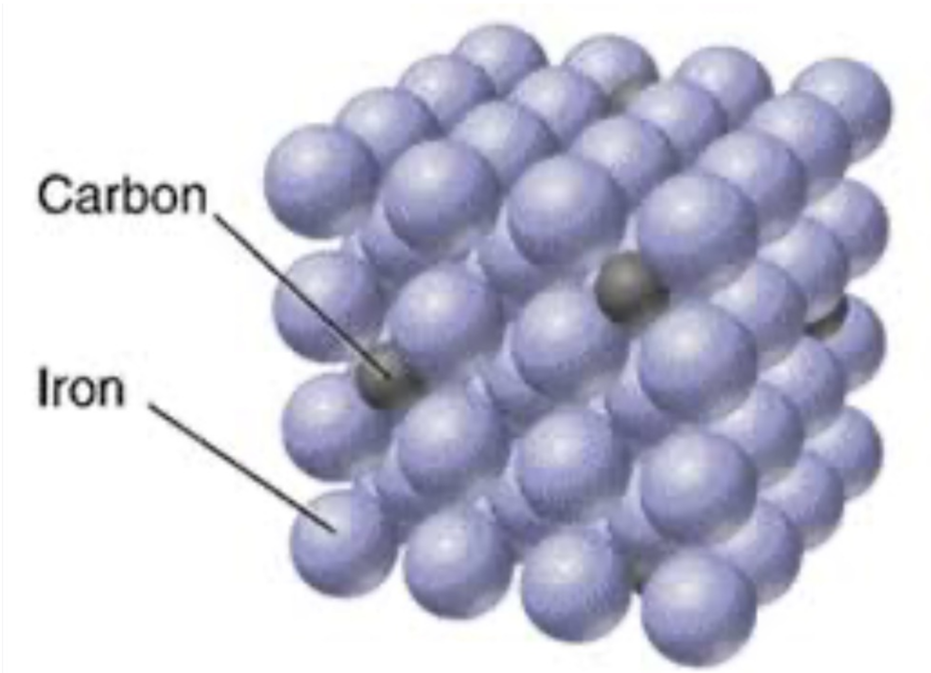
Anelastic Behavior

If time scale for relaxation of stress is comparable to time of stress application

The stress-strain relation is time dependent.



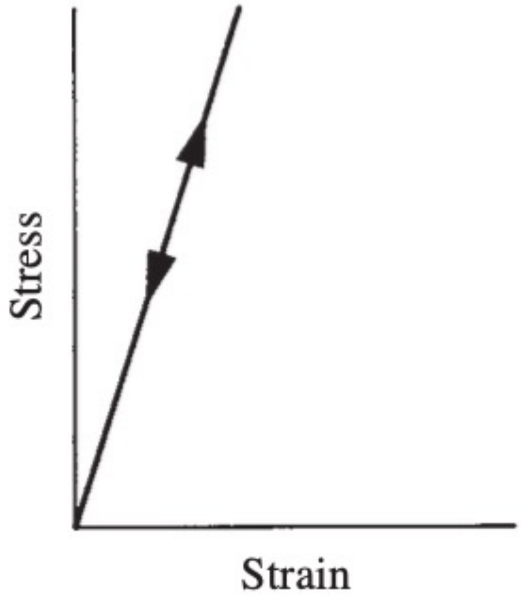
At room temperature, carbon size is much larger than interstitial space

This leads to huge lattice stress.

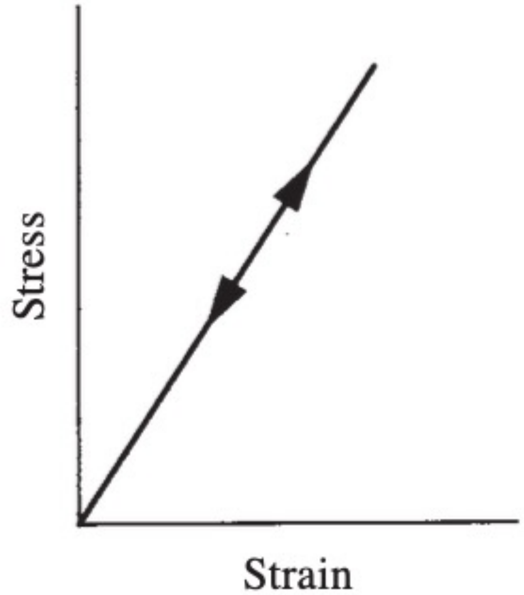
Upon tensite straining,
Carbon rearranges,slowly.

Typical time scale is ~100s at RT

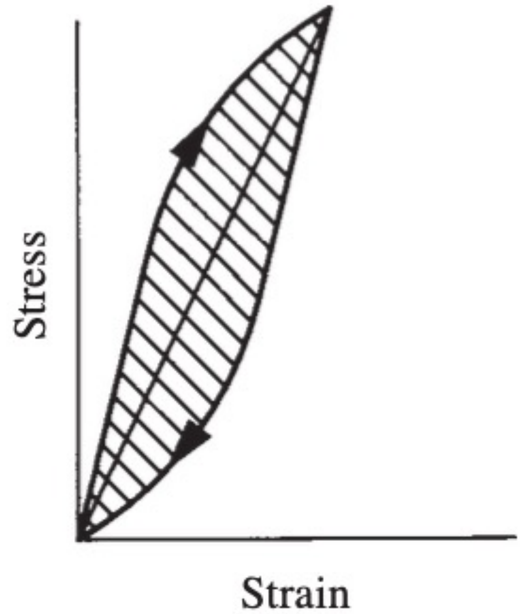
Three different cases



Purely elastic deformation



Anelastic:,
But deformation is very slow
Because of carbon finding low energy sites, the stress required to deform is lower
Lesser stiffer material



