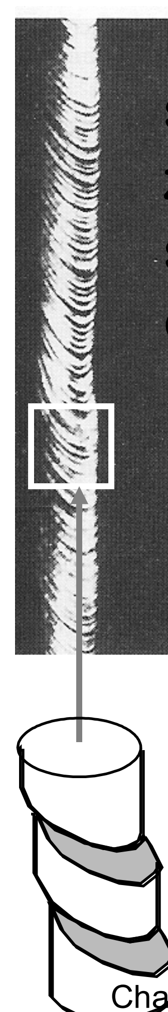
Chapter 7: Dislocations and strengthening mechanisms

- Introduction
- Basic concepts
- Characteristics of dislocations
- Slip systems
- Slip in single crystals
- Plastic deformation of polycrystalline materials

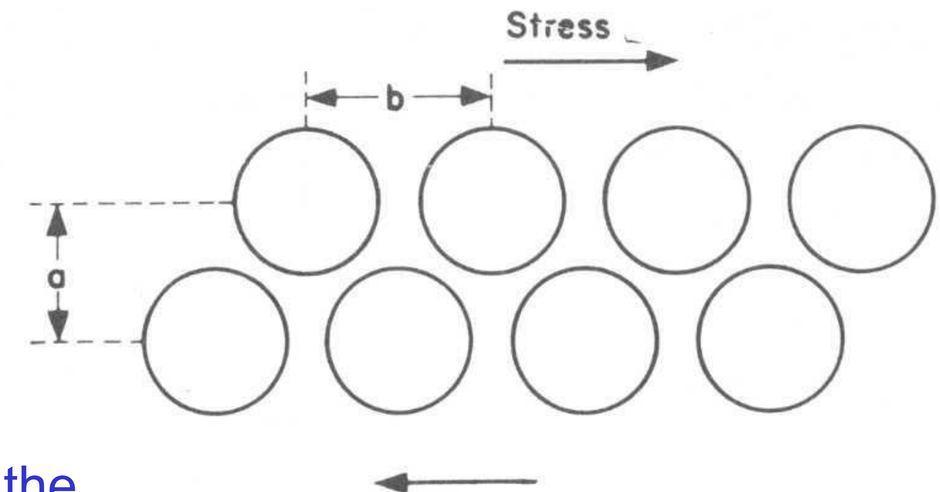


Plastically stretched zinc single crystal.

Theoretical stress

Theoretical stress (Frenkel in 1926)

$$\tau = \frac{Gb}{2\pi a} \sin \frac{2\pi x}{b}$$



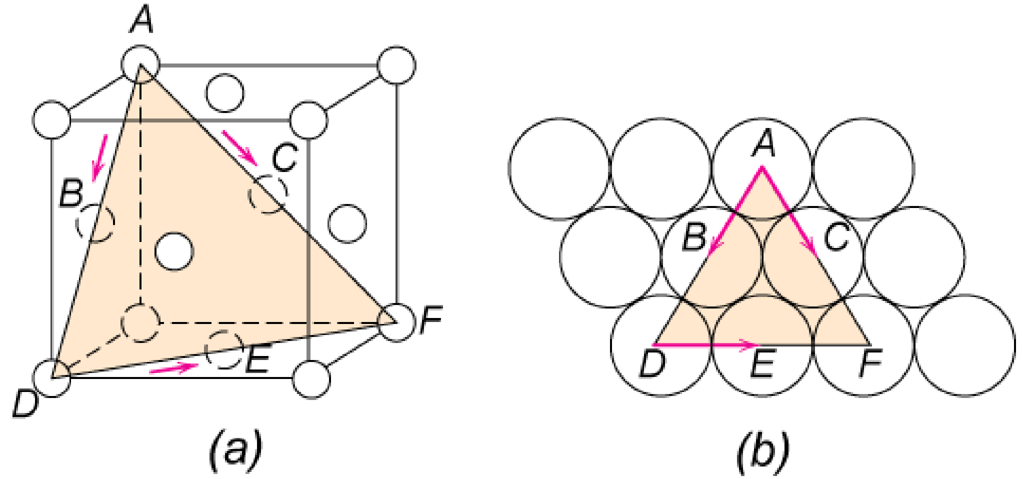
G: shear modulus
b: spacing between atoms in the direction of shear stress
a: spacing of the rows of atoms
x: shear translation

