02D1_Plasticity: Dislocation Mechanics: The geometry of strain related to the movement of dislocations

Topics:

(i) Dislocation Arrays

(ii) Strain when dislocations move

(iii) The stress required to move dislocations in a "pure" single crystal

What is meant by "pure" single crystal?

•It is a single crystal, not a polycrystal so that slip can occur across the entire cross section of the crystal without hindrance as is the case in polycrystals where crystal is obstructive by adjacent crystals

•There is little or no hindrance to "glide" of dislocations within their slip plane from impurities or hard particles.

(i) Dislocation Arrays

Dislocations exist in complicated geometries. The question is how do we simply the geometry and then analyze the relationship between the yield stress and the movement of dislocations.

The electron micrograph on the right illuminates the dislocation lines because the core of the dislocations are heavily strains and these strain scatter the electrons and create a contrast on the image plane.

•The dislocations appear to be a complex entanglement of lines. (Each line is one dislocation, or a section of it and has a given slip vector). The dislocations traverse from one slip plane to another slip plane in a different orientation leaving behind a segment pinned in one of the slip planes).

•There is a characteristic length scale associated with the spacing of the dislocations, which is about 1- 10 μ m, more frequently between 5-10 μ m. This is the length scale at which point the specimen size begins to influence the yield strength. Note the scatter in the yield strength data in the plot which implies a statistical effect of finding a dislocation within the sample.

Idealization of the geometry of dislocation arrays for quantitative analysis.

In this idealized form we have two parameters: (i) the distance between the dislocations on a given slip plane,

(ii) The vertical distance between the slip planes.

We call both quantities equal to

L

If all dislocations slide by a distance L then what would be the magnitude of the plastic strain:



$$\gamma_p = \frac{b}{L}$$

Now say the dislocations move by "n" quantum steps

Then the total distance each dislocation moves is

x = nL

Now the grand plastic strain is given by

$$\gamma_P = \frac{b}{L}n$$











10 µm

because the number of quantum events:

$$n = \frac{x}{L}$$
$$\gamma_P = \frac{bx}{L^2}$$

What is L^2 ?

It has units 1/(area). Therefore $\frac{1}{L^2}$ is the denstiy of dislocations, that is the number of dislocations per unit area.

 $\rho = \frac{1}{L^2}$ where ρ is called dislocation density.

So now we have a global equation that

 $\gamma_P = \rho bx \tag{1}$

Numerical assessment of Eq. (1)

Dislocation Density

Typical spacing, L, of dislocations is 1 - 10 μ m, that is the dislocation density $\rho = 10^{10} - 10^{12} \text{ m}^{-2}$

The Slip Vector

b is the interatomic spacing typically 0.1 to 0.2 nm

Distance that the dislocations move

x = 1 mm to 10 mm

How much plastic strain would occur if all dislocations moved by the above distance.





The above analysis discusses the strain produced when dislocations move.. now the question is the stress required to move the dislocations - this is what is the yield stress.

The yield stresses for single crystals without any impurities are very small, for example,

Yiela Stress of Single Crystals measured at 300K at a strain rate of 1e-04 per sec

(Recall that the ideal yield stress is expected to be 0.1*E, or 0.25*G

Crystal Class	! Metal	! Yield stress MPa	! A in Y S	! ctual ield tress/G
! FCC	! Al	!	0.5	2.00E-05
,	Cu		0.5	1.20E-05
: !	Au		0.5	2.00E-05
1	Ni		2	2.50E-05
: !	Ag		0.4	1.50E-05
: !	NaCl		1	6.60E-04
BCC	! Fe	!	15 [!]	1.80E-04
,	Nb		20	5.20E-04
!	Мо		70	5.60E-04
! HCP	! Cd	!	0.13	5.00E-05
1	Mg		0.5	2.80E-05
I	Zn		0.3	8.00E-06
! Notes:	!	! !	!	!
•Actual yield stress is commonly three to four orders of magnitude lower than the ideal yield stress				
•BCC crystals have a ten times or more higher yield stress than FCC crystals (why?)				
•Zinc polycrystals are brittle even though single crystals are soft and malleable (only three slip systems). However, FCC crystals are also malleable but not brittle.				

The strain field in the core of the dislocations is so large that even a small perturbation from the applied stress can cause it to move.

The message is that in single crystal where the dislocation movement is NOT impeded by adjacent crystals (as in a polycrystal) or by obstructions in the path of the dislocations, the stress to move the dislocations is very weak.

The strategy for increasing the yield strength is to "PIN" the dislocations.

This "pinning" of the dislocations is the key to creating engineering materials. We shall discuss different mechanisms for pinning the dislocations, the geometry of pinning and how this geometry can be translated into the engineering yield stress.