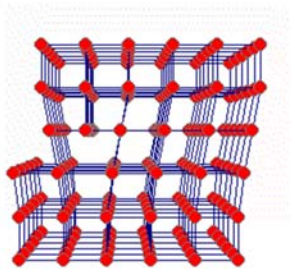
Outline

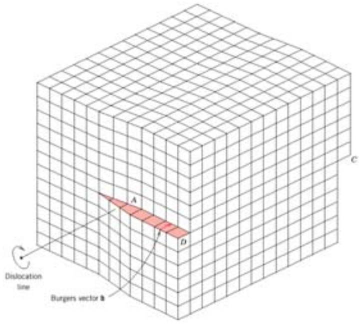
- Movement of Dislocations - *Review*
- Screw Dislocation
- Screw vs. Edge Dislocations
- Mixed Dislocations
- Observation of Dislocations
- Dislocations’ Multiplication
- Stress and Dislocation Motion
- Slip in Single Crystals
- Twining

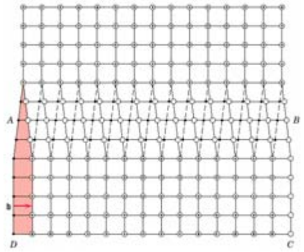
Movement Dislocations: *Review*



- Bonds across slip plane break consecutively **not simultaneously**
  - less energy is required but with same end result.
- Disl^{ns} allow deformation at much lower stress than in a perfect crystal.
- The movement of the dislocation requires the breaking and formation of only **ONE** set of bonds per step.
- Dislocations move in the close-packed directions within the close packed planes.

SCREW Dislocation:





Spiral within the lattice structure wrapped around an imperfection line, like a screw is wrapped around its axis

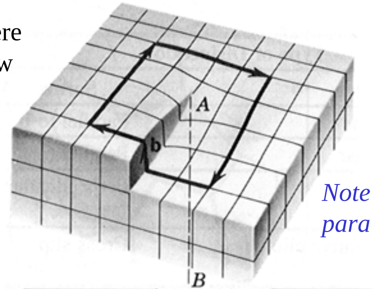
- *Crystal* is "cut halfway through and then slide sideways“

  helical path through structure hence “screw”.
- The motion of a screw dislocation can be thought of in terms of tearing a sheet of paper.

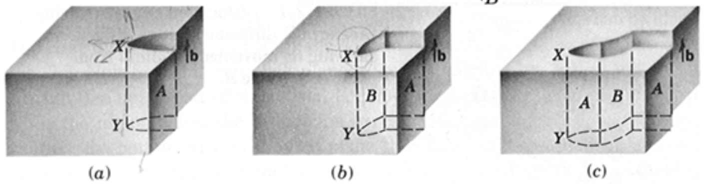
SCREW Dislocation: *Movement*

Because b and disl^{n} are parallel there is no set SLIP plane. Instead, screw disl^{ns} move on planes with low resistance to disl^{n} movement.

Can change planes if need to: …………………



Note that AB is parallel to b.

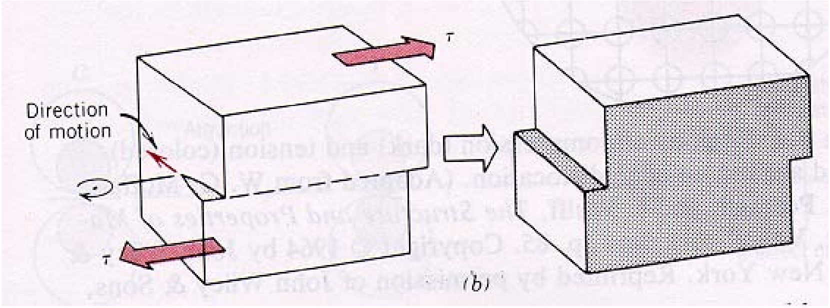


Cross-slip of a screw dislocation xy from (a) plane A to (b) plane B to (c) plane A. Slip always occurs in direction of Burgers vector b.