Deformation Mechanisms

Slip System

– Slip plane - plane allowing easiest slippage
  - Wide interplanar spacings - highest planar densities

– Slip direction - direction of movement - Highest linear densities



Adapted from Fig. 7.6, *Callister 7e.*

– FCC Slip occurs on {111} planes (close-packed) in <110> directions (close-packed)

=> total of 12 slip systems in FCC

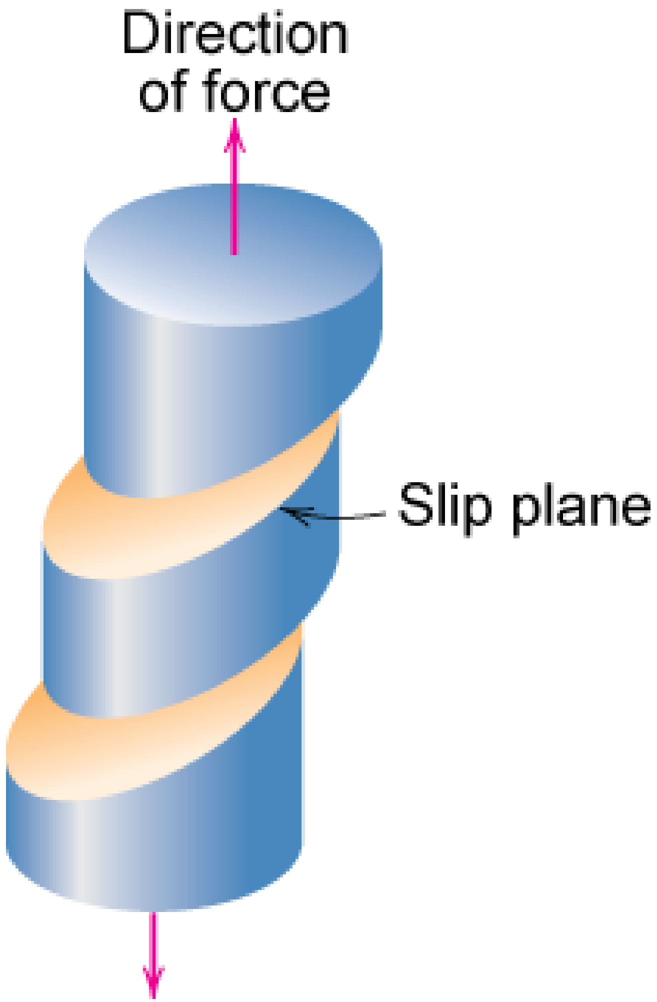
– in BCC & HCP other slip systems occur

Slip planes and directions for common crystal structure

Table 7.1 Slip Systems for Face-Centered Cubic, Body-Centered Cubic, and Hexagonal Close-Packed Metals

Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	{111}	$\langle 1\bar{1}0 \rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	{110}	$\langle \bar{1}11 \rangle$	12
α-Fe, W	{211}	$\langle \bar{1}11 \rangle$	12
α-Fe, K	{321}	$\langle \bar{1}11 \rangle$	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	{0001}	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0 \rangle$	6

