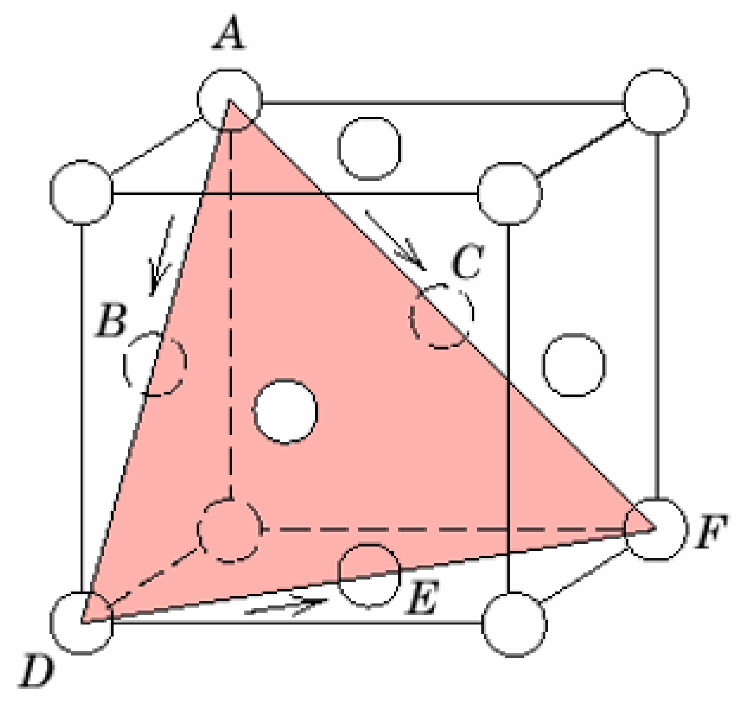
Plastic deformation of Single crystals by Slip and Twinning

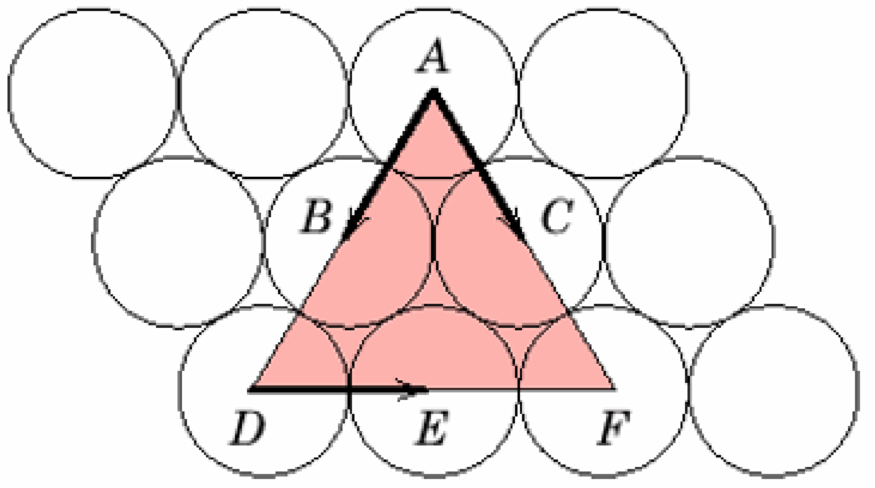
- The plastic deformation within a single crystal occurs through a permanent displacement of one plane of atoms over an adjacent plane. The net displacement effect is something like that by which a deck of playing cards can be distorted by sliding one card over another.
- Plastic deformation takes place most readily in the direction of the planes having the highest atomic density and greatest distance between similar planes.
- Plastic deformation takes place most readily in the direction of the planes having the highest atomic density and greatest distance between similar parallel planes.

In BCC metals have six planes with moderate atomic density and FCC metals have only four, in the latter structures these planes are considerably more dense. Thus face centered cubic metals tend to be more ductile than those having BCC structures.

Since hexagonal lattices have only two planes of maximum atomic density, although they can slip readily in three directions in each plane they are less ductile than either of the cubic structures.

BCC and FCC crystals have more slip systems as compared to HCP, there are more ways for dislocation to propagate ⇒ FCC and BCC crystals are more ductile than HCP crystals.