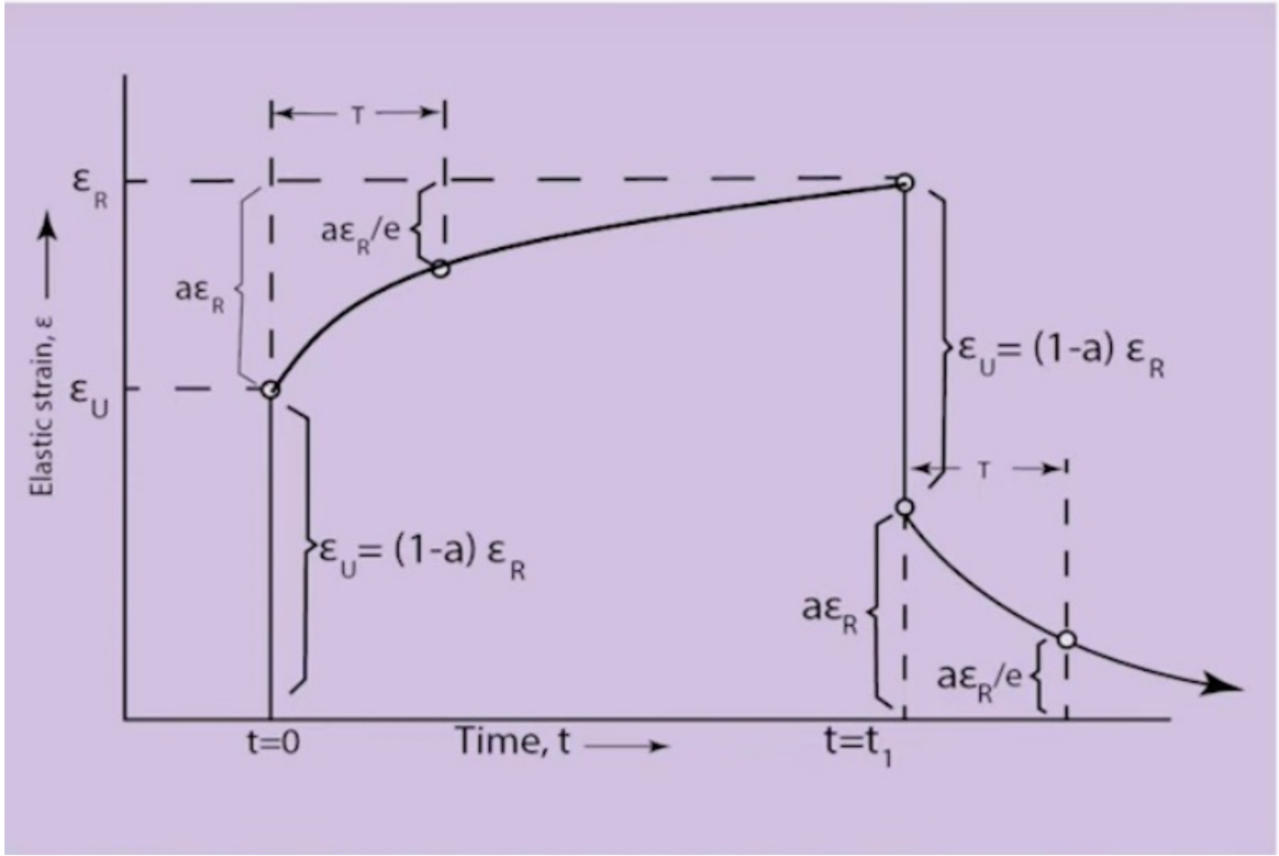
Anelastic:,
But deformation is fast.
There is hysteresis.

Strain during loading is always lower than that of unloading!

We can then define relaxation time:

Time taken to recover back by atleast 63%.

If the question is why 63 ?



If instantaneous stress is applied;

A instantaneous strain ϵ_U is seen.

A gradual strain $\epsilon_A = \epsilon_R - \epsilon_U$
Is also observed.

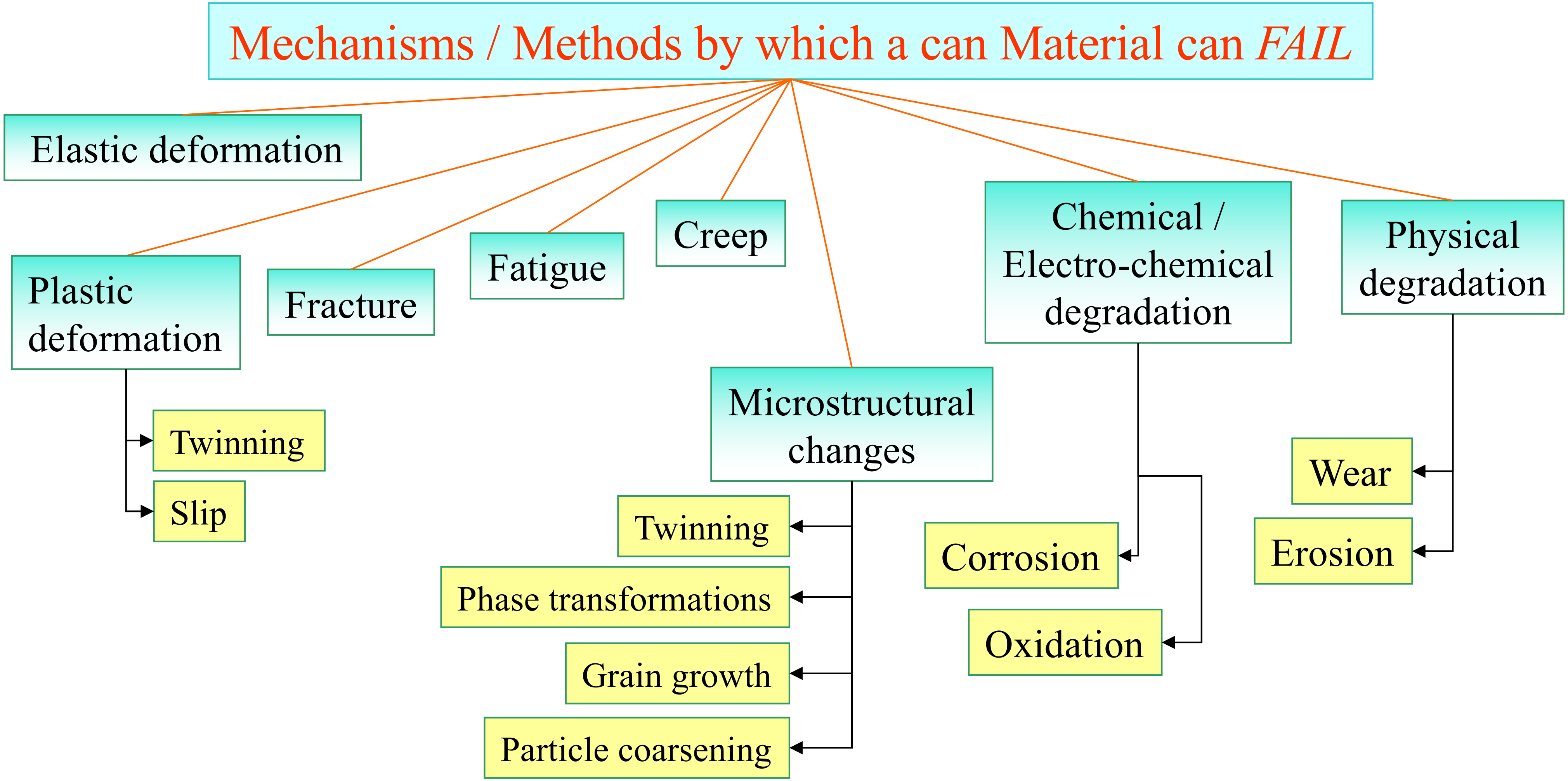
Since a exponential dependence is seen;