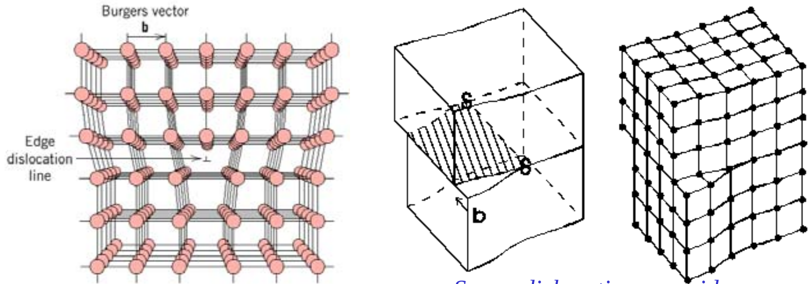
Generally, screw dislocations are more ………… than edge dislocations.

SCREW Dislocation: *Movement*

- The motion of a screw dislocation is also a result of shear stress.
  - Motion is ……………… to direction of stress, rather than ……………. (*edge*).
  - However, the net plastic deformation of both edge and screw dislocations is the same.



Screw Disl^n vs. Edge Disl^n



Screw dislocations provide pure shear lattice strain only

TABLE 2.4 Characteristics of Dislocations

Dislocation Characteristic	Type of Dislocation: Edge	Type of Dislocation: Screw
Slip direction	Parallel to **b**	Parallel to **b**
Relation between dislocation line and **b**	Perpendicular	Parallel
Direction of dislocation line movement relative to **b**	Parallel	Perpendicular
Process by which dislocations may leave the glide plane	Nonconservative climb	Cross-slip

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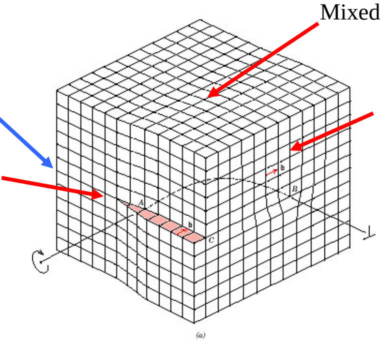
Dislocations

Usually, dislocations have both an edge and a screw character; i.e., they are ………… dislocations:



Mixed mode here

Slip plane

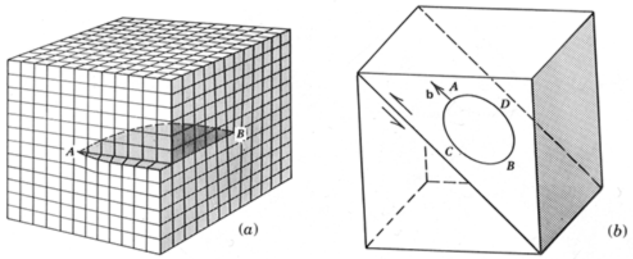
Pure edge here

Pure screw here

makes up most of the dislocations encountered in real life

- *very difficult to have pure edge or pure screw dislocations*

Mixed Dislocation and Disl^n LOOPS



Mixed dislocation **Dislocation loop**

Curved dislocations containing edge and screw components

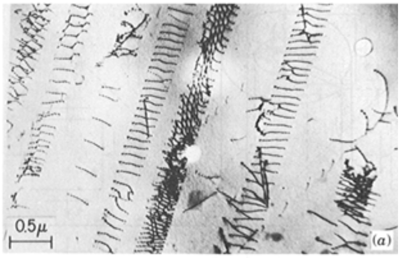
For a dislocation loop:
Front + back are (+ve) and (-ve) edge
Sides are LH + RH screw

Shear stress expands loop radially (grows outwards)

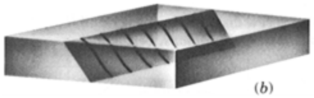
Observation of Dislocations

• Dislocations have been observed by the Transition Electron Microscope (TEM)

Observation of individual dislocations in thin foil. *(a)* Planar arrays of dislocations in *18Cr-8Ni stainless steels (b)* diagram showing position of dislocations on the guide plane in the foil.



Each disl^n lies along a particular plane and extends from the top to the bottom of the foil



Observation of Dislocations

Due to dislocations interaction similar dislocations will pile-up at barriers on SLIP planes (grain boundaries, precipitates) and cause stress concentrations.

