MSE200

Lecture 8 (CH. 6.5-6.8)

Mechanical Properties I

Instructor: Yuntian Zhu

•Objectives/outcomes: You will learn the following:

•Plastic deformation single crystals.

•The slip mechanism and dislocations.

•Slip systems and the critical resolved shear stress.

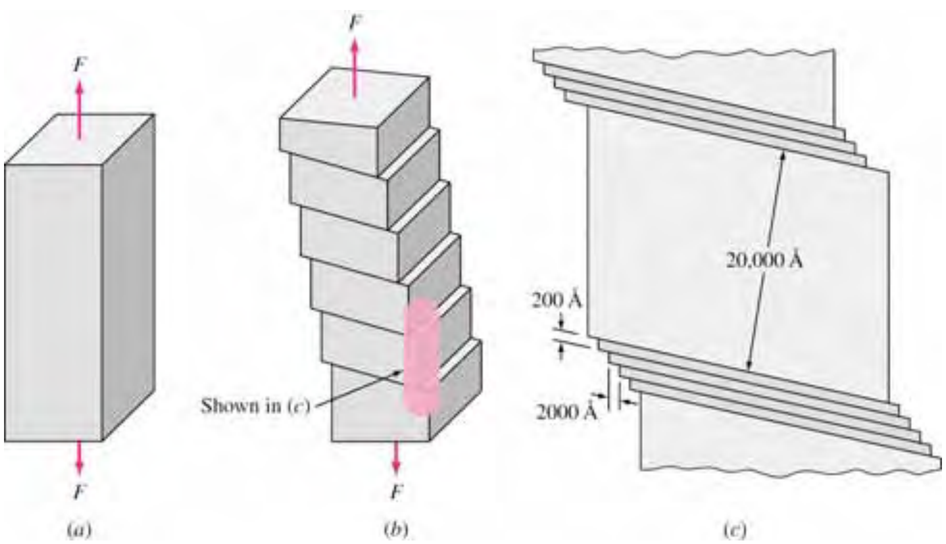
•Schmid's law.