Single Crystal Slip



Adapted from Fig. 7.8, *Callister 7e.*

Adapted from Fig. 7.9, *Callister 7e.*

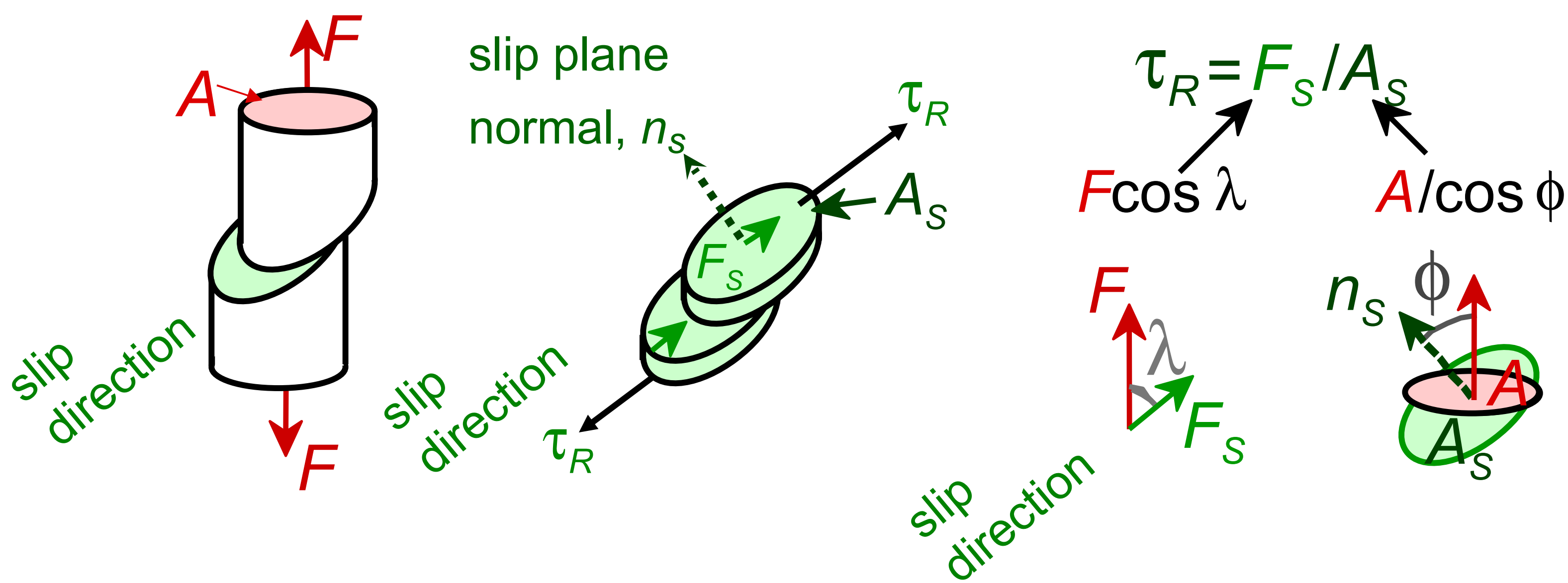
Stress and Dislocation Motion

- Crystals slip due to a resolved shear stress, τ_R.
- Applied tension can produce such a stress.

