02C_Plasticity: Yield Stress in Engineering Materials

Topics:

(i) Guidance from the equation for the ideal shear stress

$$\sigma_Y^{ideal} = 0.25 \frac{b}{d} G$$

(2) Defects: length scale, the distance between slip planes.

$$\gamma_S = \frac{nb}{\Delta}$$

(3) A line Defect called "dislocation"

(4) Geometry of a dislocation

(5) many dislocations - an array of them: dislocation density.

(5) Dislocation Mechanics

- Force on a dislocation by an applied shear stress
- Strain when a dislocation moves.

To what extent is the Yield Strength of Engineering Materials guided by the Ideal Yield equation.

$$\sigma_Y^{ideal} = 0.25 \frac{b}{d} G \qquad (1)$$

•The yield strength always scales with the elastic modulus.

•The slip system with the lowest strength remains the one with the shortest slip vector, and the largest spacing betwen the slip planes.

How is the yield strength of engineering materials different from the ideal as in Eq. (1)?

$$\sigma_y \le 0.01G \qquad (2)$$

The map on the following page:

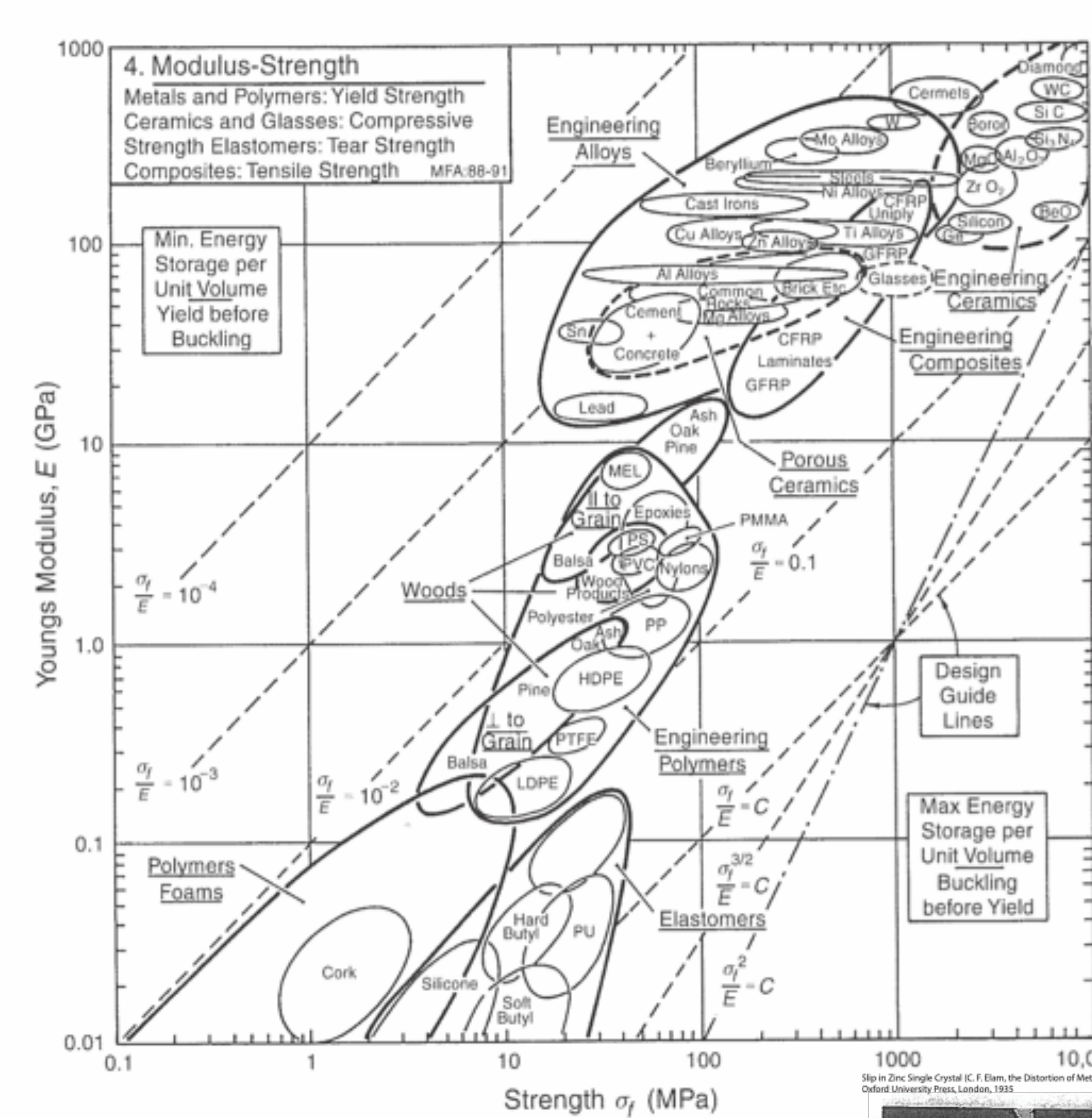
(i) It shows plots for the strength (which could be plastic deformation in metals or fracture in brittle materials) as a function of E (Youngs modulus) which is fine since E and G scale with each other.