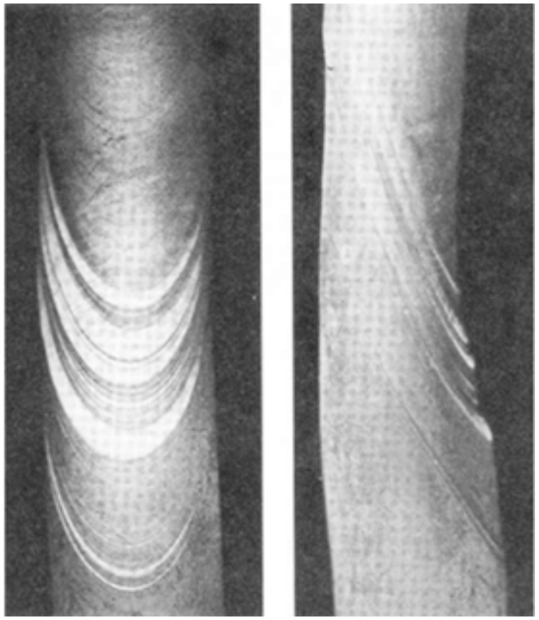
•Twinning

•Grain boundary strengthening

Slip Bands and Slip Planes in Single Crystals

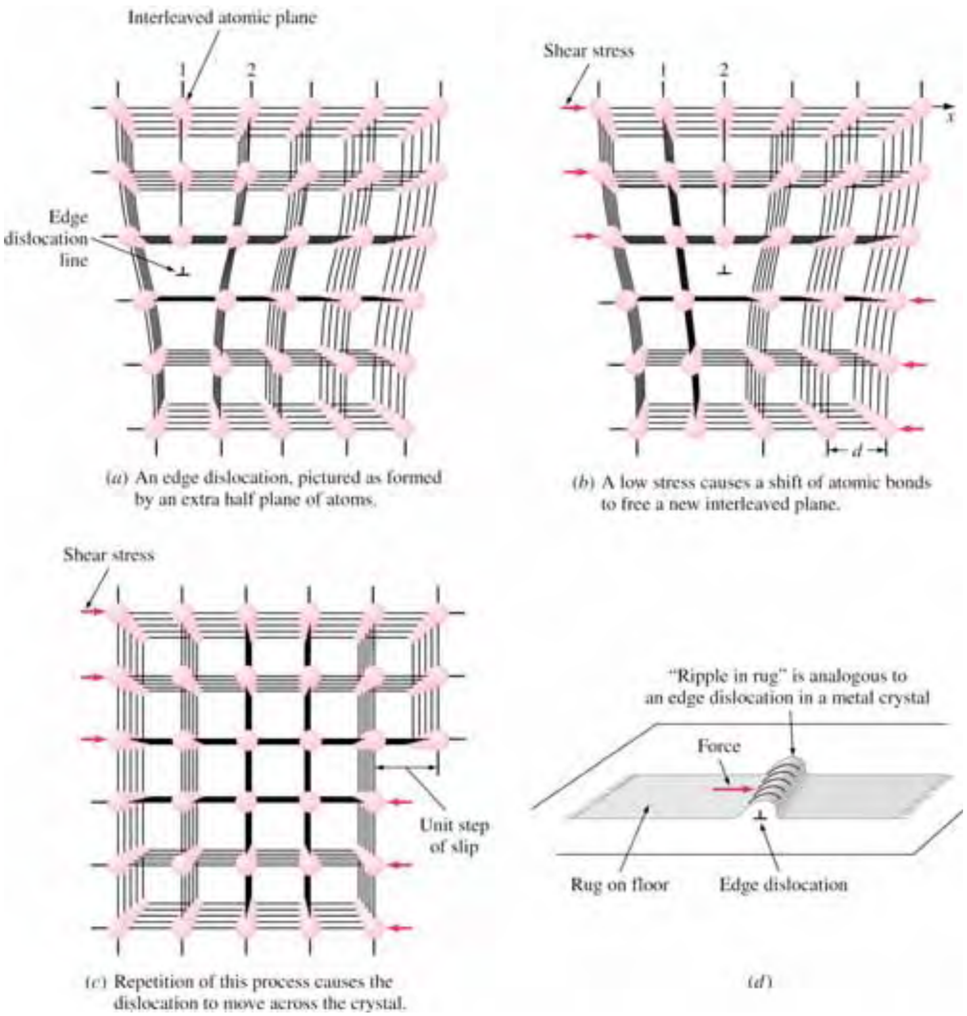
- **Happens in the plastic deformation of single crystals**
- **Slip bands in ductile metals occurs in many slip planes.**
- **Slip occurs in many *slip planes* within slip bands.**
- **Caused by dislocation slip (glide)**





Slip Mechanism

The slip occurs due to movement of dislocations.



(a) An edge dislocation, pictured as formed by an extra half plane of atoms.

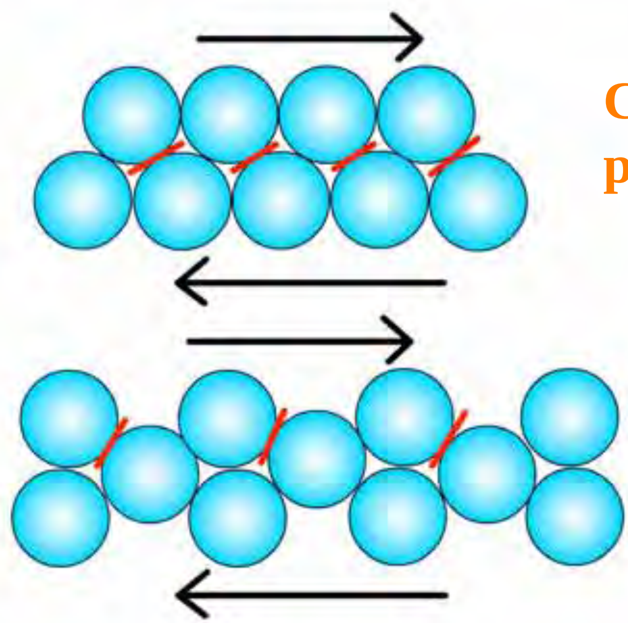
(b) A low stress causes a shift of atomic bonds to free a new interleaved plane.

(c) Repetition of this process causes the dislocation to move across the crystal.

