#14: The Orowan Stress

From the previous lecture

•A curved dislocation has an arc (of a line), even though its slip vector is constant throughout its length.

•Since an applied stress exerts a force that is normal to the length vector of the dislocation and lies in the glide plane defined by the line vector and the slip vector, the dislocation curves out into a shape of a circle.

•The arc of the circle is pinned at two points. These are defined by cross slip where the screw section of the dislocation cross-slips into an adjacent slip plane in the same family of the slip system (as the plane containing the full curved dislocation.

•Since only a section of a curved dislocation can have a pure "screw" character, it gets pinned what the screw segment cross-slips into the adjacent plane.

Today's Topics

•We will discuss again - from the notes of the last lecture - the equation that related the force on a curved dislocation to the applied stress and the radius curvature of its shape.

•The above derivation will be generalized to any dislocation that is pinned between two points.

•Dislocation multiplication

•The mechanisms of pinning will be discussed: (i) cross slip, (ii) grain boundaries, and (iii) hard particles in the slip plane.

•It will been that there is a limit to the pinning event: when the radius of curvature becomes equal to one half the distance between the pinning points - this is the condition of maximum curvature that the dislocation line can sustain.

•Orowan Stress and its application to the engineering design of metals that can be "hardened" in different ways.

Radius of curvature and the applied stress to a dislocation in the form of a circular arc

$$\sigma = \frac{Gb}{2R}$$

•R is the radius of curvature of the circular arc

•b is the slip vector.

Again we emphasize that the force on a dislocation always acts normal to the line vector of the dislocation. (Please understand the reason for this statement)

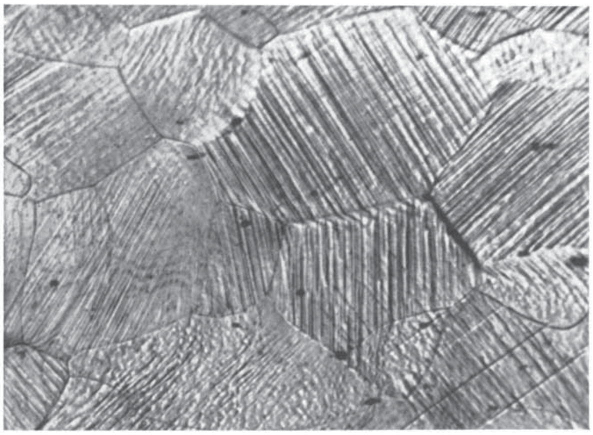
Strengthening Mechanisms, i.e. how to increase the Yield Stress of metals.

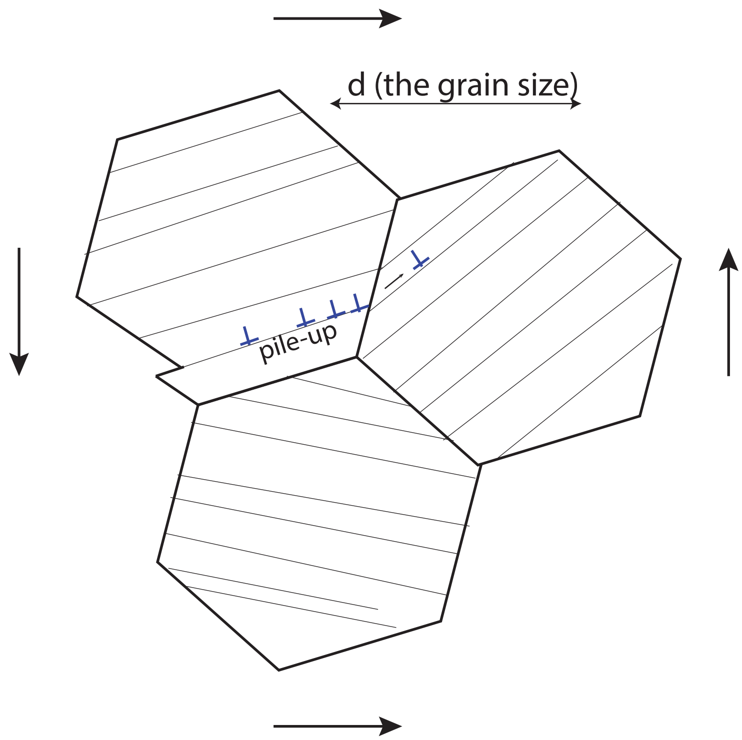
•The concept here is to prevent the dislocations from moving through the crystal under an applied stress.

•What are the mechanisms for "pinning" the dislocations.

Grain boundaries in a polycrystal obstructs dislocation movement

The length scale in the figures below is: (i) the grain size about 10-100 μm. The distance between the slip planes is from 1 to 10 μm.





$$\sigma_{Yield} = \sigma_o + \frac{k_{HP}}{d^{1/2}}$$

Hall-Petch Equation
for grain size dependence of the yeild stress

In the above equation, k_{HP} is called the Hall Petch parameter, and σ_o is the yield stress of single crystals ($d \rightarrow \infty$).