(ii) The higher the modulus the higher the "strength"

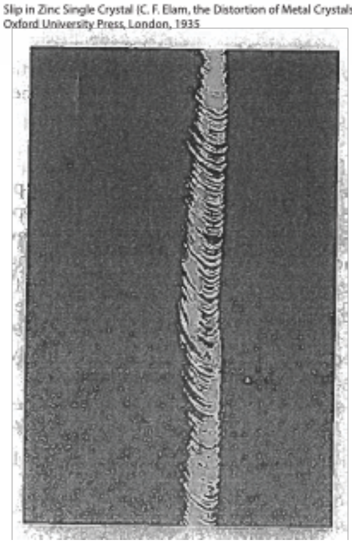
(iii) The dotted lines are contours for a constant value of $\frac{\sigma_f}{E} or \frac{\sigma_Y}{G}$

(iv)Therefore, 1% rule for yield strength would follow $\frac{\sigma_f}{E} or \frac{\sigma_Y}{G} = 10^{-2}$

(v) Metals are somewhat weaker that is $\frac{\sigma_f}{E} = 10^{-3}\,to\,10^{-2}$, while ceramic which fail by fracture do fit the 1% rule.



Slip in Zinc Single Crystal (C. F. Elam, the Distortion of Metal Crystals, Oxford University Press, London, 1935

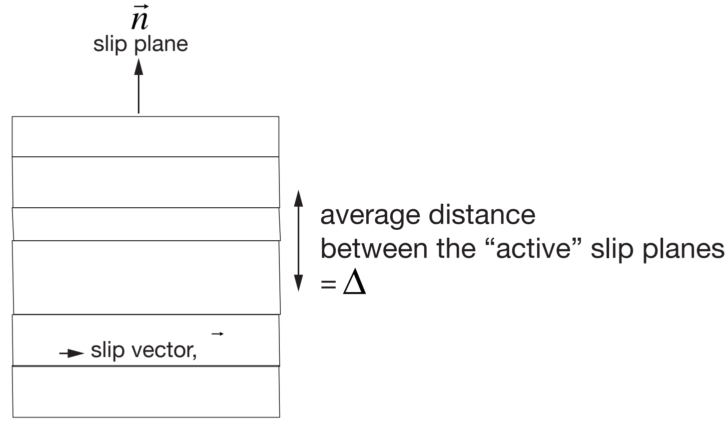


Why is the yield strength of Engineering Materials so much lower than the ideal value (keeping in mind that small scale specimens, typically smaller than 1 μm can approach the ideal yield or failure strength.

Let us consider the influence of length scale for slip on yield strength.

We note that slip planes have a typical spacing which from experiment varies from about 1 to 10 μm.

The geometrical description of plastic deformation by slip on slip planes is given by the actual distance between the slip planes (as seen in the deformation of the zinc single crystal) and some multiple of the slip vector $\vec{b}$ which is a lattice translation vector. Slip occurs by quantum jumps of $\vec{b}$ on the slip planes.



There the shear strain is related to the slip vector and the distance between the slip planes by

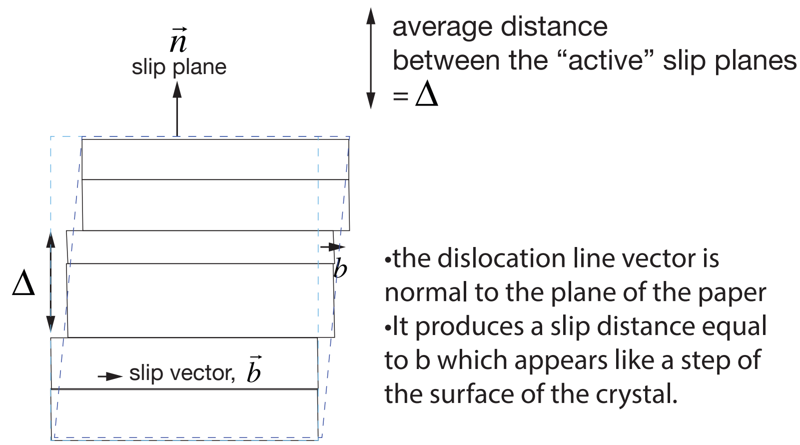
$$\gamma_S = \frac{nb}{\Delta}$$

"n" is the number of slip events on the slip plane (the figure at the bottom is not correct: "b" should be replaced by "nb")

