurity atoms that go into either substitutional or interstitial solid solution.** Accordingly, this is called **solid-solution strengthening.** High-purity metals are almost always softer and weaker than alloys composed of the same base metal. Increasing the concentration of the impurity results in an attendant increase in tensile and yield strengths.

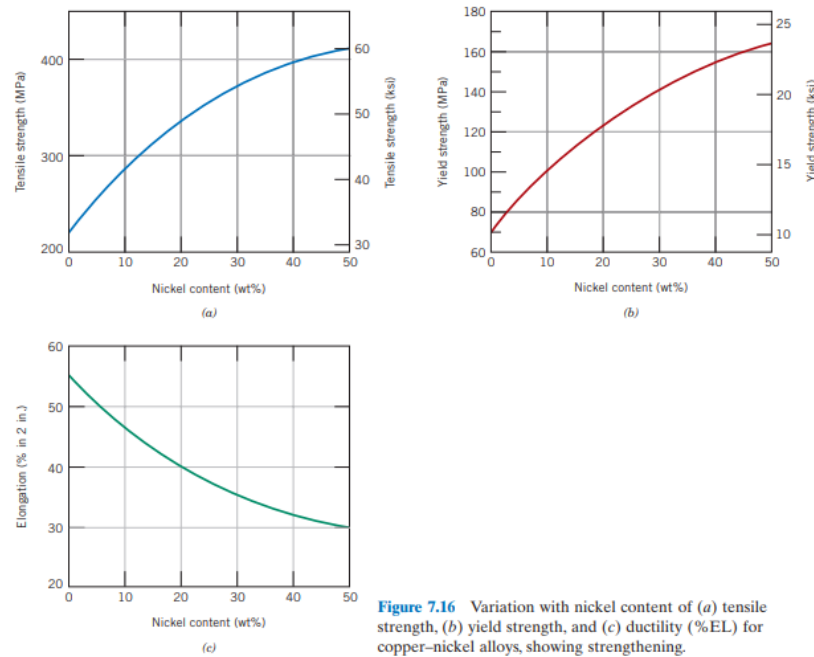


Figure 7.16 Variation with nickel content of (a) tensile strength, (b) yield strength, and (c) ductility (%EL) for copper-nickel alloys, showing strengthening.

Alloys are stronger than pure metals because impurity atoms that go into solid solution ordinarily impose lattice strains on the surrounding host atoms. Lattice strain field interactions between dislocations and these impurity atoms result, and, consequently, dislocation movement is restricted. For example, an impurity atom that is smaller than a host atom for which it substitutes exerts tensile strains on the surrounding crystal lattice.

3-Strain Hardening

Strain hardening is **the phenomenon whereby a ductile metal becomes harder and stronger as it is plastically deformed**. Sometimes it is also called work hardening, or, because the temperature at which deformation takes place is “cold” relative to the absolute melting temperature of the metal, cold working. Most metals strain harden at room temperature. It is sometimes convenient to express the degree of plastic deformation as percent cold work (%CW) is defined as

$$\%CW = \left(\frac{A_0 - A_d}{A_0} \right) \times 100$$

Where A_0 is the original area of the cross section that experiences deformation and A_d is the area after deformation. The price for this enhancement of hardness and strength is in the ductility of the metal. In which the ductility, in percent elongation, experiences a reduction with increasing percent cold work for the same three alloys.



Strain hardening is demonstrated in a stress–strain diagram presented earlier. *Initially, the metal with yield strength is plastically deformed to dislocation multiplication or the formation of new dislocations, as noted previously. Consequently, the average distance of separation between dislocations decreases the dislocations are positioned closer together. On the average, dislocation–dislocation strain interactions are repulsive. The net result is that the motion of a dislocation is hindered by the presence of other dislocations.* As the dislocation density increases, this resistance to dislocation motion by other dislocations becomes more pronounced. *Thus, the imposed stress necessary to deform a metal increases with increasing cold work.*

Strain hardening is often utilized commercially to enhance the mechanical properties of metals during fabrication procedures. *The effects of strain hardening may be removed by an annealing heat treatment.* In passing, for the mathematical expression relating true stress and strain, the parameter n is called the strain-hardening exponent, which is a measure of the ability of a metal to strain harden; the larger its magnitude, the greater the strain hardening for a given amount of plastic strain.

Tensile Strength and Ductility Determinations for Cold-Worked Copper

Compute the tensile strength and ductility (%EL) of a cylindrical copper rod if it is cold worked such that the diameter is reduced from 15.2 mm to 12.2 mm (0.60 in. to 0.48 in.).

Solution

It is first necessary to determine the percent cold work resulting from the deformation. This is possible using Equation 7.8:

$$\%CW = \frac{\left(\frac{15.2 \text{ mm}}{2}\right)^2 \pi - \left(\frac{12.2 \text{ mm}}{2}\right)^2 \pi}{\left(\frac{15.2 \text{ mm}}{2}\right)^2 \pi} \times 100 = 35.6\%$$

The tensile strength is read directly from the curve for copper (Figure 7.19b) as 340 MPa (50,000 psi). From Figure 7.19c, the ductility at 35.6%CW is about 7%EL.