FCC

Close packed plane: {111} = 4/unit cell

Close packed direction: <110> = 3/ slip plane

4 x 3 = 12 slip systems

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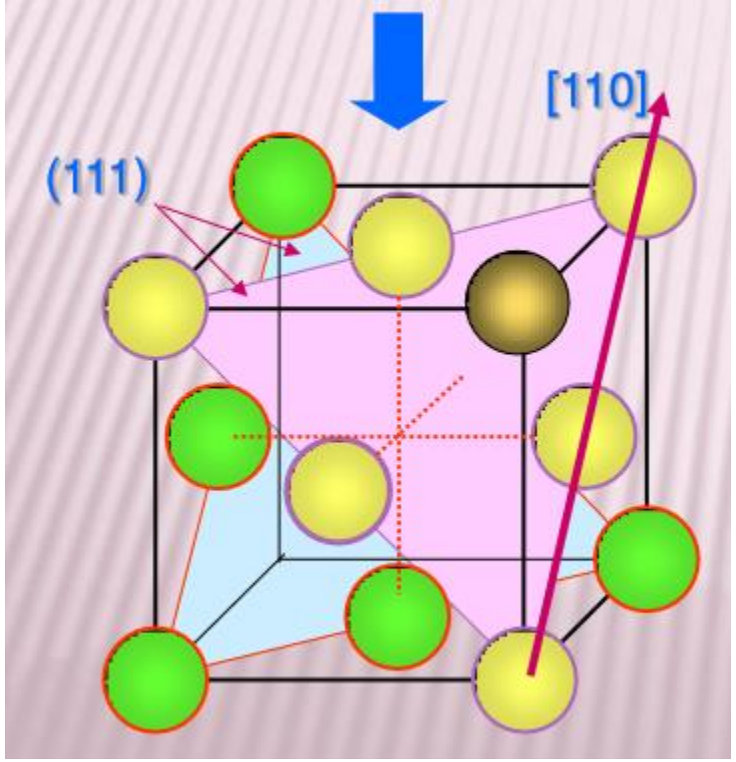
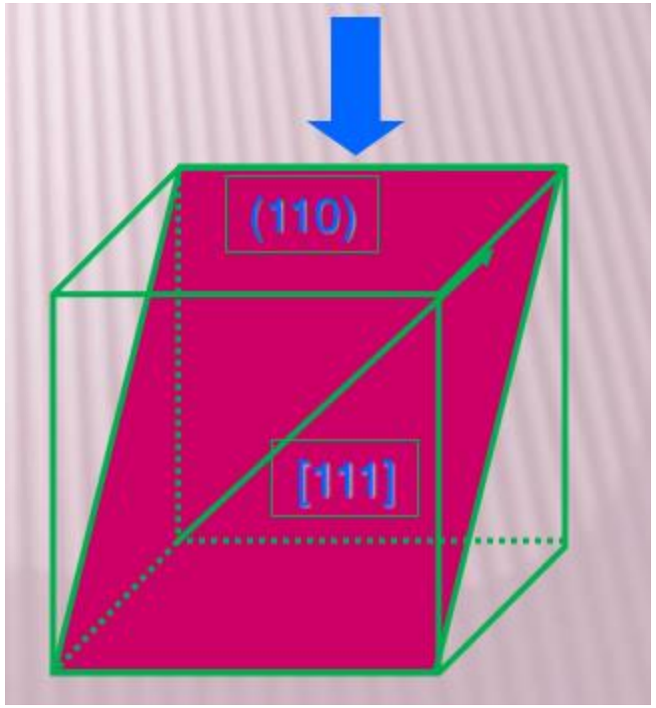


BCC

Close packed plane: {110} = 6/ unit cell

Close packed direction: <111> = 2/ slip plane

6 x 2 = 12 slip systems



Mechanism of Plastic deformation:

Plastic deformation of a single crystal occurs either by (a) Slip or by (b) Twinning

