02D2_Plasticity: Dislocation Mechanics - Impediments to the Movement of Dislocations

Topics:

•Force on a dislocation

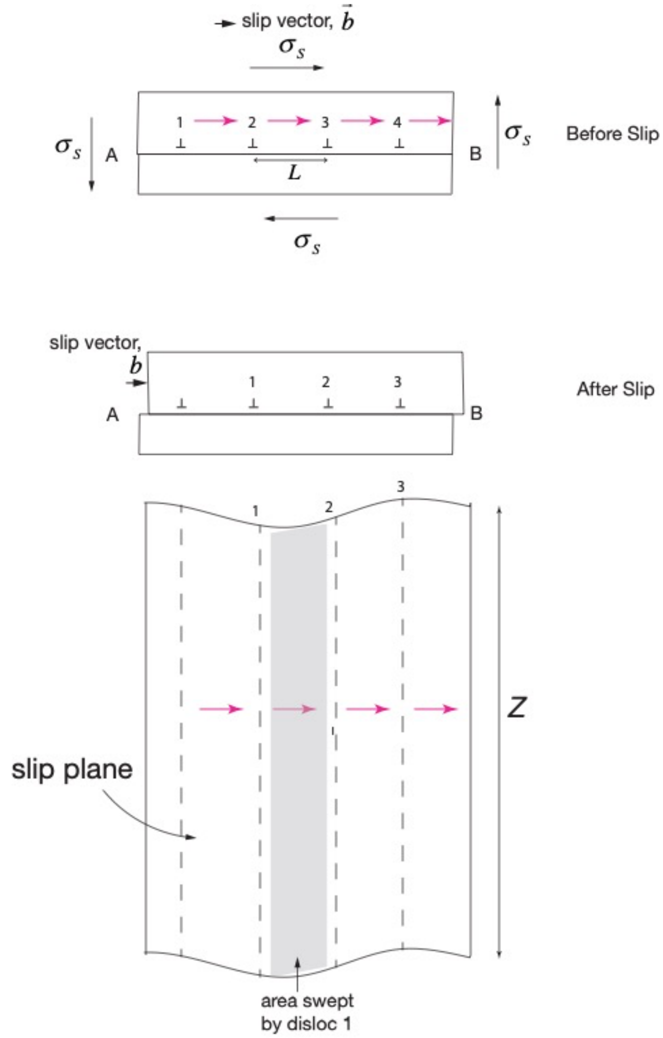
•Curved dislocations and their origins

•Orowan stress: Stress required for dislocations to overcome hard particles without having to shear them

•Strain hardening due to pinning with hard particles

•Metallurgical processing - second phases and heat treatments

Force on a Dislocation



The Concept

Equate the local work done by the dislocation when it moves to the work done by the external stress (force x displacement).

The answer will be as follows

$$F = \sigma b \qquad \text{(D2.1)}$$

Notes:
•What is the direction of the force: the force acts normal to the length vector of the dislocation line, because the dislocation must move normal to itself to increase the slip on the slip-plane, that is, to produce external displacement which then allows the applied stress to do work on the system

•Units of (D2.1): stress is force per unit area, times b which is length, therefore F has units of force per unit length.

Proof:

Local work done by the dislocation when it moves a distance, L , will be equal to $F.Z.L$.

This quantity must be equal to the work done by the applied stress on the system, which will be,
(stress x area)x displacement $= \sigma ZLb$

$$\sigma ZLb = FZL$$
$$F = \sigma b \qquad \text{(D2.1)}$$

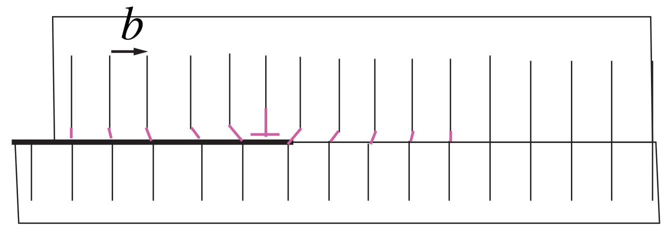
The direction of the force must be normal to the line vector of the dislocation.