Applied **tensile** stress: $\sigma = F/A$

Resolved shear stress: $\tau_R = F_S/A_S$

Relation between σ and τ_R



$$\tau_R = \sigma \cos\lambda \cos\phi$$

Critical Resolved Shear Stress

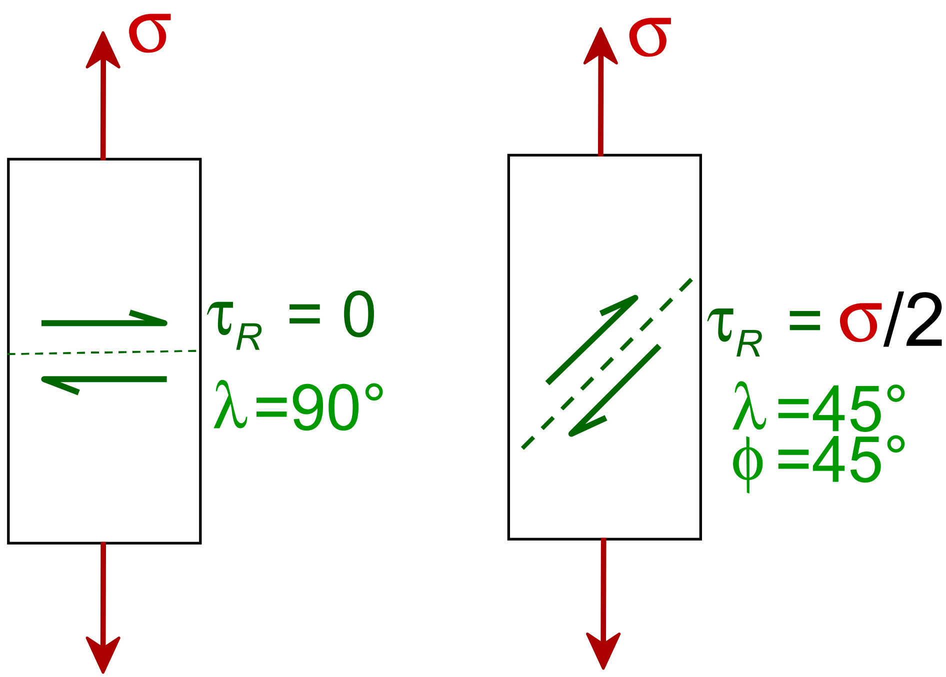
- Condition for dislocation motion: $\tau_R > \tau_{CRSS}$

typically

10^{-4} GPa to 10^{-2} GPa

- Crystal orientation can make it easy or hard to move dislocation

$\tau_R = \sigma \cos\lambda \cos\phi$



τ maximum at $\lambda = \phi = 45°$

Theoretical & experimental strength

There is much difference between theoretical and experimental strength

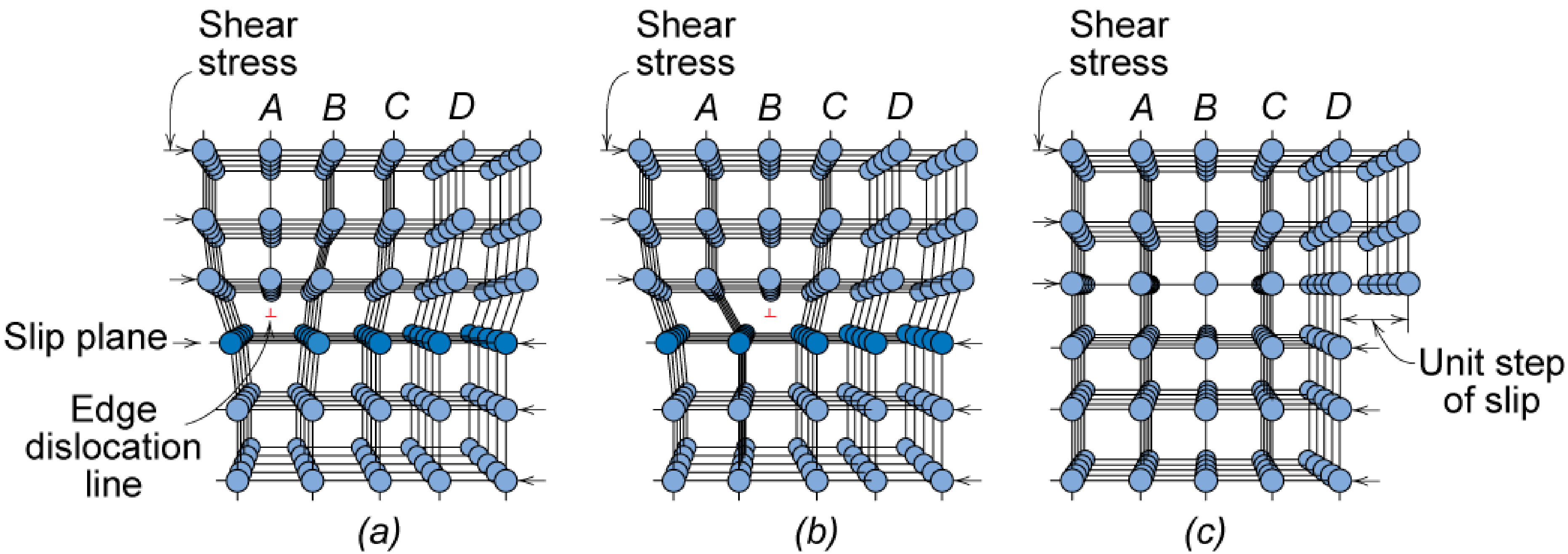
Reasons are:

- Defects are present in all perfect crystal
- Dislocation movement makes plastic deformation easier than that predicted by the Frenkel calculation

Dislocation Motion

Dislocations & plastic deformation

- Cubic & hexagonal metals - plastic deformation by plastic shear or slip where one plane of atoms slides over adjacent plane by defect motion (dislocations).

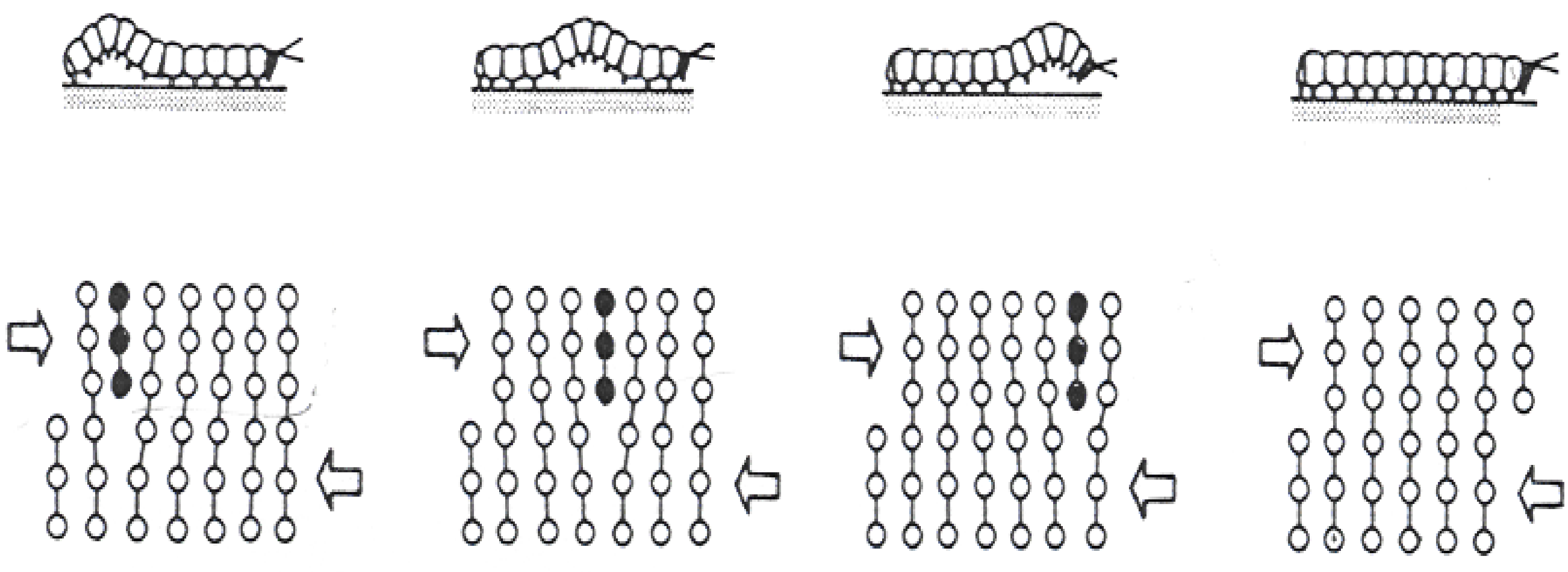


- If dislocations don't move, deformation doesn't occur!