Total strain at any time after loading

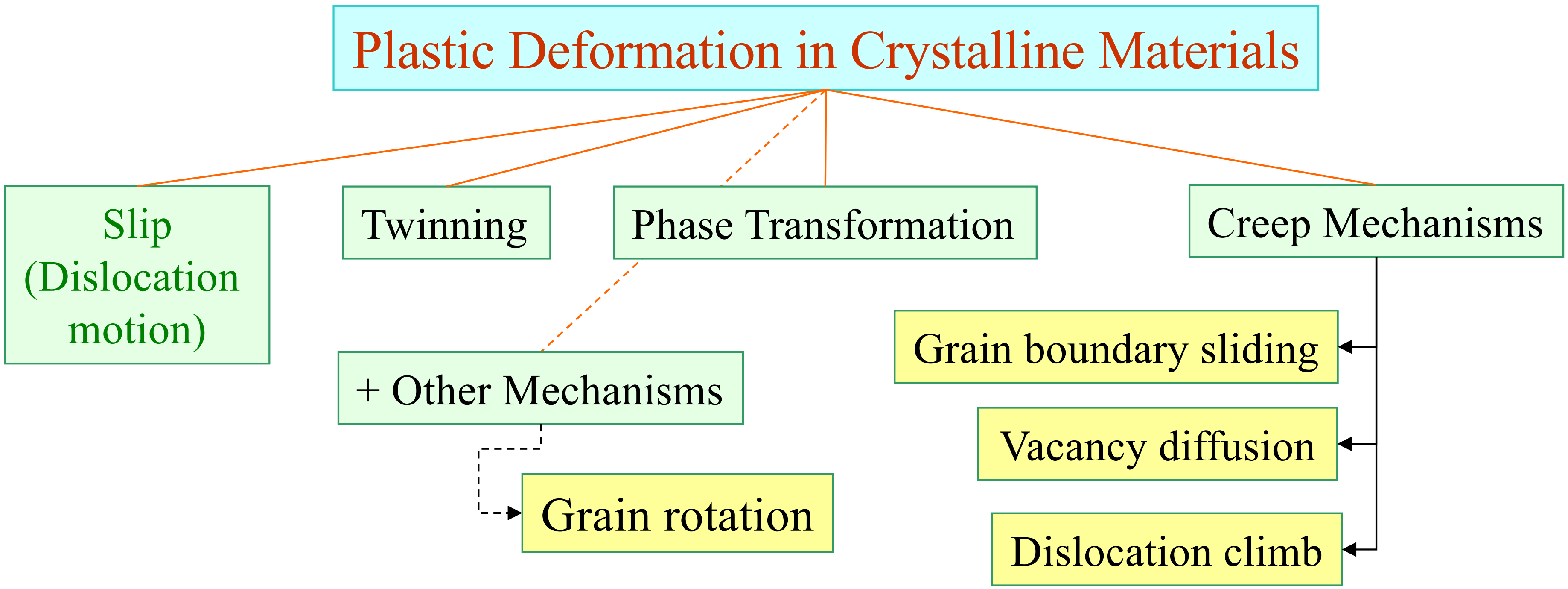
$$\epsilon(t) = \epsilon_U + \epsilon_R\left(1 - ae^{-\frac{t}{\tau}}\right)$$

Where $a = \frac{\epsilon_A}{\epsilon_R}$

So what is the microscopic origin for difference in material properties ?

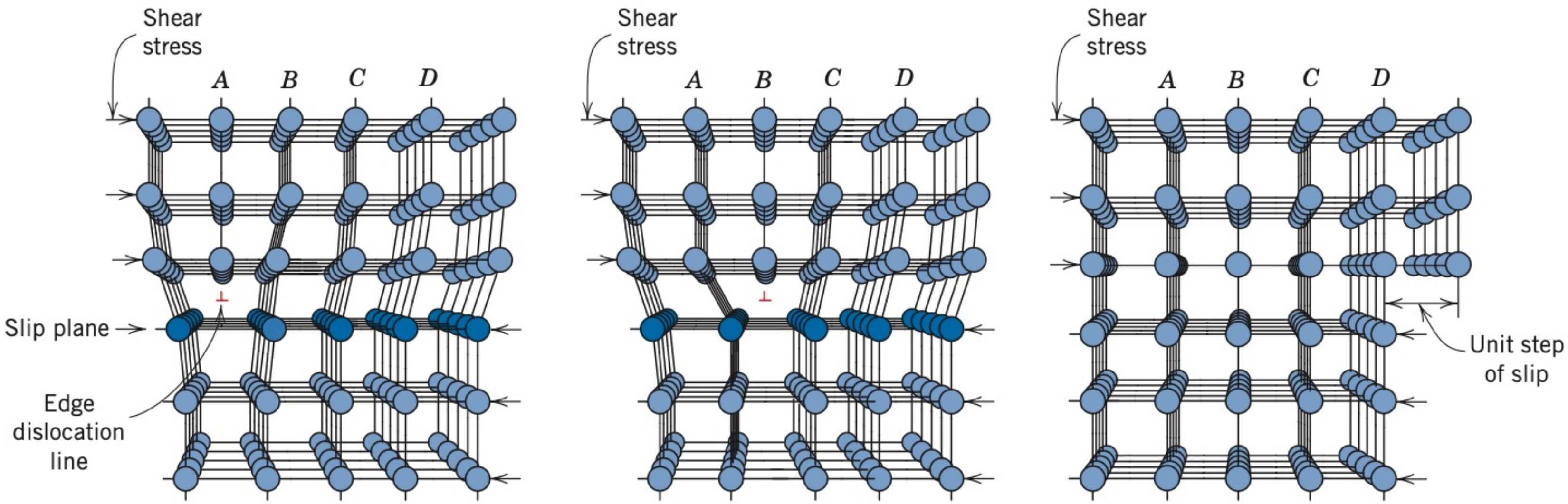


- Plastic deformation in the broadest sense means permanent deformation in the absence of external constraints (forces, displacements) (i.e. external constraints are removed).
- Plastic deformation of crystalline materials takes place by mechanisms which are very different from that for amorphous materials (glasses). The current chapter will focus on plastic deformation of crystalline materials. Glasses deform by shear banding etc. below the glass transition temperature (T_g) and by 'flow' above T_g.
- Though plasticity by slip is the most important mechanism of plastic deformation, there are other mechanisms as well. Many of these mechanisms may act in conjunction/parallel to give rise to the observed plastic deformation.