Energy of a Dislocation

•Units for the energy of the dislocation would be energy per unit length, U units are Joules per m.

The answer is

$$U = \frac{Gb^2}{2} \qquad \text{(D2.2)}$$

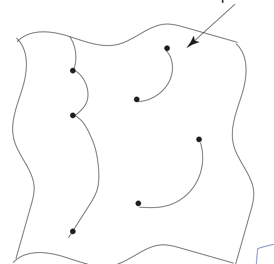


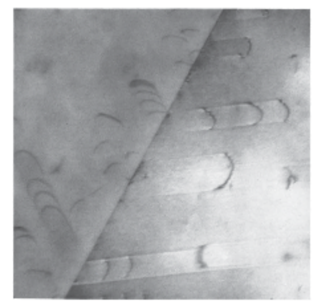
Dislocation core embodies a strain energy.
In the above equation G represents the stiffness of the bonds as a shear modulus. G has units of stress which is also energy per unit volume.

The volume of the core of the dislocation is going to scale as the area of the core of the dislocation where the strain resides, which must scale as b^2; thus the volume per unit length of the dislocation is also b^2.

Hence the nature of Eq. (D2.2)

Curved Sections in Dislocations





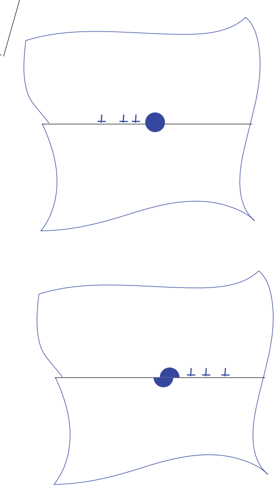
The concept is that if the movement of dislocations is impeded, as for example by a hard particle in its path, then it will move forward with curved shape.

•The curved line of dislocation that is pinned between two points will have the shape of a circle (for the reasons discussed just above).

•The radius of curvature of the dislocation bowing out will depend on the force exerted by the applied stress (σb) and the distance between the pinning points.

Relating the Applied stress to the curvature in the dislocation?

$$\sigma = \frac{Gb}{2R} \qquad \text{(D2.3)}$$

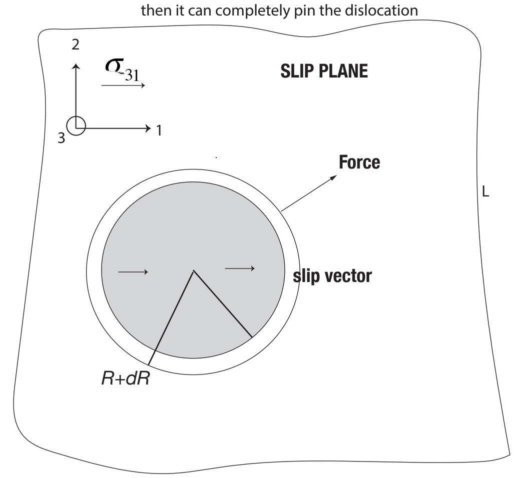


If the particle is difficult to shear line a ceramic or a hard metal, then it can completely pin the dislocation

where R is the radius of curvature of the circle.

The approach is to consider a circular dislocation loop which is held open by an applied stress σ to a radius R, where the applied stress exerts a outward force on the dislocation line equal to σb per unit length of the dislocation This force is perpendicular to the line of the dislocation, that is an outward force on the loop.

Now apply the virtual work principle*. We perturb the circle to extend it slightly; in this way the applied stress does a small amount of work equal to the total force on the circle multiplied by the expansion of the circle (dR).



This work is now stored as the increased energy of the dislocation because it is now of slightly greater total length.

Equating these two quantities leads to Eq. (D2.3).

*In the virtual work principle, we consider a closed system, so that if the system configuration changes the total change in energy is zero. In the present case, for example, the work done in expanding the loop is stored as an increment in the line energy of the dislocation loop.