Still have not answered the question:

(i) Why the very low yield stress?

(ii) What determines the magnitude of Δ.



The answer to these question lies in crystal defects that control the yield behavior of engineering materials.

In other words engineering materials have "defects" that control their properties.

This is infact generally true in the the study of the materials science of materials.

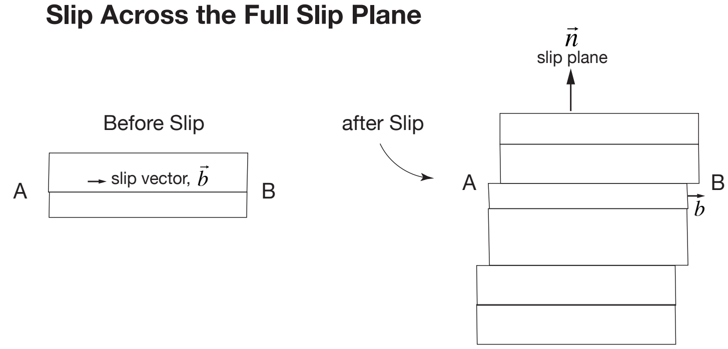
The defects that control yield strength of metals are called dislocations. They are line defects (one dimensional defect), like lines meandering through a crystal in many different ways, and these line defects have a specific slip vector which is called the Burgers Vector, $\vec{b}$, which is the shortest lattice translation vector in the crystal.

We now consider the crystallography of slip.

In the figure just above slip occurs fully across the slip plane without any constraint.

Now consider that slip occurs over a part of the slip plane as shown in the lower figure on the right.

Slip Across the Full Slip Plane



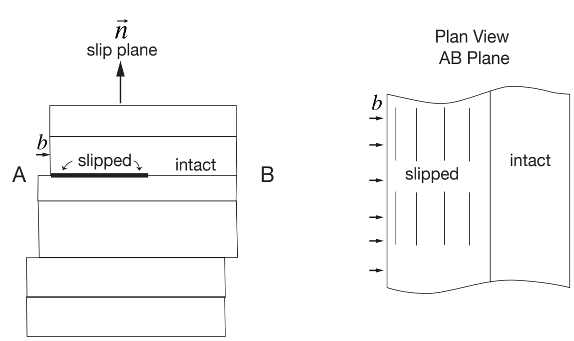
The "partial slip" is characterized by,

•A single slip vector

•The area of the slipped versus un-slipped portion of the slip plane.

The edge of boundary that defines the slipped and the unslipped region is a line.