Deformation via slip

Slip is a plastic deformation via dislocation motion



Entire crystal is invariant, other than the dislocation line(the plane).

When stresses, the plane moves much like a caterpillar

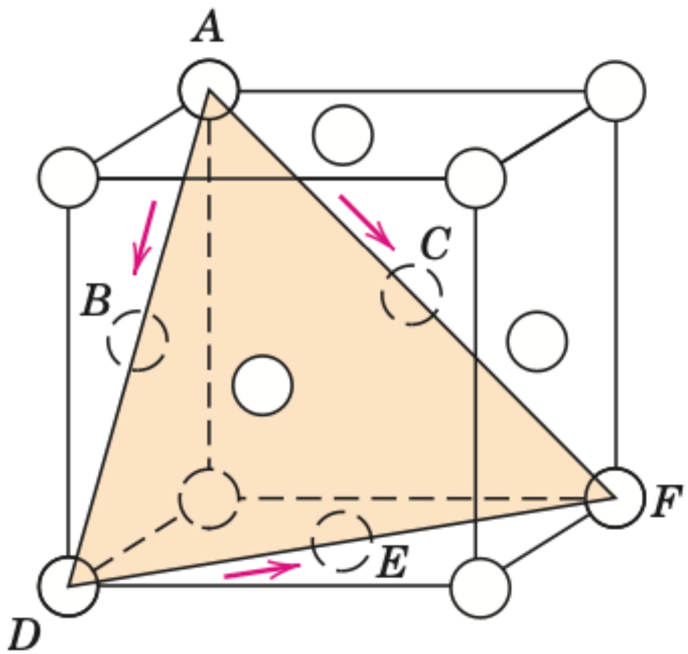
Buffer labs next week.

Will decide the dates based on the numbers.
Will circulate a google form today to see the count.

Slip planes

Planes on which the dislocation moves.
The dislocations do not move with equal ease on all planes

The plane with maximum atomic packing density tends to be the slip plane



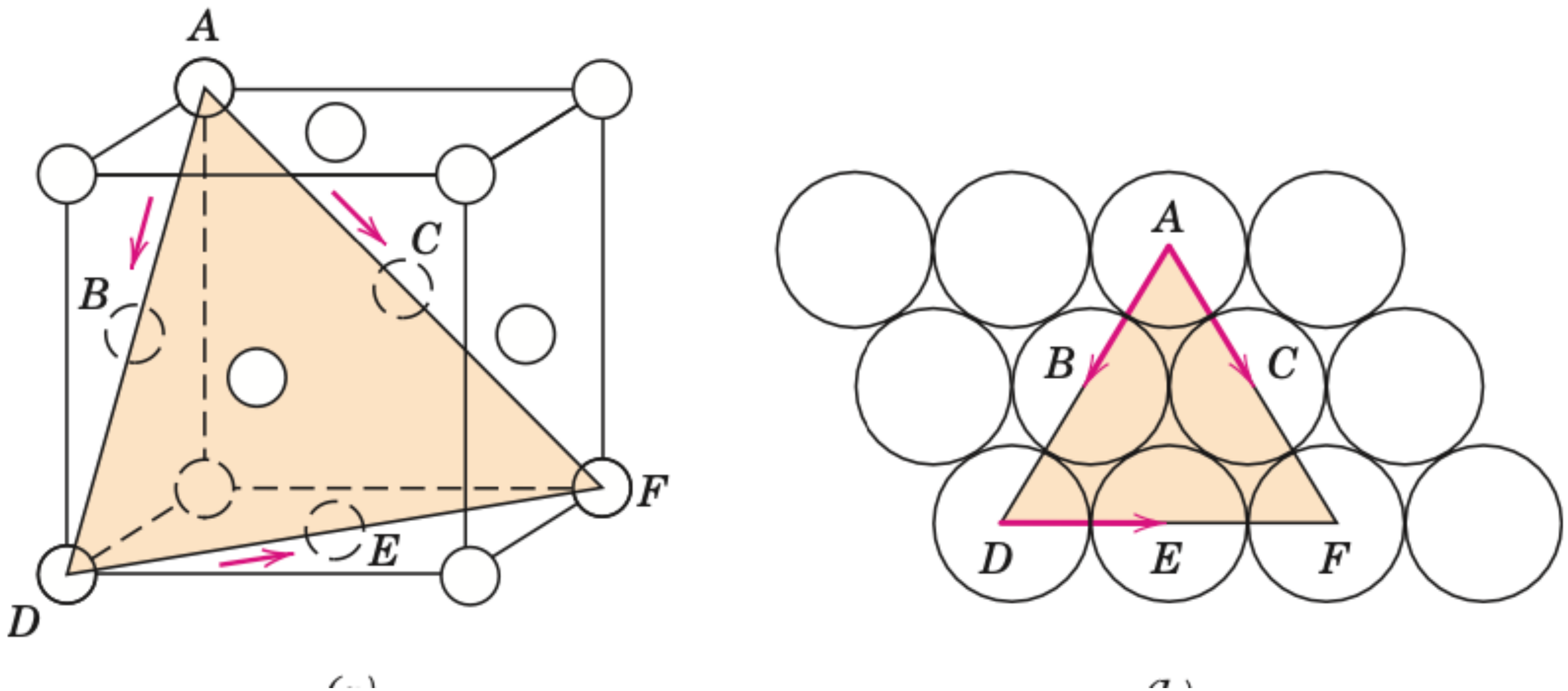
Planes of maximum packing density are the widely separated

For a FCC crystal [111] family of planes are the most dense.

Slip Directions

On the slip plane the direction of largest atomic density tends to act as slip directions.