Hard Particles (particles of a second phase) in the slip plane can pin dislocations

Notes:

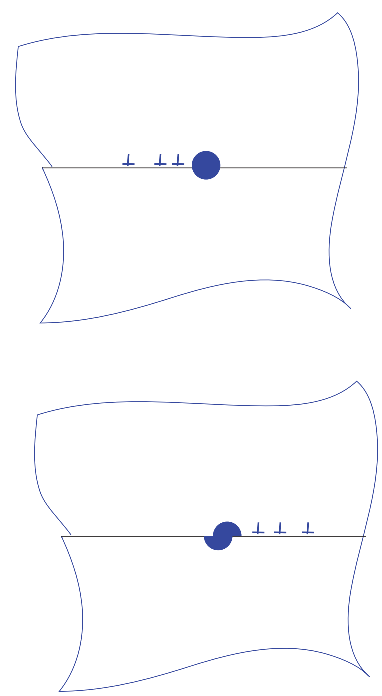
•As the dislocation sweeps to the right is causes the upper crystal to slide by the slip vector (a lattice translation vector) relative to the lower part of the crystal.

•If a hard particle is placed in its path in the "glide plane" then the dislocation must either climb over the particle, or it must shear through the particle to move beyond.

•Climbing over the particle is unlikely because the dislocation must then move to new slip systems which is hard.

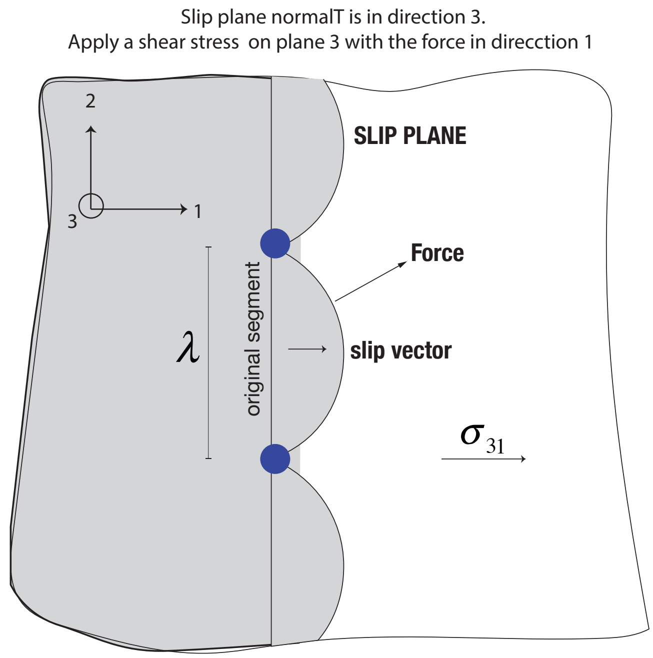
Therefore the dislocation is essentially immobilized at the particle unless the particle can be sheared.

These particles are precipitates produced by heat treatments, for example carbon compounds in steels, intermetallic of copper in aluminum, or particle so glass or ceramics.



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

Is there a threshold stress which if crossed allows the dislocation to move free?



$$\sigma = \frac{Gb}{2R}$$

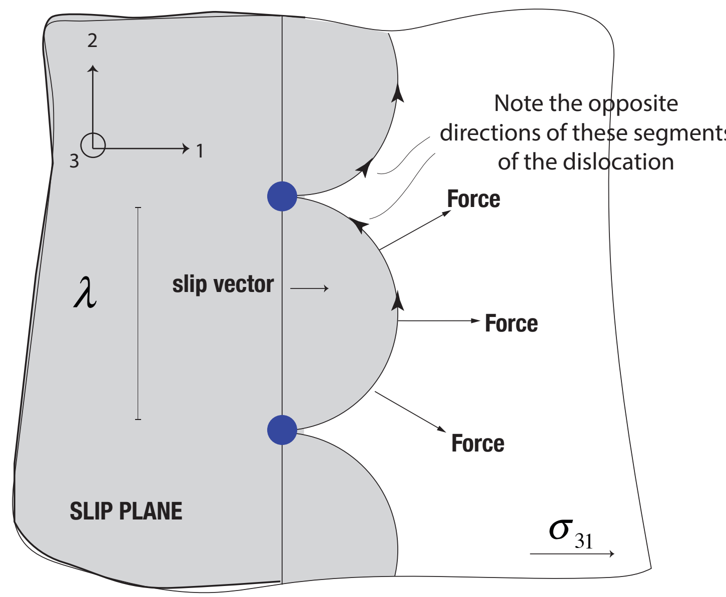
•Note that the yield stress is related to the minimum possible value for R.

•As the pinned segment of the dislocation bows out as a segment of a circle, its radius of curvature decreases as the applied stress is increased.

•However, the minimum value of $R = \frac{\lambda}{2}$.

•Beyond above the dislocation can no longer by held back by the particles no matter how strong the particles.

•The passing through of each dislocation leaves behind circles around the particle, which effectively makes the size of the particle bigger, and the spacing between the particles smaller.



•Since the yield stress depends on the pinned segment of the dislocation it becomes higher with plastic strain - known as strain hardening.

•The yield stress is now obtained from

$$\sigma = \frac{Gb}{2R} \text{ by setting } 2r = \lambda$$

$$\sigma_{OR} = \frac{Gb}{\lambda}$$

•Let us say we wish to achieve a yield stress that is 1% of the shear modulus G . It means that the microstructure should be designed such that

$$\frac{b}{\lambda} = \frac{1}{100}$$

Recall the b is the shortest lattice translation vector. Let us say about 0.2nm

Therefore the microstructure must be designed so that $b \rightarrow 20nm$.

NOTE THE NEED FOR NANOSCALE DESIGN OF THE MICROSTRUCTURE TO ACHIEVE 1% YIELD STRESS.

Please recall that while the Elastic Modulus of materials made with two "phases" somewhat follows the rule of mixtures, the yield stress depends on the nanoscale microstructure. Even 1 -5 vol% of a second phase can have a very large influence on the yield strength if the particle are very small and the distance between them is a few tens of nanometers.