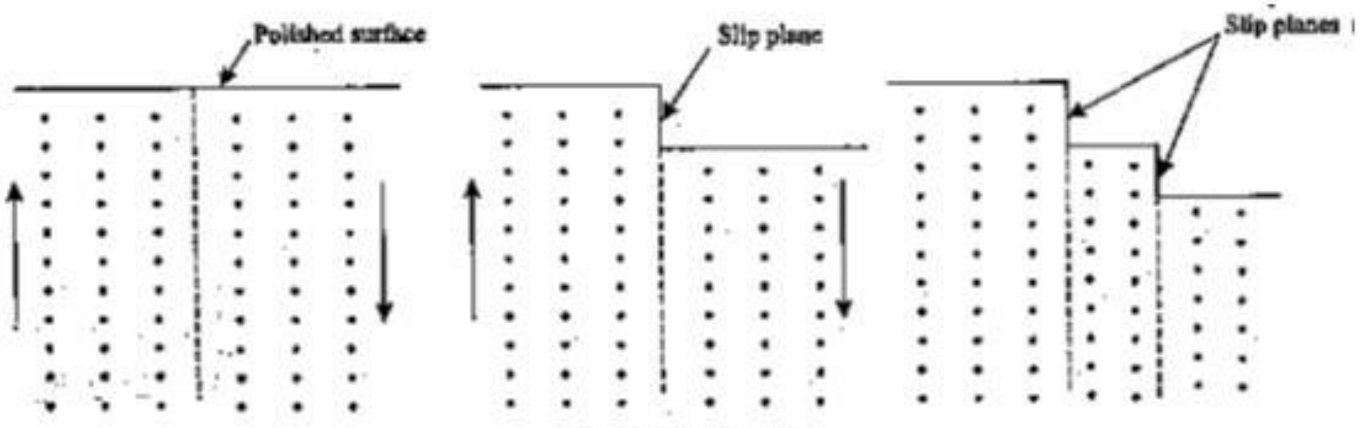
Deformation by slip:

Slip is that mechanism of deformation wherein one part of the crystal moves, glides or slips over another part along certain planes known as slip planes.

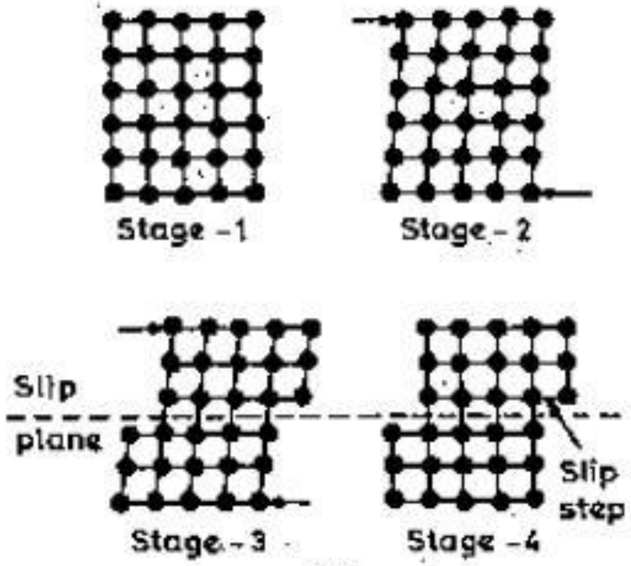
Generally, the slip plane is the plane of greatest atomic density and the slip direction is the closest packed direction within the slip plane.

- Plastic deformation, involves motion of dislocations. There are two prominent mechanisms of plastic deformation, namely ***slip*** and ***twinning***.
- Slip is the prominent mechanism of plastic deformation in metals. It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes.
- It is analogous to a deck of cards when it is pushed from one end. Slip occurs when shear stress applied exceeds a critical value. During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Steps observable under microscope as straight lines are called slip lines.

Deformation by Slip:



Slip in a single crystal



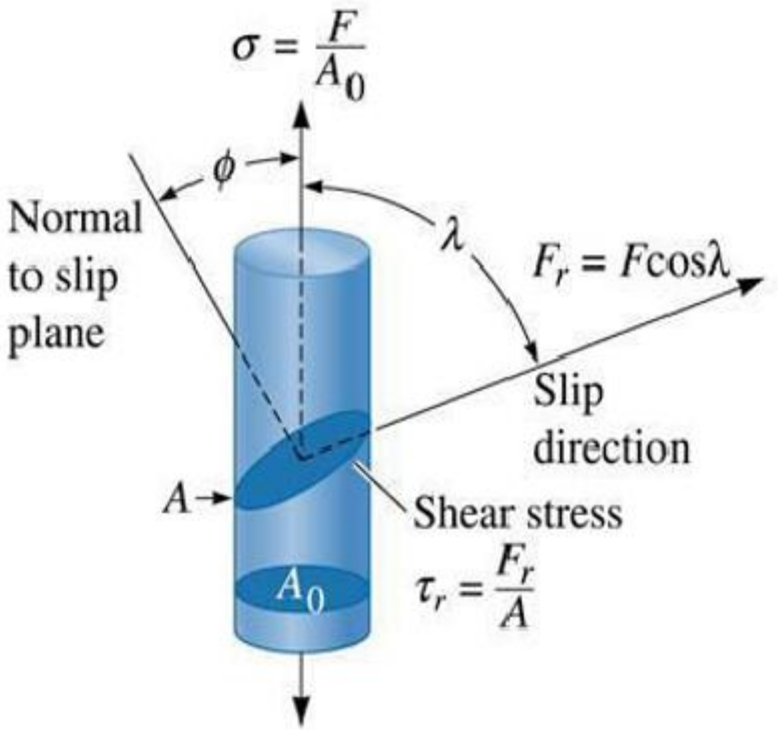
(a)

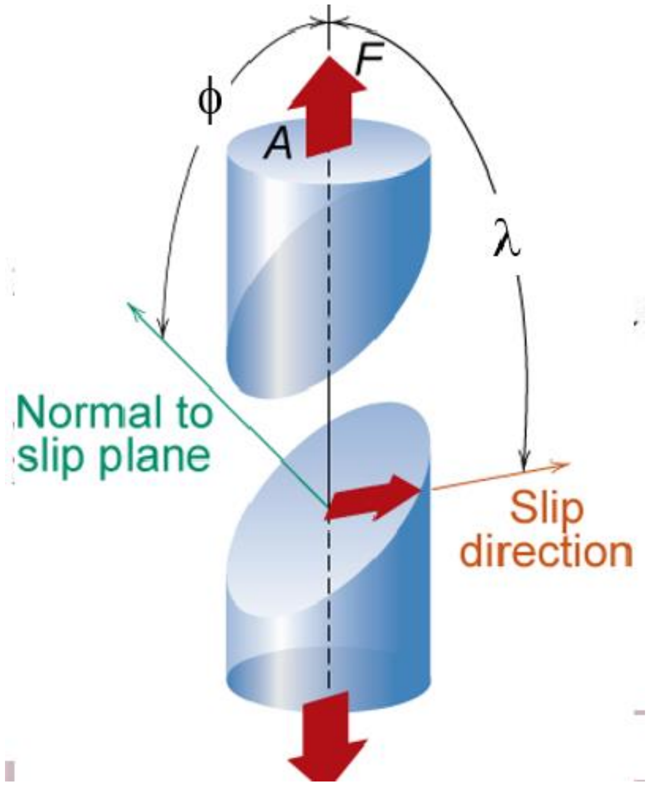
- Slip occurs most readily in specific directions (slip directions) on certain crystallographic planes. This is due to limitations imposed by the fact that single crystal remains homogeneous after deformation.
- Generally slip plane is the plane of greatest atomic density, and the slip direction is the close packed direction within the slip plane. It turns out that the planes of the highest atomic density are the most widely spaced planes, while the close packed directions have the smallest translation distance.
- Feasible combination of a slip plane together with a slip direction is considered as a slip system.

Critical Resolved Shear Stress for Slip

- All metals of similar crystal structure slip on the same crystallographic planes.
- Slip occurs when the shear stress resolved along these planes reaches a certain value is the critical resolved shear stress. This is a property of the material and does not depend upon the structure.
- The value of the critical resolved shear stress depends on composition and temperature.

- ➢ Besides being a function of critical stress, the force required to produce slip also depends upon the
- (1) Angle between the slip plane and the direction of force (ϕ is the angle between the direction of force and the normal to the slip plane)
- (2) Angle ƛ between the slip direction and the direction of force.