Lines of maximum atomic density have the least separation -> smallest $\vec{b}$



Slip System –Plane {} Direction <>

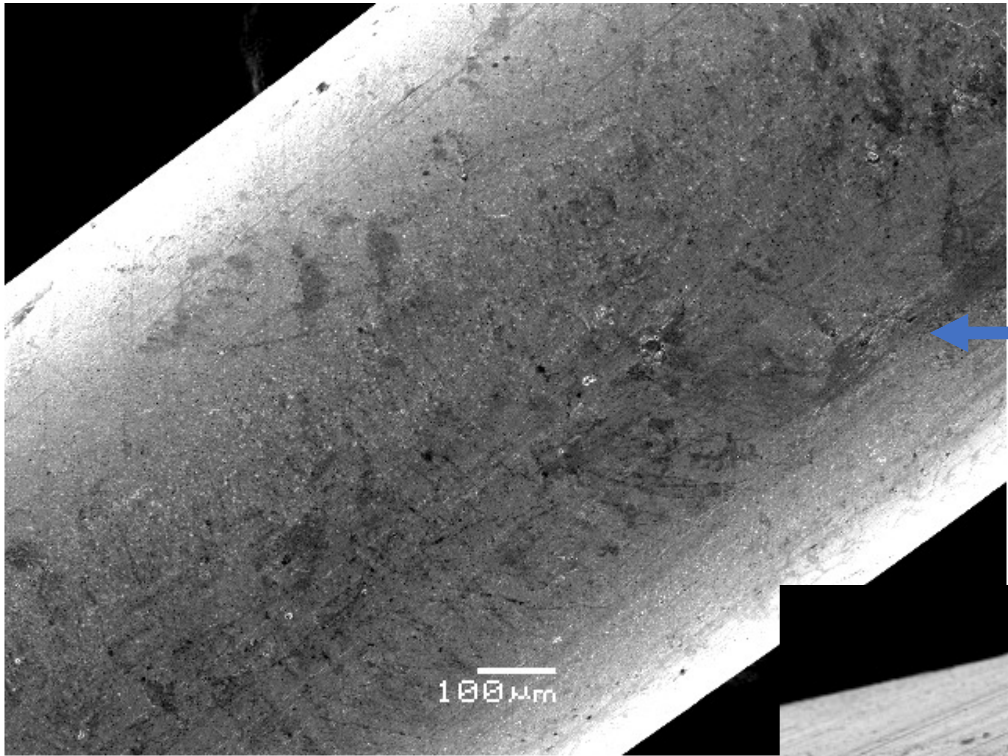
Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	{111}	$\langle 1\bar{1}0 \rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	{110}	$\langle \bar{1}11 \rangle$	12
α-Fe, W	{211}	$\langle \bar{1}11 \rangle$	12
α-Fe, K	{321}	$\langle \bar{1}11 \rangle$	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	{0001}	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0 \rangle$	6

For the case of 111 planes,

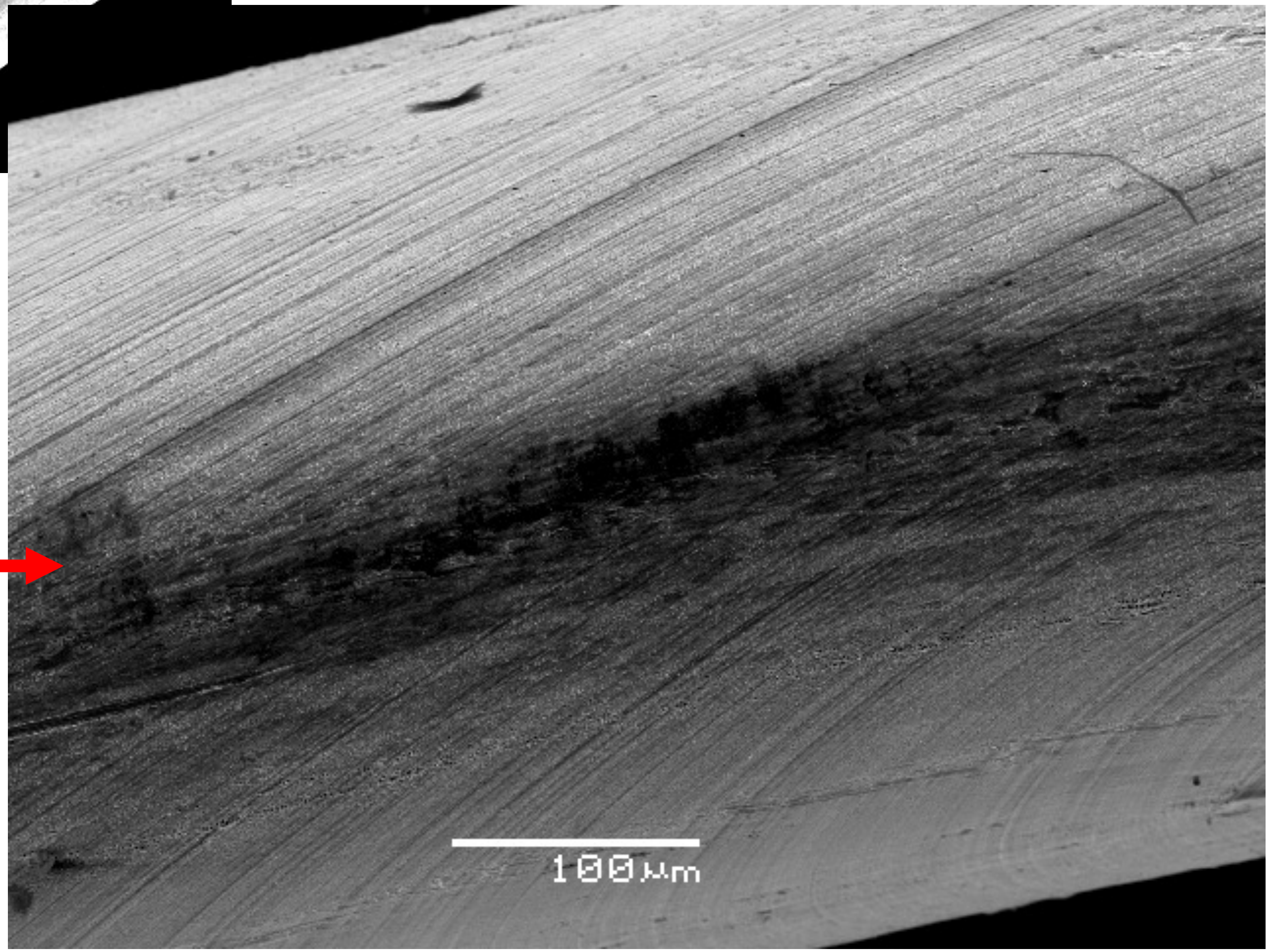
There are four inequivalent planes (non-parallel

Each plane as e unique directions (non-parallel)