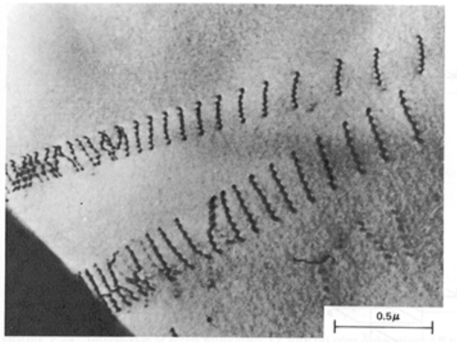


FIGURE 2.22 Dislocation pileups on two systems against a grain boundary in 309 stainless steel ($\gamma = 35$ mJ/m^2). (Courtesy of Anthony Thompson, Carnegie-Mellon

Can we observe the SLIP step in a light optical microscope (LOM)?

Dislocation Multiplication

In order to see slip step under a LOM, it requires ~ 10^4 dislocations in order to 1μm size.

➔ Requires many disl^n !

Do we have All originally present in crystal? ……!
new dislocations are created during deformation

Disl^n density (cm of disl^n/cm^2) increases from

10^4 - 10^5 → 10^{11}-10^{12}
annealed cold-worked (heavily deformed)

A widely accepted mechanism for disl^n multiplication is **FRANK-READ** Source

- *Segment of disl^n is pinned (by other disl^n or ppts/foreign atoms) Shear stress causes bowing out of segment.*
- *Curves round on itself; eventually meets itself form Dislocation **LOOP** and Segment.*
- *LOOP moves out radially,*
- *Segment can produce another loop if maintained.*

Frank-Read source for dislocation multiplication

A-B is pinned segment

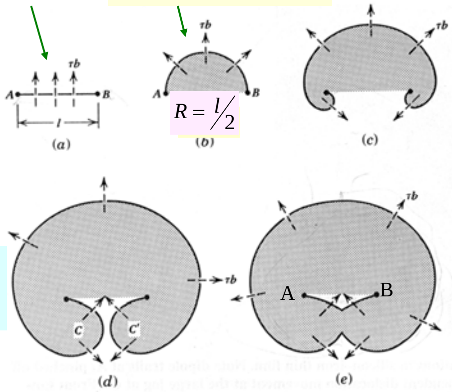
Shear stress causes bowing out of disl^n line between A and B

Instability reached when:

$$\tau \approx \frac{Gb}{l}$$

$$\tau \propto \frac{Gb}{R}$$

$$R = l/2$$

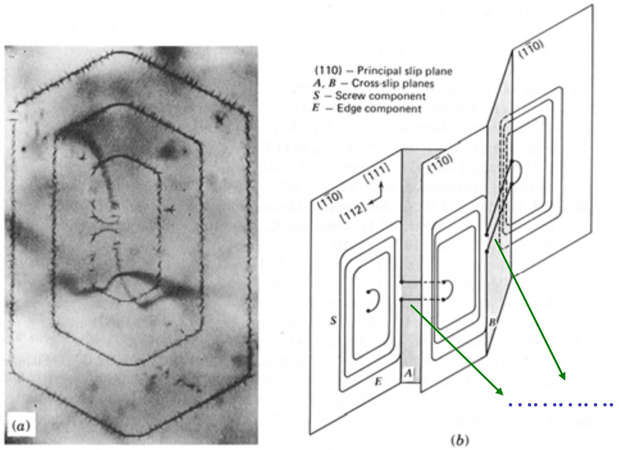


At C-C’ there are screw disl^{ns} of opposite sign. Annihilate each other.

A-B segment can produce another disl^n loop if shear stress is maintained. First loop moves out causing slip