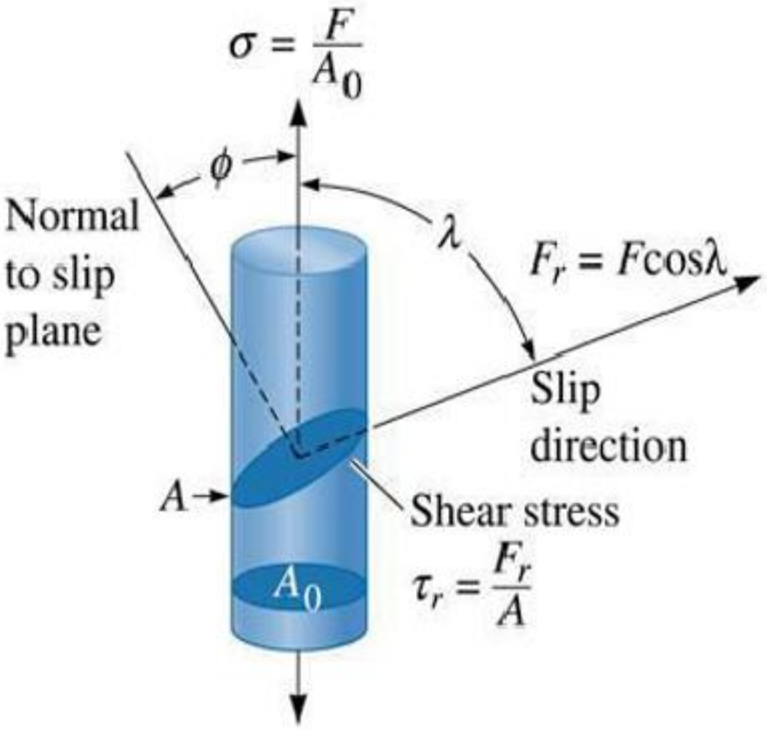


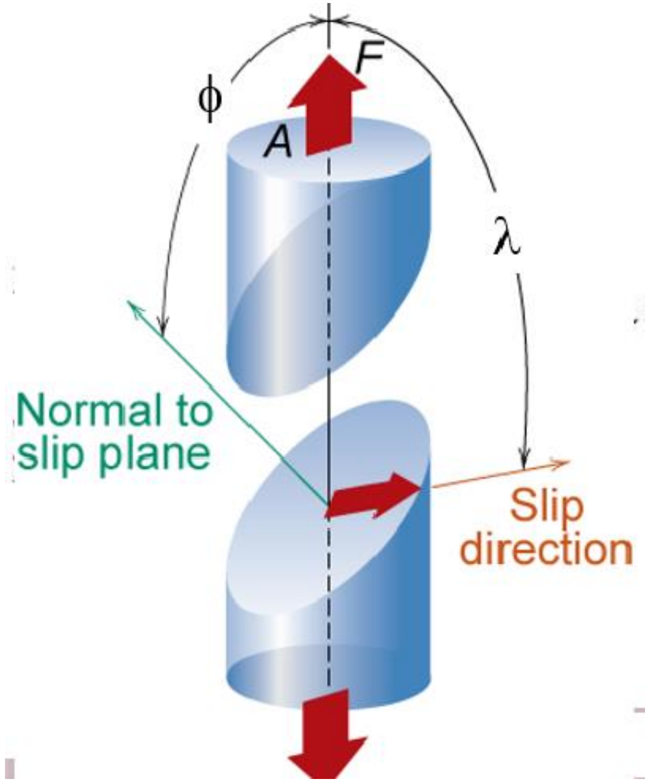
Consider a cylindrical shaped single crystal subjected to axial tensile load.

Where A_0 is the cross sectional area perpendicular to the direction of the tensile force F.

The area of the slip plane inclined at an angle ϕ will be $A/\cos\phi$ and the component of the axial load acting in the slip plane in the slip direction is $F\cos\lambda$.