(d)

Slip in Crystals

- **Slip occurs in densely or close packed planes.**
- **Lower shear stress/energy is required for slip to occur in densely packed planes.**



Close packed plane

Non-close-packed plane

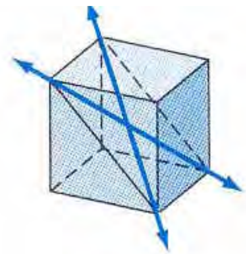
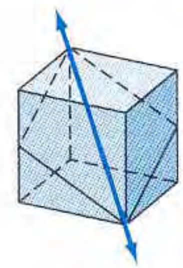
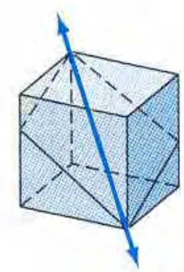
Slip Systems

- **Slip systems are combination of slip planes and slip direction (Burgers vector).**
- **In FCC crystal, slip takes place in {111} planes and <110> directions.**
- 12 slip systems in fcc metals:

Slip Systems in BCC Crystal

BCC crystals are not close packed. The slip predominantly occurs in {110} planes, which has highest atomic density.

The slip direction in BCC metal is <111>

BCC: αFe, W, Mo, β brass	{110}	$\langle\bar{1}11\rangle$	$6 \times 2 = 12$	
αFe, Mo, W, Na	{211}	$\langle\bar{1}11\rangle$	$12 \times 1 = 12$	
αFe, K	{321}	$\langle\bar{1}11\rangle$	$24 \times 1 = 24$	

Critical Resolved Shear Stress

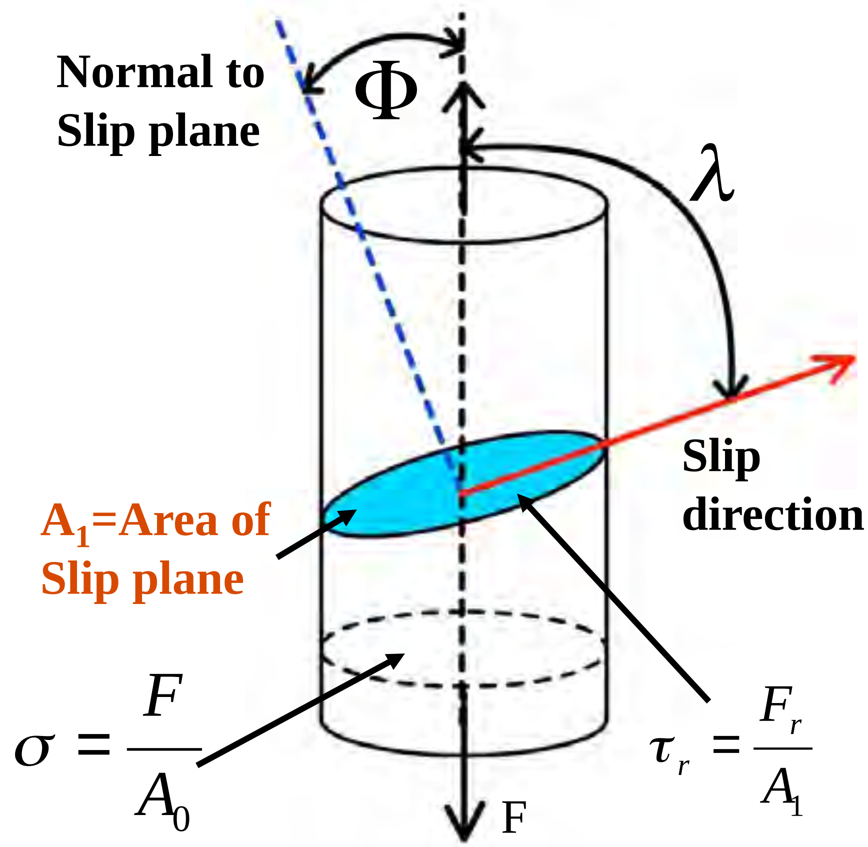
- **Critical resolved shear stress is the stress required to cause slip in pure metal single crystal.**
- **Slip begins when shear stress in slip plane in slip direction reaches critical resolved shear stress.**
- **This is equivalent to yield shear stress.**

Schmid's Law

- **The relationship between uniaxial stress and resulting resolved shear stress produced on a slip system is give by**