Adapted from Fig. 7.1, *Callister 7e.*

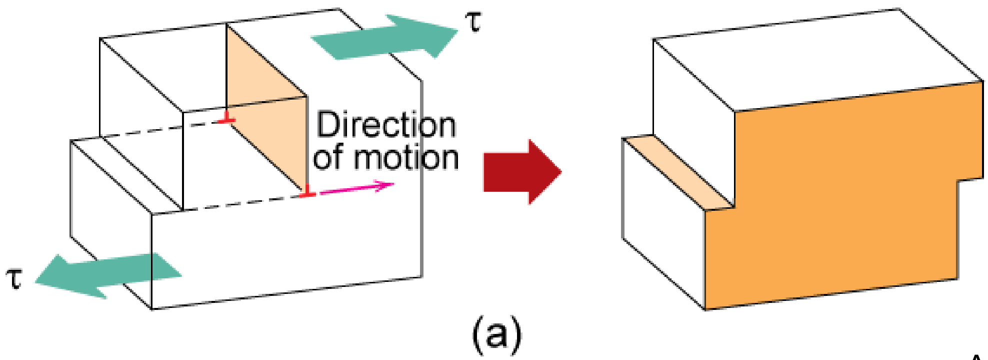
Analogy between caterpillar and dislocation motion

- **Dislocation density: total dislocation length per unit volume**
- **10^3 mm^{-2} for pure metal crystals; 10^9-10^{10}mm^{-2} for heavily deformed metals; 10^5-10^6mm^{-2} for heat-treated deformed metals**



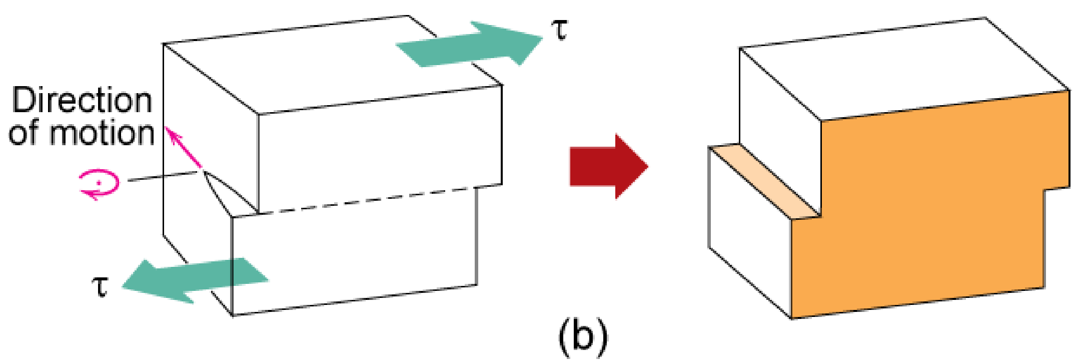
Dislocation Motion

- Dislocation moves along slip plane in slip direction perpendicular to dislocation line
- Slip direction same direction as Burgers vector