- *LOOP moves out radially,*
- *Segment can produce another loop*

Frank-Read source for dislocation multiplication

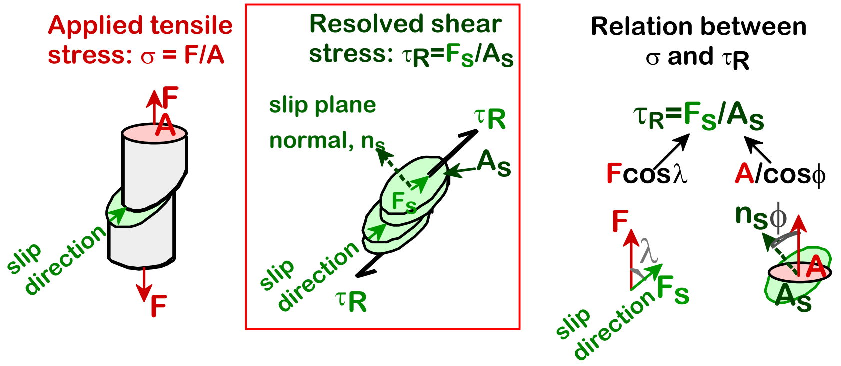


Silicon crystal

FIGURE 2.30 Frank-Read sources. (*a*) Photomicrograph in silicon crystal. (From Dash;[24] reprinted with permission of General Electric Co.) (*b*) Dislocation multiplication by double cross-slip mechanism. (From Low and Guard;[26] reprinted with permission from Low, *Acta Met.* 7 (1959), Pergamon Press, Elmsford, NY.)

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

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

magnitude depends on applied stress, as well as its orientation with respect to both the slip plane *and* slip direction

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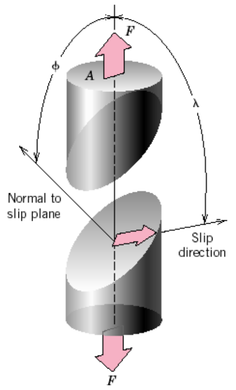
SLIP IN SINGLE CRYSTAL

- So, even if an applied stress is purely tensile, there are shear components to it in directions at all but the parallel and perpendicular directions

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

(often λ and $\phi \neq 90^o$ i.e. slip direction, slip plane normal and tensile axis are not usually in same plane).

Several slip systems exist in a crystal. τ_R varies depending on ϕ and λ. System with maximum value of τ_R is one on which slip is ……………..



$$\tau_{R(Max)} = \sigma(\cos\lambda\cos\phi)_{Max}$$

SLIP IN SINGLE CRYSTAL

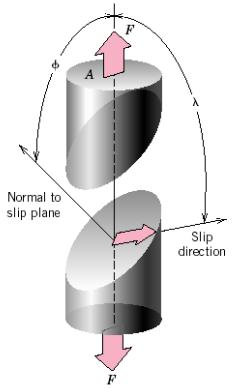
When σ sufficiently high, τ_R reaches τ_{CRSS} (critical resolved shear stress – this is the minimum stress that will cause slip to start) and then slip starts; i.e. yielding begins in that crystal.

$$\sigma_y = \frac{\tau_{CRSS}}{(\cos\lambda\cos\phi)_{\max}}$$

Maximum value of ($\cos\lambda \times \cos\phi$) is 0.5 so therefore:

$$\sigma_y = 2\tau_{CRSS}$$

Other slip systems may then start to operate (especially as the crystal rotates towards tensile axis)



CRITICAL RESOLVED SHEAR STRESS

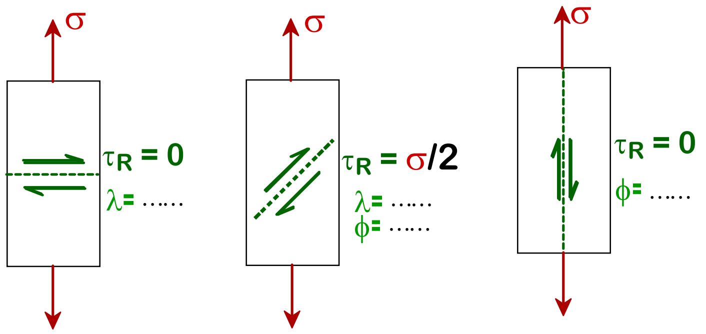
- Condition for dislocation motion: $\tau_R > \tau_{CRSS}$

typically

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

- Crystal orientation can make it easy or hard to move disl.