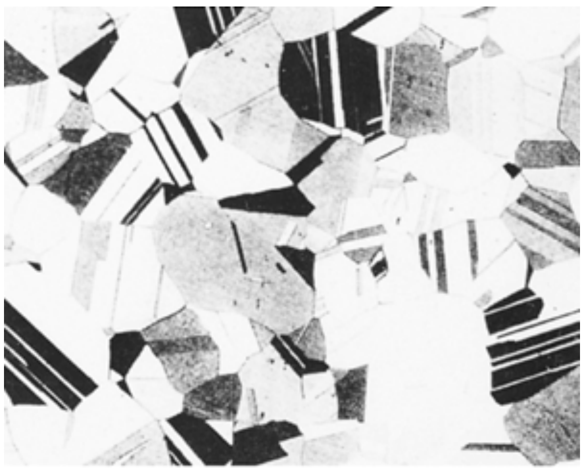
$$\tau_r = \sigma Cos\lambda Cos\Phi$$

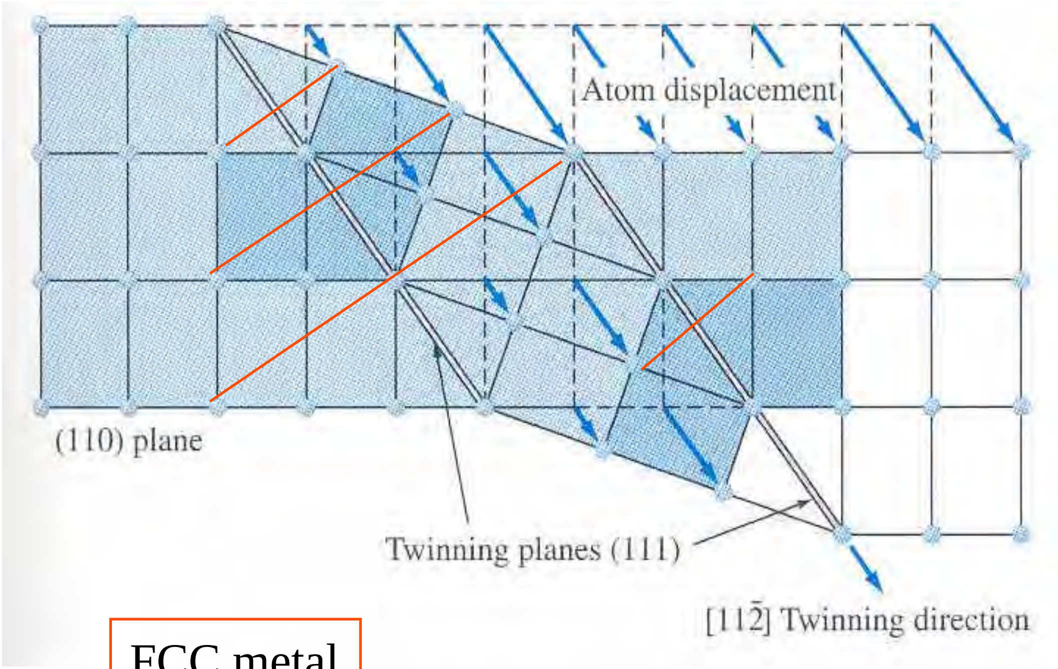
Example 6.9



Twinning

- **In twinning, a part of atomic lattice is deformed and forms *mirror image* of lattice next to it.**
- **Usually straight boundary**
- **Twinning reorient the slip system.**