Therefore the critical resolved shear stress is given by,





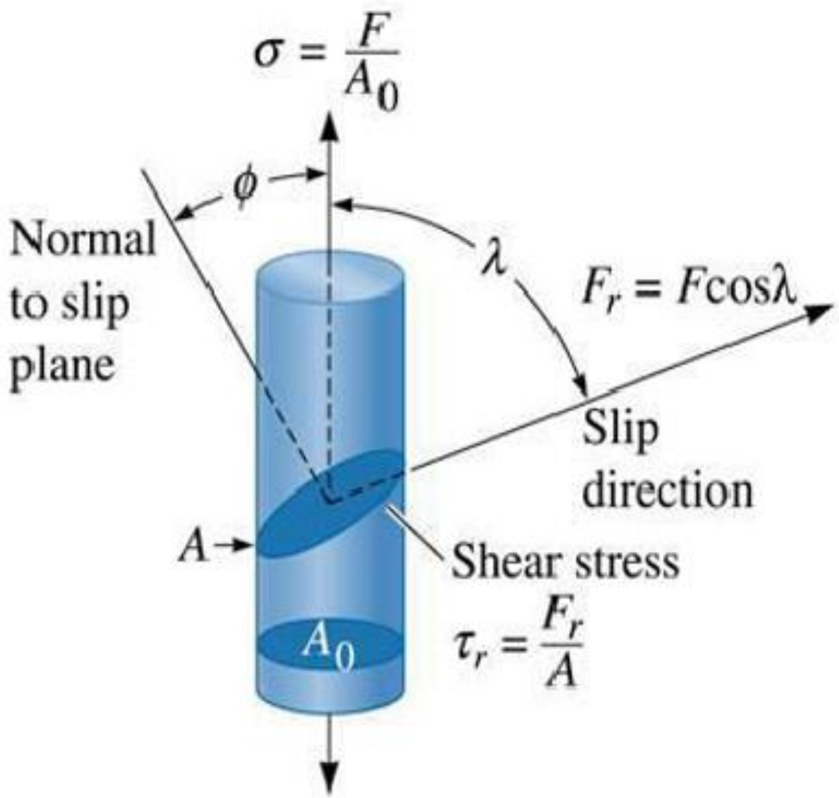
$$\tau_{cr} = \frac{F\cos\lambda}{A/\cos\phi} = \frac{F}{A}\cos\lambda\cos\phi$$

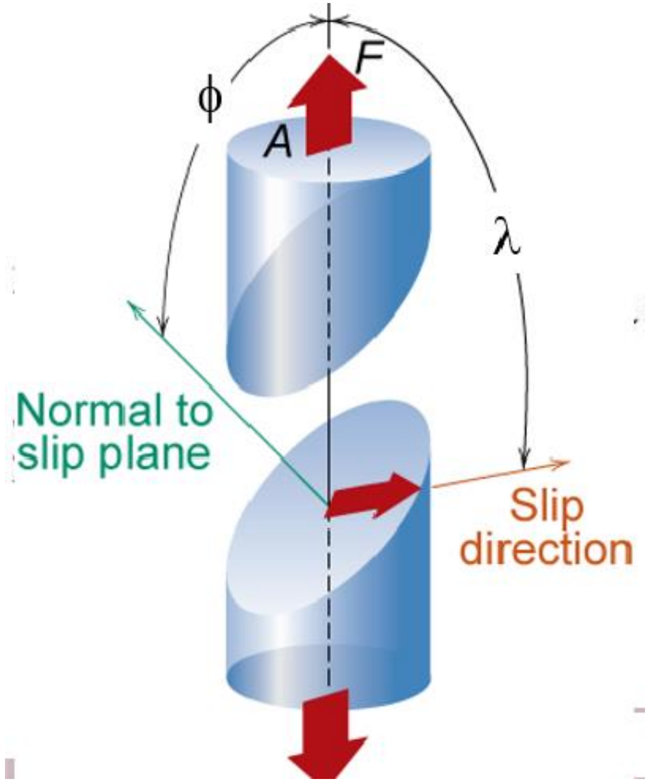
$$\tau_{cr} = \sigma\cos\lambda\cos\phi$$

Critical Resolved Shear Stress for Slip

$$\boxed{\tau_{cr} = \sigma \cos\lambda \cos\phi}$$

$$\boxed{\tau_{cr} = \sigma_{ys}/2}$$





where F – external load applied,

A_0 – cross-sectional area over which the load applied

A – Area of the slip plane

λ – angle between slip direction and tensile axis,

$\o$ – angle between normal to the slip plane and the tensile axis

m – Schmid factor.