Edge dislocation

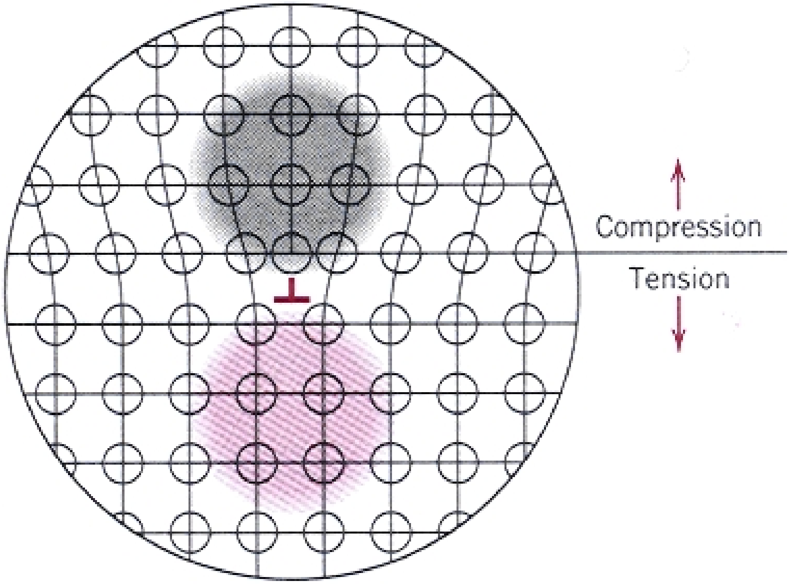
Adapted from Fig. 7.2, *Callister 7e.*



Screw dislocation

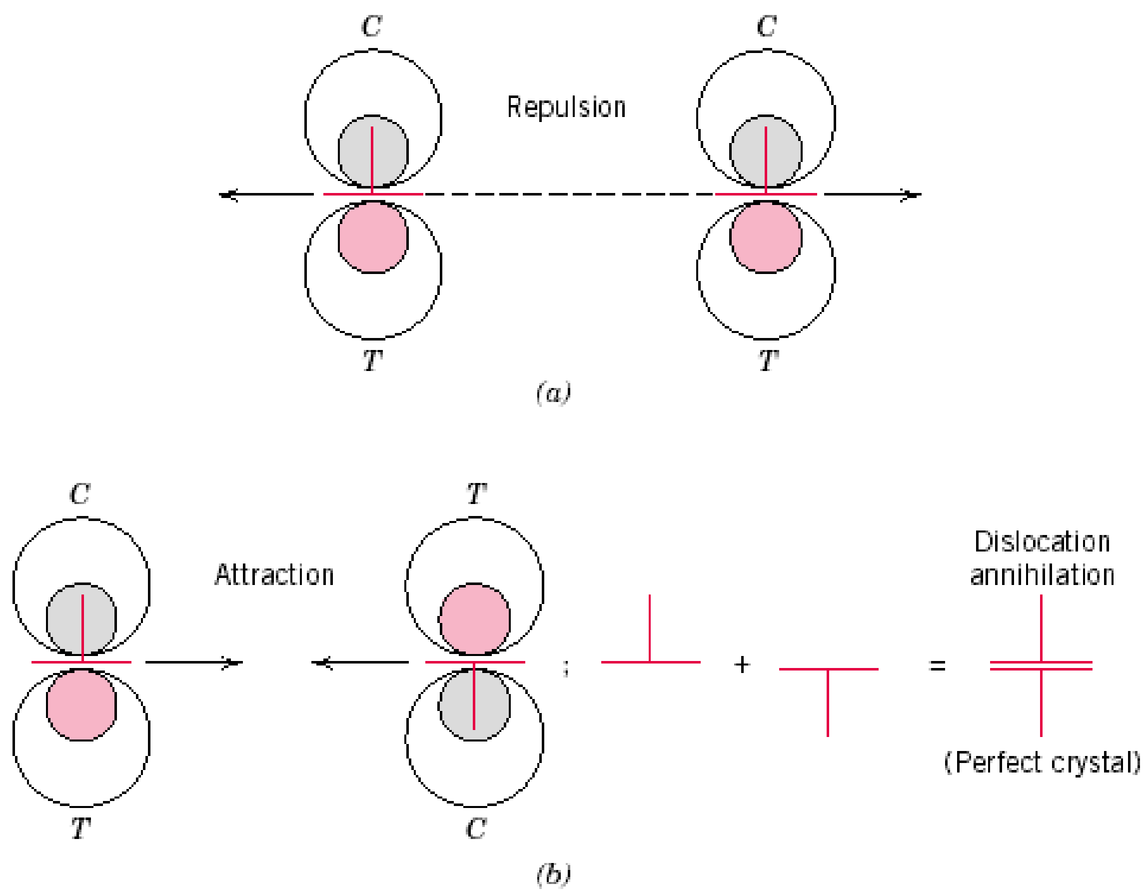
Characteristics of dislocations

- **Strain fields: determining the mobility of the dislocations and their ability to multiply**
- **Compressive, tensile, and shear lattice stains**