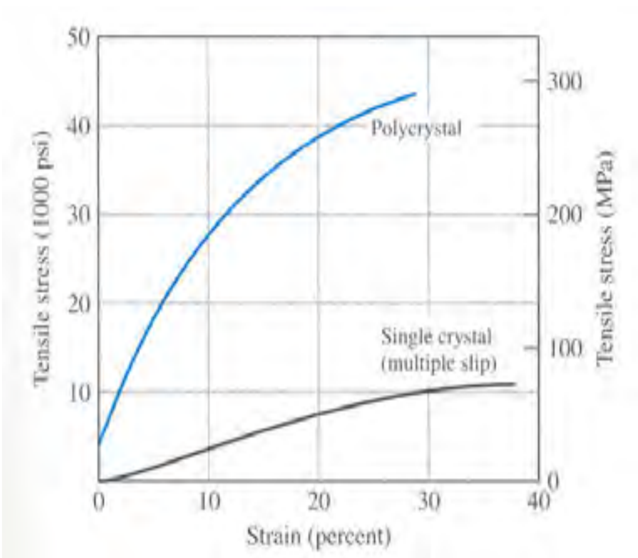




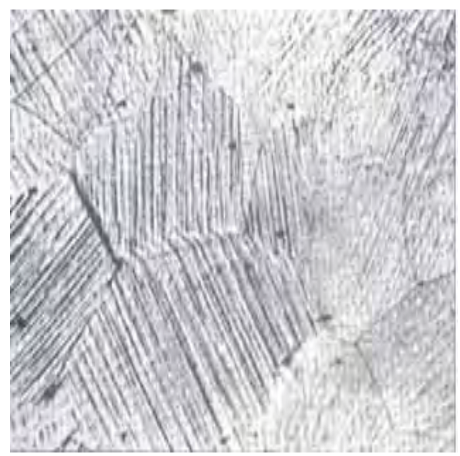
FCC metal

Effects of Grain Boundaries on Strength

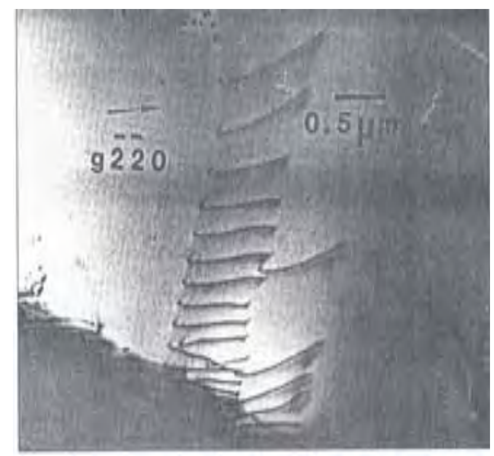
- **Grain boundaries stop dislocation movement and hence strengthen the metals.**
- **Fine grain size is desirable, and hence metals are produced with finer grains.**



Stress-strain curve of single and polycrystalline copper



Slip bands in polycrystalline aluminum grains



Dislocations piled up against grain boundaries in stainless steel

Hall Petch Equation

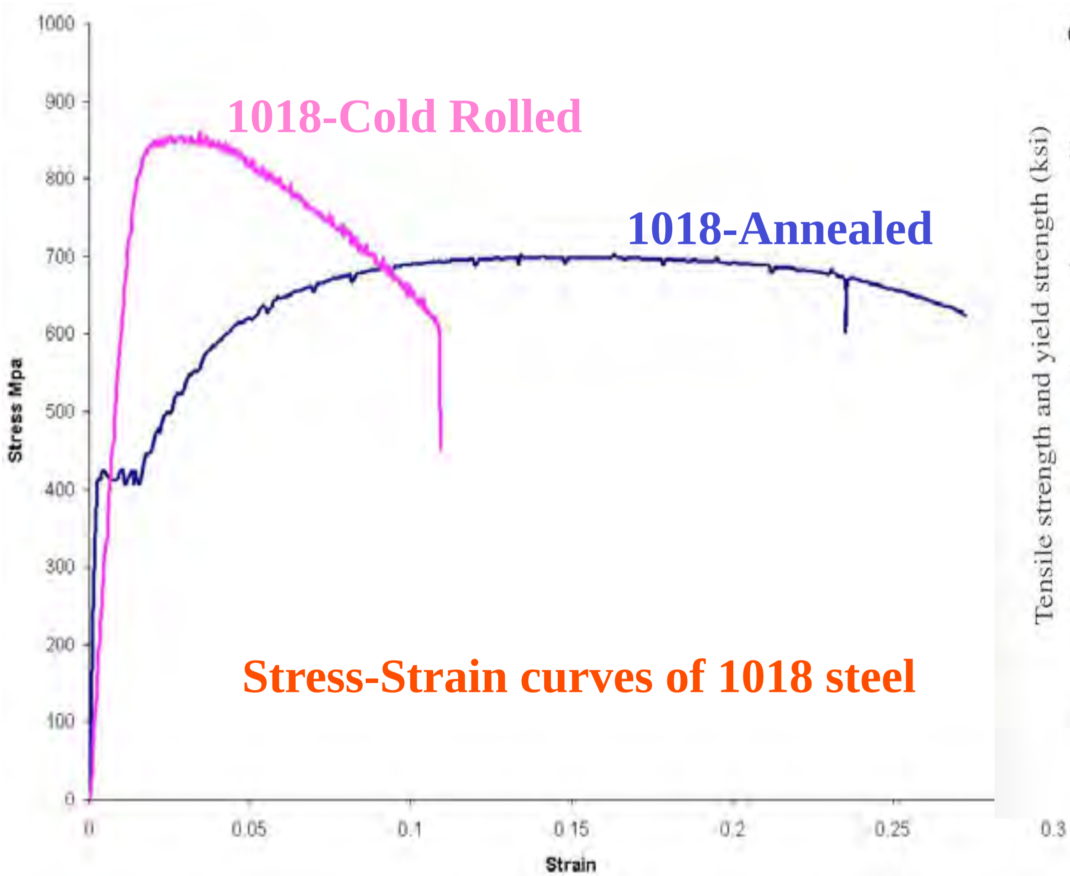
- **Finer the grains, superior are the mechanical properties (at room temperature).**