Partial Slip

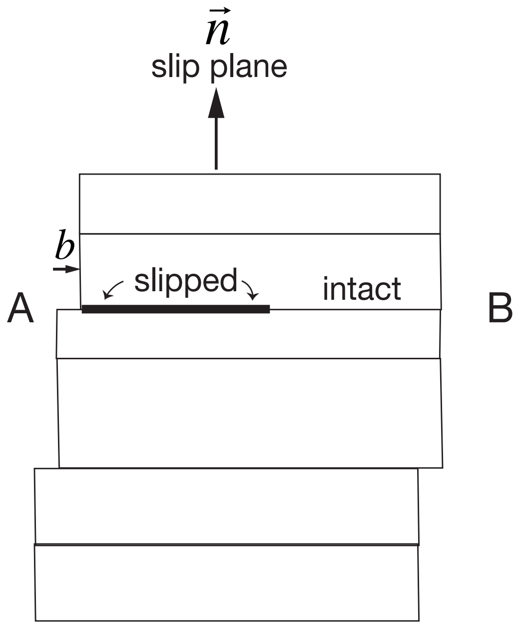


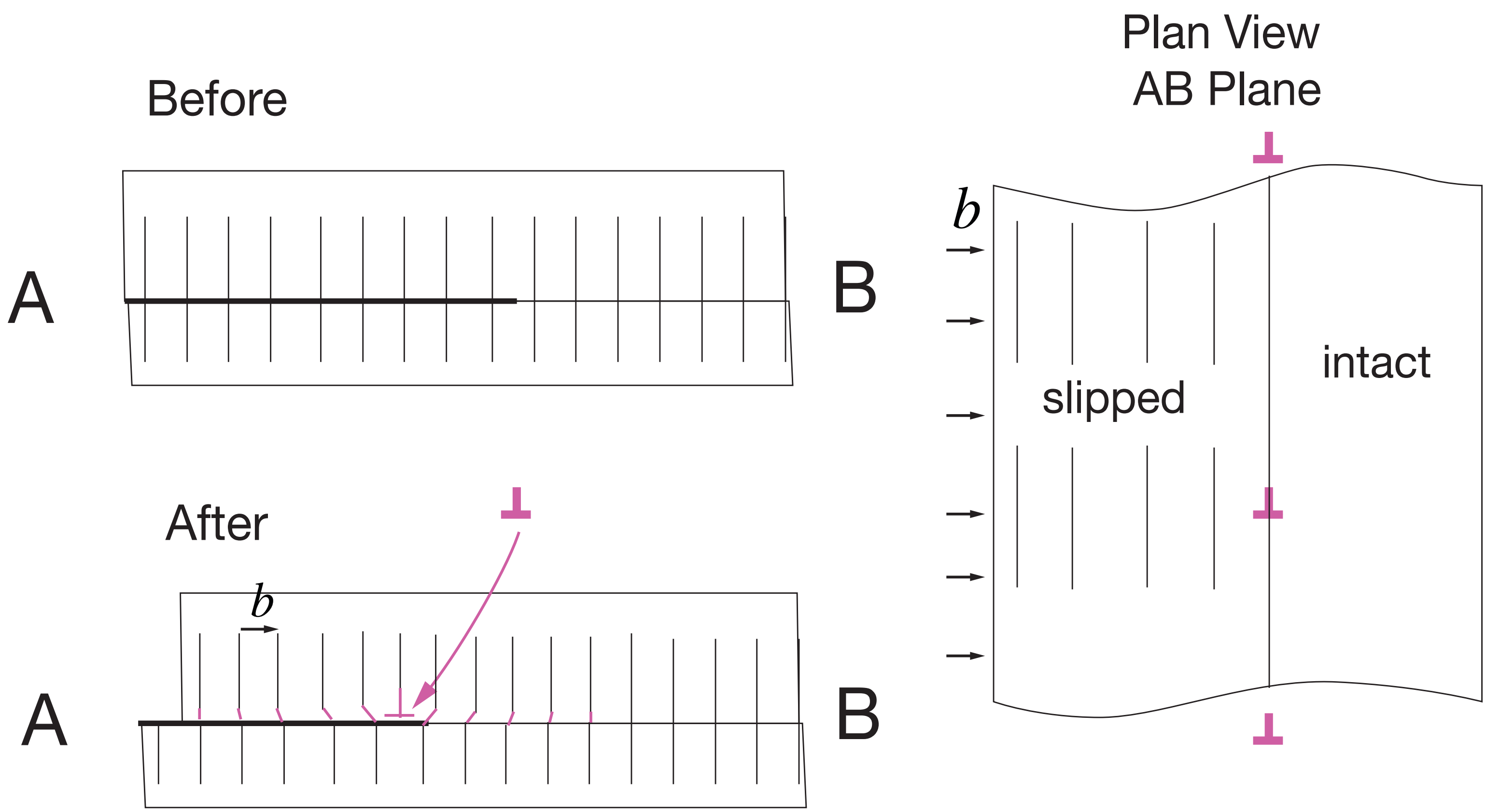
Now,

The line (the boundary) is the defect which is now a line vector. The line separates the region which has slipped by $\vec{b}$ and the un-slipped area of slip plane.

This line is a crystal defect which is called a dislocation. It is a line vector, $\vec{\ell}$, embodying a slip vector $\vec{b}$.

Partial Slip





The dislocation is a line with a strain field at its core, and slip vector which is necessarily a lattice translation vector.

The above description of a dislocation poses specific questions that we will address for example,

Can the dislocation be a curved line?

What is the force required to move the dislocation how is this force related to the applied shear stress (i.e. the yield stress)?

How can the dislocation be prevented from moving, thereby enhancing the yield stress of the crystal?