- Consider slip in a single crystal:
- Slip occurs (crystal deform) by shear on the plane with the highest resolved shear stress

$$\tau_{cr} = \sigma \cos\lambda \cos\phi$$

$$\tau_{cr} = \frac{F\cos\lambda}{A/\cos\phi} = \frac{F}{A}\cos\lambda\cos\phi$$

- $F \cos\lambda$ is the shear force in the slip direction
- The minimum shear stress required for slip (yield) in single crystal to occur is when $\Phi = \lambda = 45^o$ and is equal to:

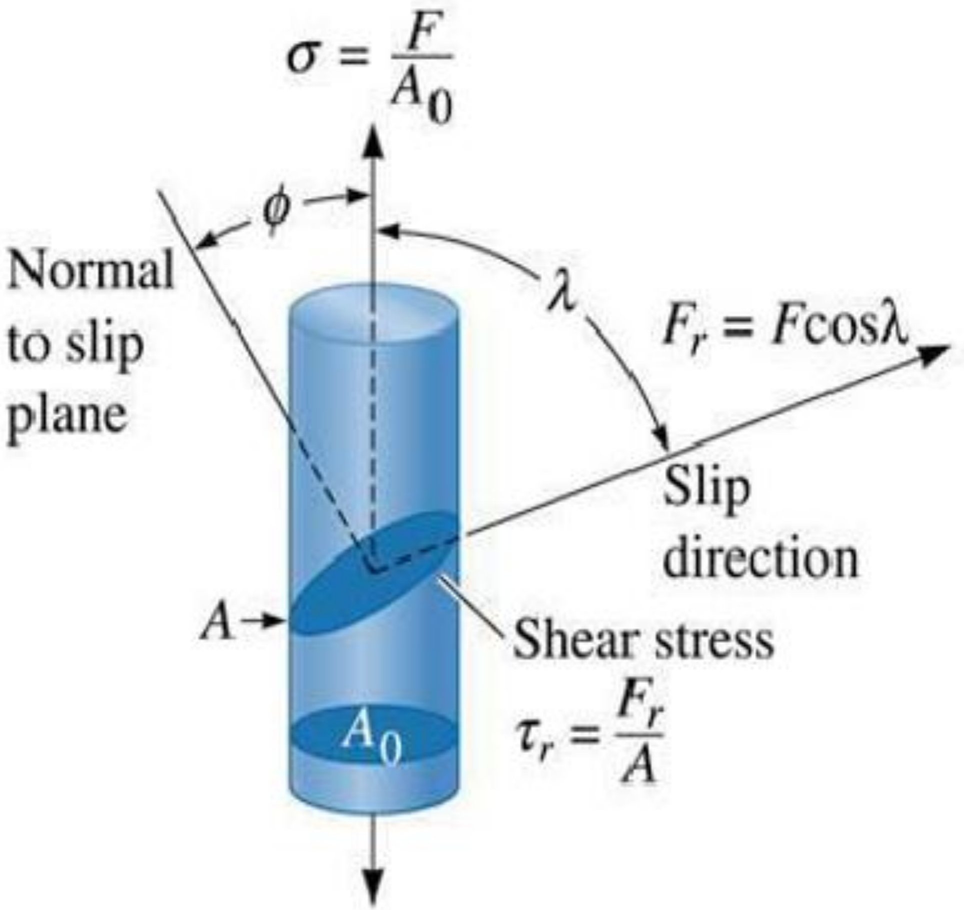
$$\tau_{cr} = \sigma_{ys}/2$$

$$\tau_{cr} = \frac{F\cos\lambda}{A/\cos\phi} = \frac{F}{A}\cos\lambda\cos\phi$$

Shear stress is maximum for the condition where $\lambda = ø = 45$.

$$\tau_{cr} = \sigma_{ys}/2$$

- If either of the angles are equal to 90 ,
- Resolved shear stress will be zero, and thus no slip occurs.
- If the conditions are such that either of the angles is close to 90 ,
  crystal will tend to fracture rather than slip.