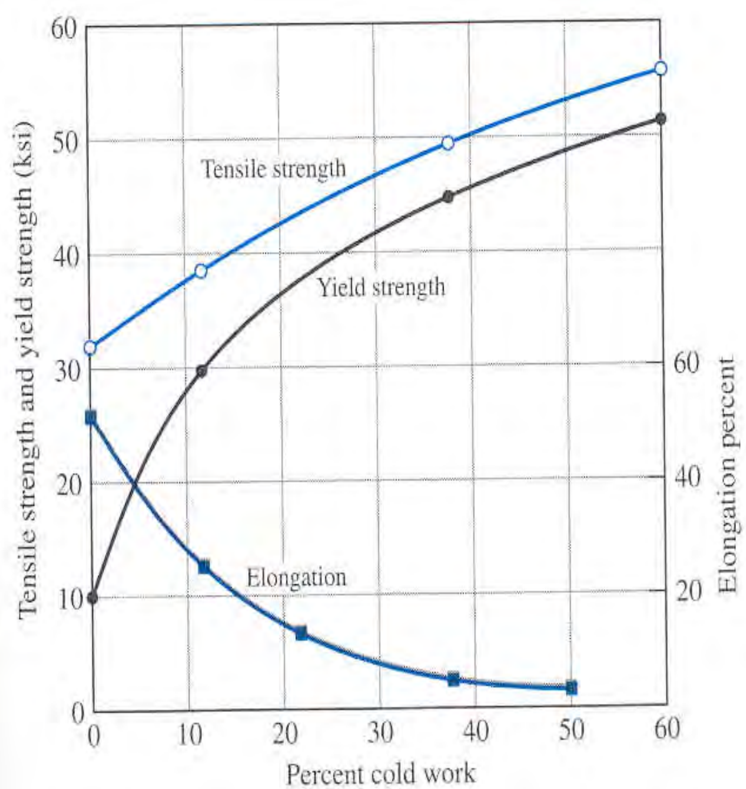
Hall-Petch equation - Empirical

$$\sigma_y = \sigma_o + k / (d)^{1/2}$$

Effect of Cold Work on Tensile Strength

- **Number of dislocations are increased by cold work.**
- **Dislocation movements are hindered by both grain boundaries and other dislocations** → **Strain Hardening**





Solid Solution Strengthening

- **Addition of one or more metals can increase the strength of metals.**
- **Solute atoms, on case of substitutional solid solution, create *stress fields* around themselves and hinder the dislocation movement.**
- **Distortion of lattice and clustering of like atoms also impede dislocation movement.**
- **Example: Brass, Jewelry**

Nanocrystalline/nanostructured Metals

- Nanocrystalline: average grain diameter < 100 nm
- Nanostructured: average structural feature < 100 nm
- Results in high strength and hardness
- If d < 5 nm, elastic modulus drops as more atoms are in grain boundary
- Negative Hall-Petch effect might take place

<u>3 important strategies for increasing the strength:</u>

Survey and homework

Example Problems: 6.9, 6.10
Regular Problems, Chapter 6: 46, 47, 48, 49, 63, 65,
Reading assignment: section 6.5-6.8