A total of 12 Slip systems

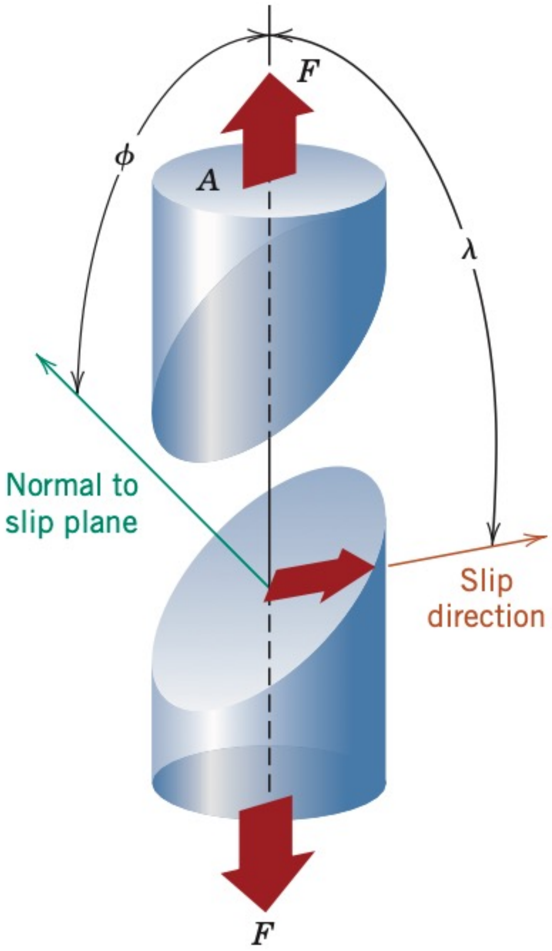


Before deformation
Cd single crystal



After deformation
Cd single crystal

Slipping in a material with tensile force



If F is the applied force along the sample surface.

The area on the slip plane handling the force $\frac{A}{\cos\phi}$

Where is the surface area.

The slip plane normal makes ϕ to the surface

The projection of the applied force on the slip direction

$$F \cos\lambda$$

The applied stress resolved along the slip direction is then:

$$\tau_R = \frac{F cos\lambda}{\frac{A}{\cos\phi}} = \sigma\cos\phi\cos\lambda$$

This is called as the resolved stress along the slip direction

In any given material, there are multiple slip planes and directions, each having its resolved stress

Schmid Law:

For a material with defined defect density and purity, the resolved stress at which the material slips to plastically deform is called as critically resolved shear stress. τ_C

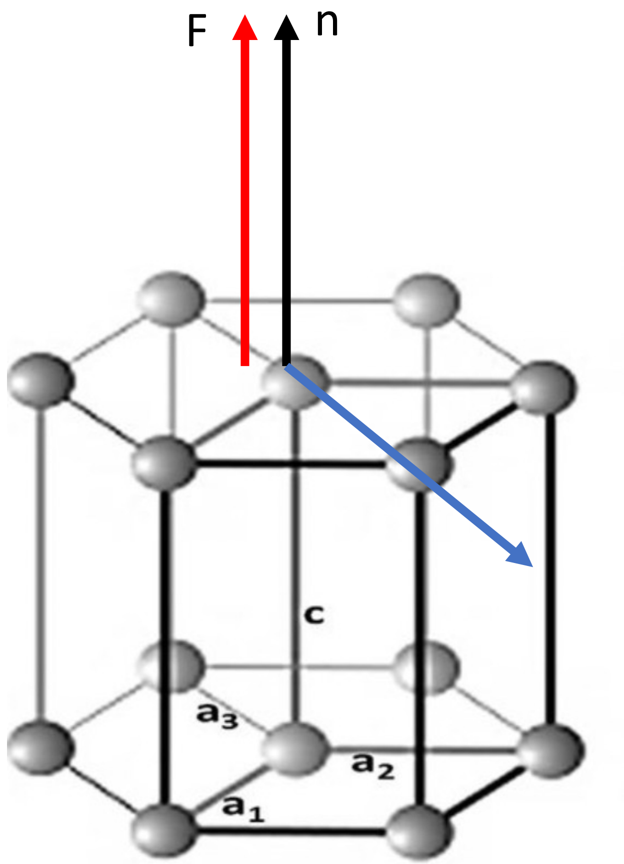
Factor $\cos\phi \cos\lambda$ is called as the Schmid factor.

When a tensile strain is applied, all the slip systems in the material experiences a resolved stress.

Primary slip system (slip system most often observed) is the one with maximal Schmid factor.

When the material slips, the applied stress is the Yield stress

For a HCP crystal



The slip planes are [0001].

When tensile strained along the surface, the resolved stress

$$\tau_R = F \cos\phi \cos\lambda$$

Since, the tensile axis is along the normal to the slip plane,
The component of the force along the slip direction $\cos\lambda \rightarrow 0$

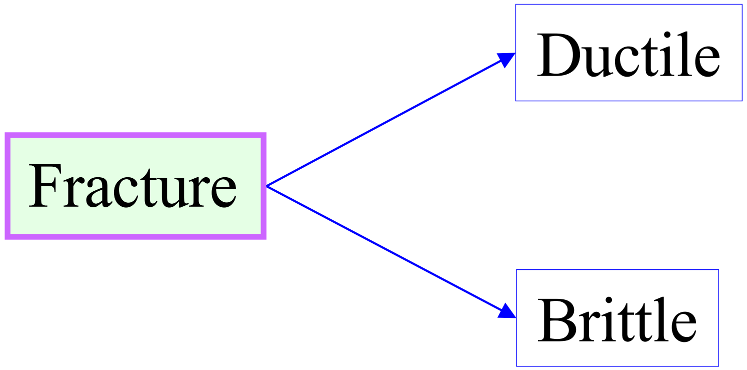
Thus, there is minimal resolved stress along the slip direction.

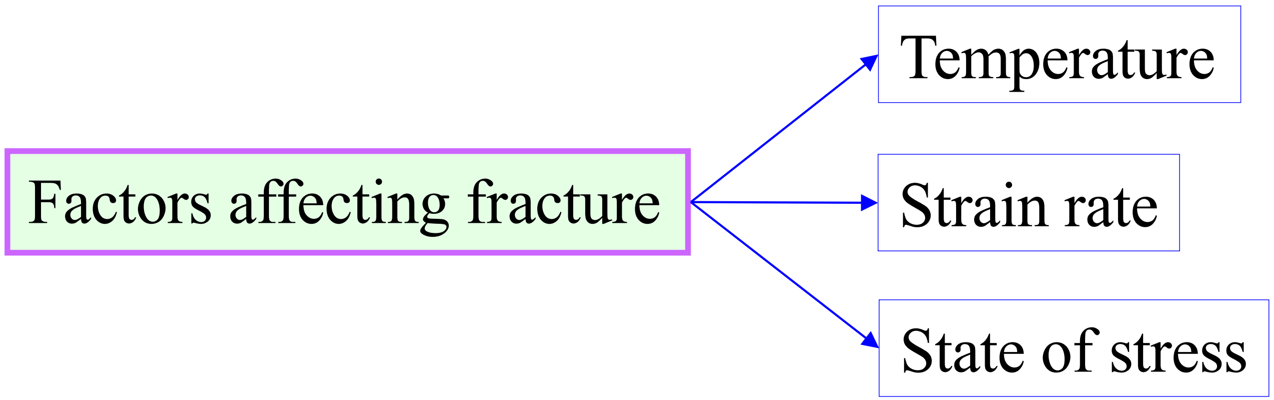
So, these materials do not prefer to slip plastically, but rather break via fracture