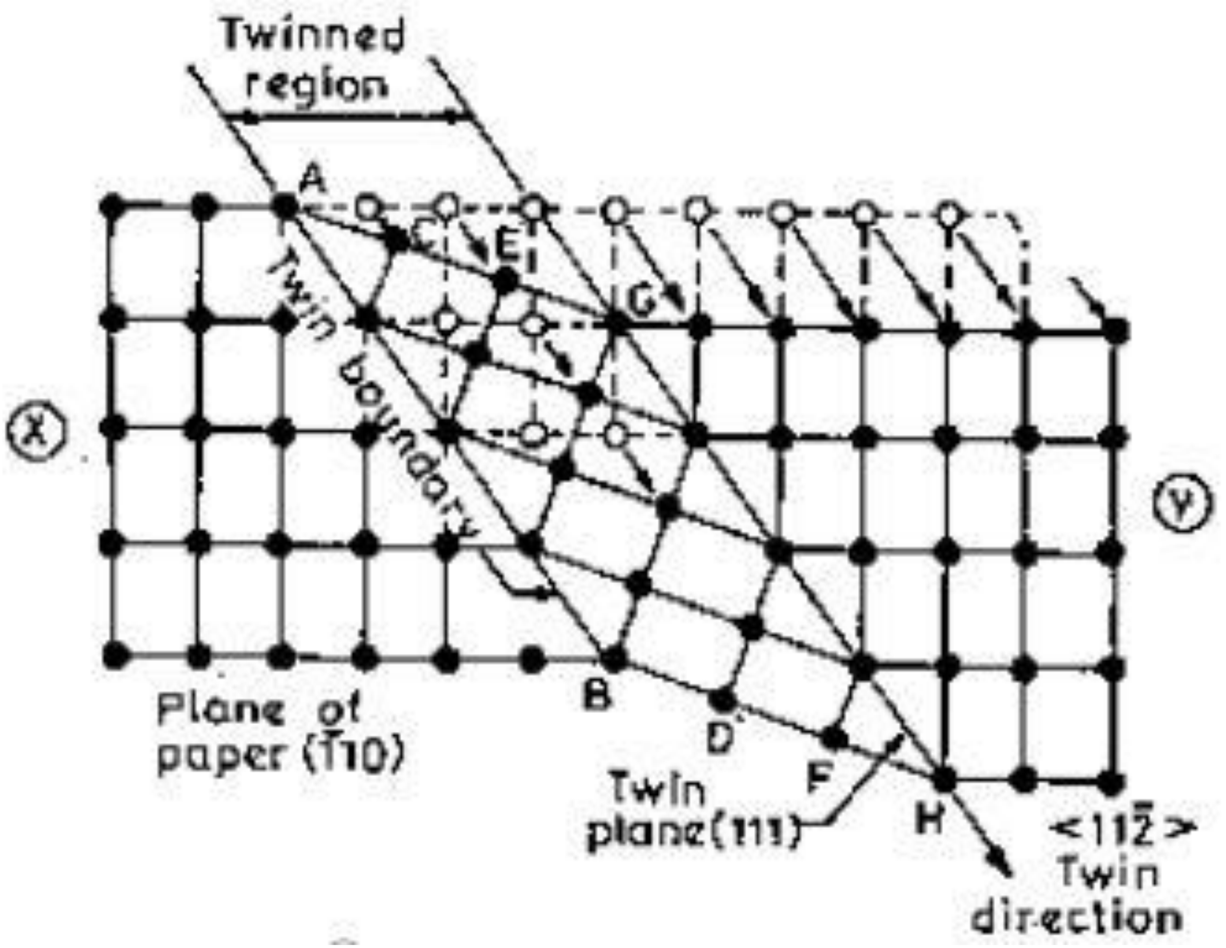


- In a single crystal, plastic deformation is accomplished by the process called slip, and sometimes by twinning. The extent of slip depends on many factors including external load and the corresponding value of shear stress produced by it, the geometry of crystal structure, and the orientation of active slip planes with the direction of shearing stresses generated.

Deformation by Twinning

The second important mechanism of plastic deformation is twinning. It results when a portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way. The twinned portion of the crystal is a mirror image of the parent crystal. The plane of symmetry is called twinning plane.

Each atom in the twinned region moves by a homogeneous shear a distance proportional to its distance from the twin plane. The lattice strains involved in twinning are small, usually in the order of fraction (few) of inter-atomic distance, thus resulting in very small gross plastic deformation.



- Twinning also occurs in a definite direction on a specific plane for each crystal structure. However, it is not known if there exists resolved shear stress for twinning.
- Twinning generally occurs when slip is restricted, because the stress necessary for twinning is usually higher than that for slip. Thus, some HCP metals with limited number of slip systems may preferably twin.
- Also, BCC metals twin at low temperatures because slip is difficult. Of course, twinning and slip may occur sequentially or even concurrently in some cases.

Thank You