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



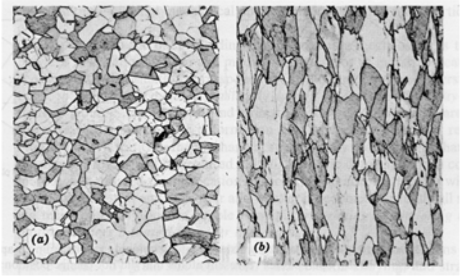
DISL. MOTION IN POLYCRYSTALS

- Slip planes & directions 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.
- As grains do not split from each other during deformation, they must deform together. Accommodate each other's shape change.
- Puts CONSTRAINT onto deformation. (grain can only change shape if neighbours also undergo some complementary shape change).
- **Higher** stress is required.

copper 173X

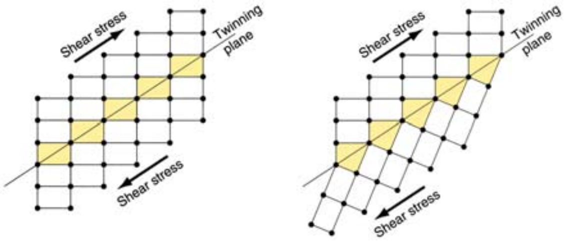
DISL. MOTION IN POLYCRYSTALS

- During deformation, coherency is maintained at grain boundaries
  - As mentioned before, grain boundaries do not rip apart, rather they remain together during deformation.
- This causes a level of constraint in the grains, as each grain's shape is formed by the shape of its adjacent neighbors.
  - Most prevalent is the fact that grains **will elongate** along the direction of deformation



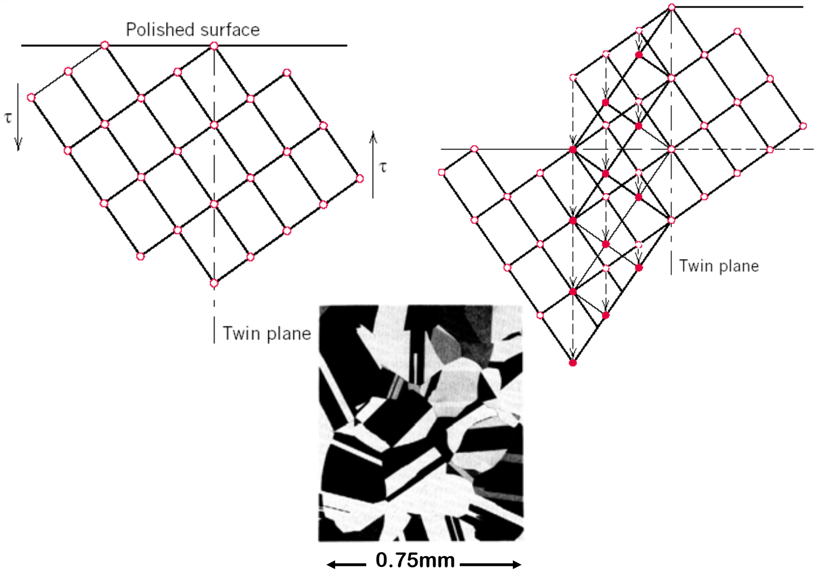
Twinning

A second mechanism of plastic deformation in which atoms on one side of a plane (called the *twinning plane*) are shifted to form a mirror image of the other side by the effect of a shear force.



Twinning, involving the formation of an atomic mirror image (i.e., a "twin") on the opposite side of the twinning plane: (a) before, and (b) after twinning

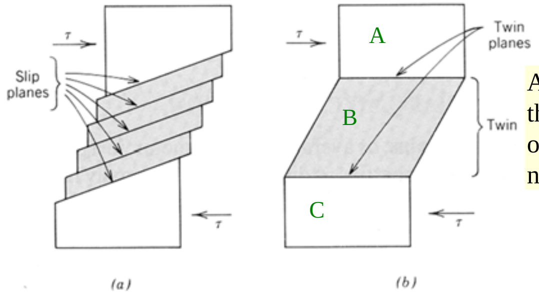
Twinning



Twinning

- Displacement magnitude in the twin region is proportional to the atom’s distance from the twin plane
- takes place along defined planes and directions depending upon the system.
  - *Ex: BCC twinning occurs on the (112)[111] system*

All parts have same crystal orientation



A and C have the same crystal orientation, but not B.

displacements take place in exact atomic spacings

atomic displacement is less than interatomic spacing

Twinning

- Properties of Twinning
  - occurs in metals with BCC or HCP crystal structure
    - occurs at low temperatures and **high** rates of shear loading (shock loading)
    - conditions in which there are few present slip systems (restricting the possibility of slip)
  - ………. amount of deformation when compared with slip.

Next time:
Strengthening Mechanisms