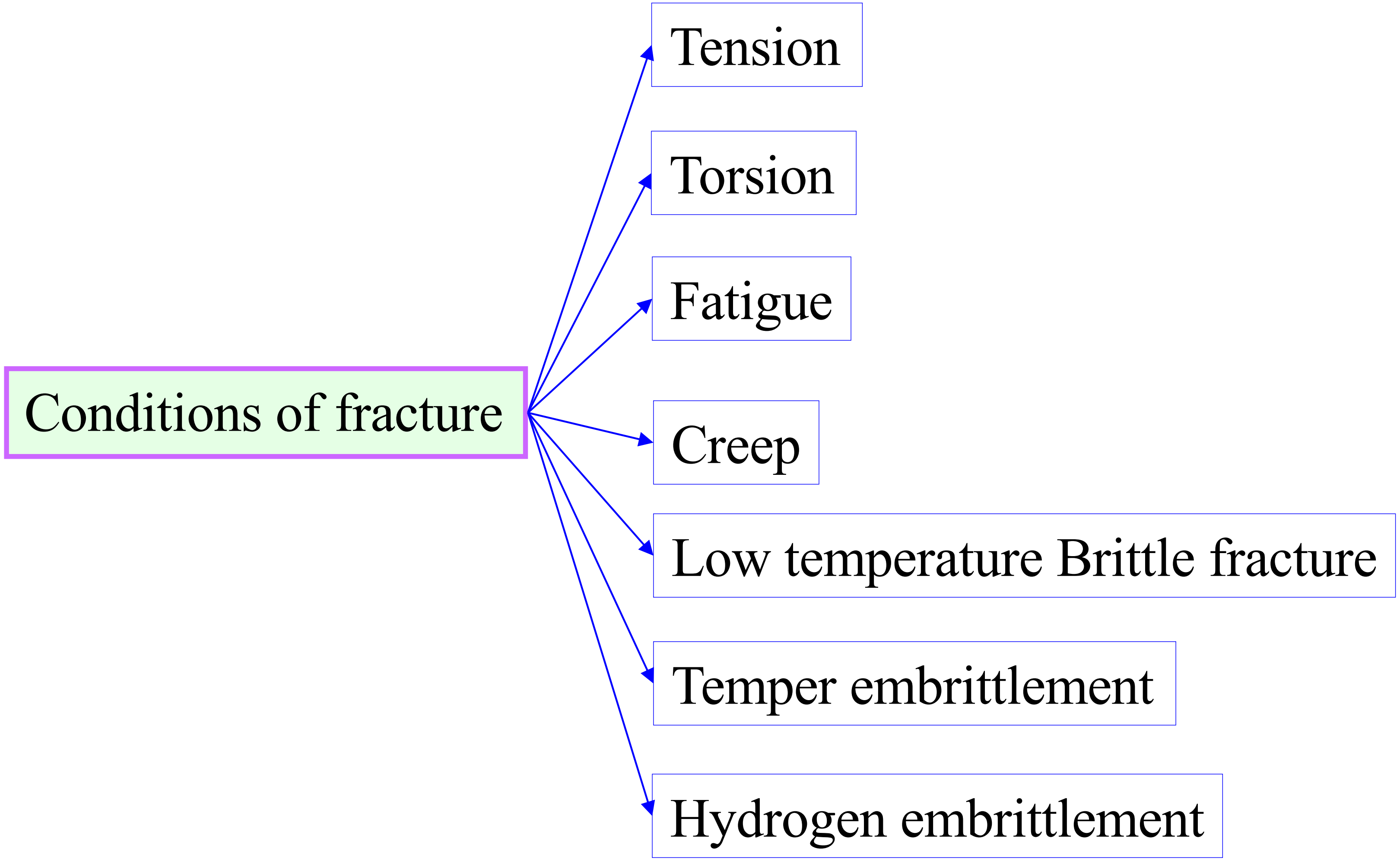
FRACTURE

- Brittle Fracture
- Ductile to Brittle transition

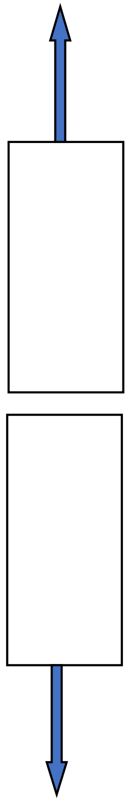
Fracture Mechanics
T.L. Anderson
CRC Press, Boca Raton, USA (1995)


Fracture
Ductile
Brittle


Factors affecting fracture
Temperature
Strain rate
State of stress

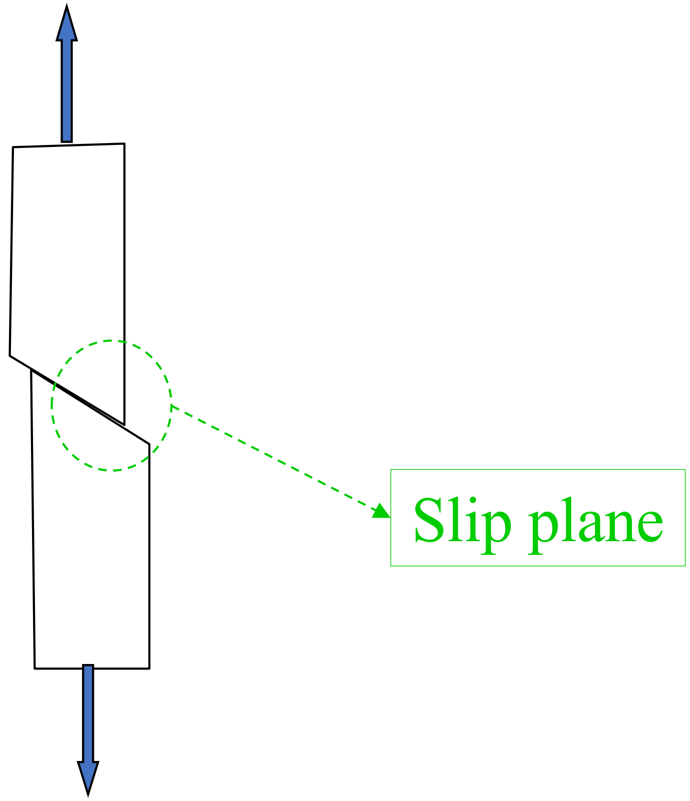

Conditions of fracture
Tension
Torsion
Fatigue
Creep
Low temperature Brittle fracture
Temper embrittlement
Hydrogen embrittlement