Dislocation interaction

- **Edge dislocation**
- **Positive sign**
- **Negative sign**



Slip Motion in Polycrystals

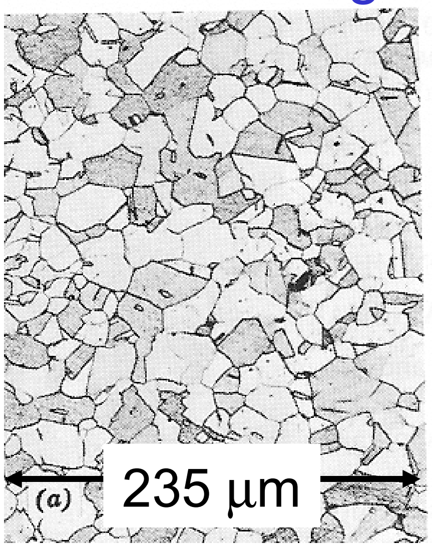
- Stronger - grain boundaries pin deformations
- Slip planes & directions (λ, ϕ) change from one crystal to another.
- τ_R will vary from one crystal to another.
- The crystal with the largest τ_R yields first.
- Other (less favorably oriented) crystals yield later.

Adapted from Fig. 7.10, *Callister 7e.* (Fig. 7.10 is courtesy of C. Brady, National Bureau of Standards [now the National Institute of Standards and Technology, Gaithersburg, MD].)

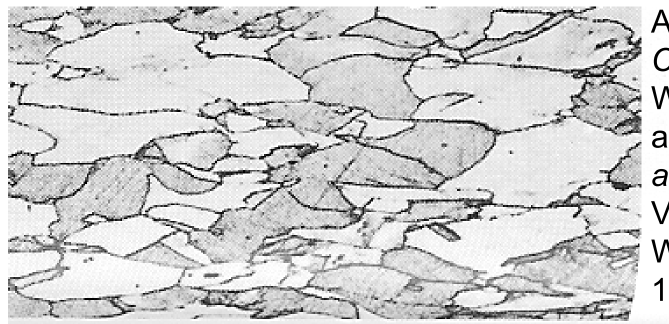
Anisotropy in σ_y

- Can be induced by rolling a polycrystalline metal

- before rolling



- after rolling



Adapted from Fig. 7.11, *Callister 7e.* (Fig. 7.11 is from W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. I, *Structure*, p. 140, John Wiley and Sons, New York, 1964.)

- isotropic

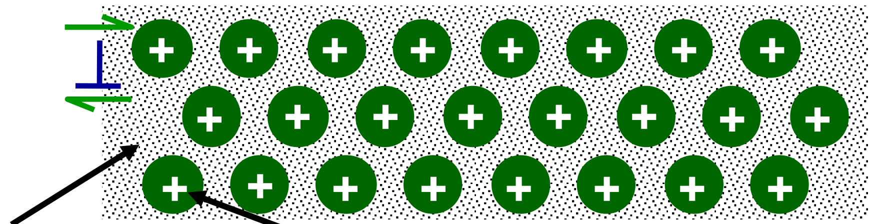
since grains are approx. spherical & randomly oriented.

- anisotropic

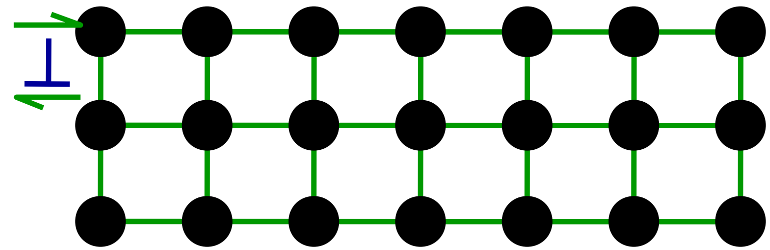
since rolling affects grain orientation and shape.

Dislocations & Materials Classes

- Metals: Disl. motion easier.
  - -non-directional bonding
  - -close-packed directions for slip.



- Covalent Ceramics (Si, diamond): Motion hard.
  - -directional (angular) bonding



- Ionic Ceramics (NaCl): Motion hard.
  - -need to avoid ++ and - - neighbors.