Types of failure

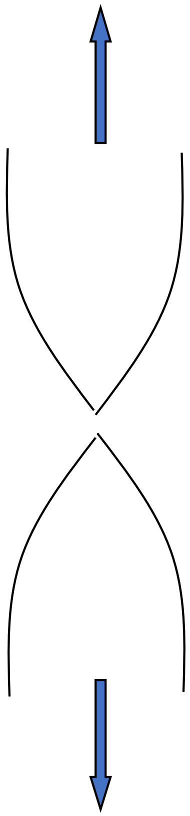


Promoted by
- Low Temperature
- High Strain rate
- Triaxial state of State of stress

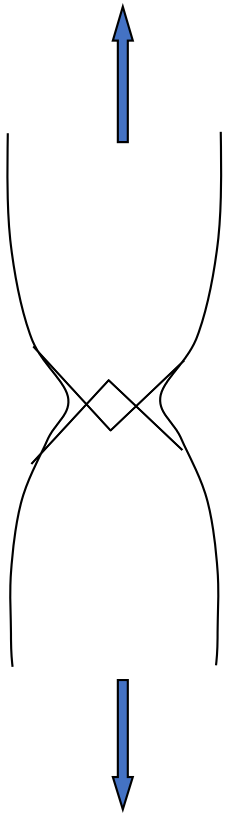
- Brittle fracture
- Little or no deformation
- Observed in single crystals and polycrystals
- Have been observed in BCC and HCP metals but not in FCC metals



- Shear fracture of ductile single crystals
- Not observed in polycrystals



- Necking till the ultimate limit in completely ductile materials

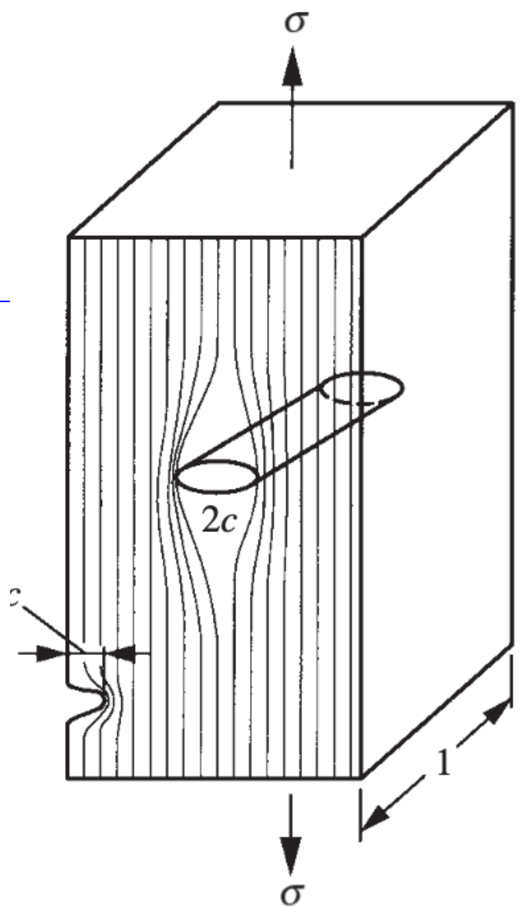


- Necking until some brittle particles crack. The crack propagates and fracture

Brittle Fractures

Theoretical shear strength and cracks

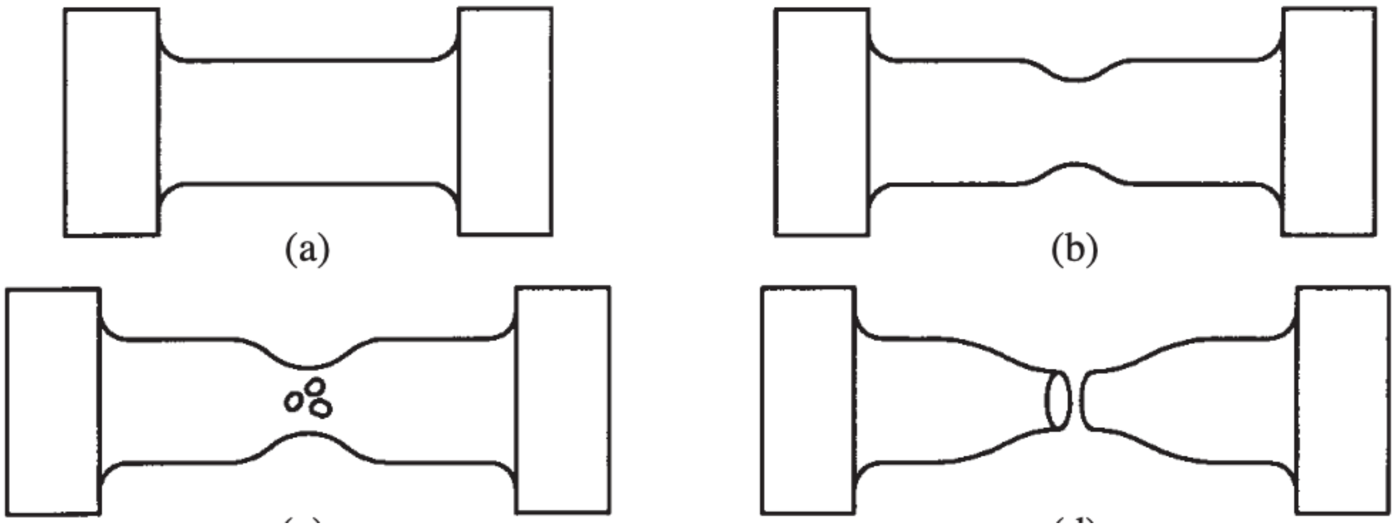
- The theoretical shear strength *(to break bonds and cause fracture)* of perfect crystals ~ (E / 6)
- Strength of real materials ~ (E / 100 to E /1000)
- Tiny cracks are responsible for this
- Cracks play the same role in fracture *(of weakening)* as dislocations play for deformation



Contrasting energetics:

a. surface energy of the crack as it expands
b. Strain energy relaxation as the crack expands

Ductile -> Brittle transformations



Even in simple ductile materials, close to necking, cracks start to appear on brittle particles.

Eg: Cementite in steel.

Therefore, its important to know about the various phases of materials.
And also about phase transformations.