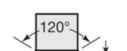
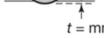


Test		Shape of Indentation		Load, P	Hardness number
	Indenter	Side view	Top view		
Brinell	10-mm steel or tungsten carbide ball			500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid			1–120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid			25 g–5 kg	$HK = \frac{14.2P}{L^2}$
Rockwell	Diamond cone			60 kg 150 kg 100 kg	HRA HRC HRD
				100 kg 60 kg 150 kg	HRB HRF HRG
				100 kg	HRE

Slip Systems

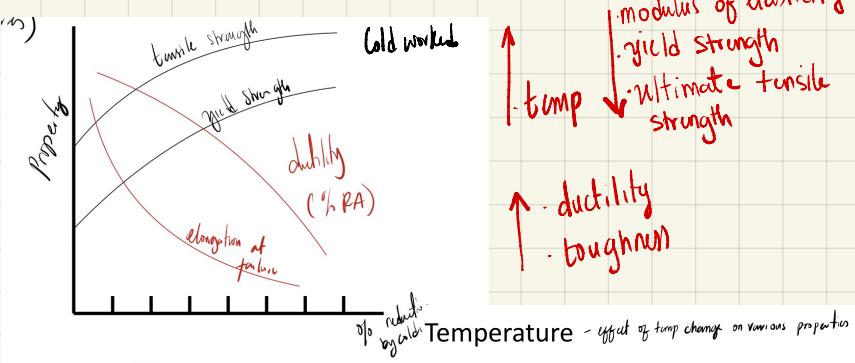
- A Slip plane in slip direction
 - partially governs the strength + ductility of material
 - 5 or more slip systems needed for ductile behavior
 - b/a ratio varies for different slip systems \rightarrow Anisotropy
 - **BCC** \rightarrow 4/8 different Slip Systems
In BCC material, many slip planes with high b/a ratio which increases strength + reduces ductility
 - g. strength + moderate ductility
 - **FCC** \rightarrow 12 different slip systems
 - b/a is not as high as bcc
 - moderate strength but good ductility
 - **HCP** \rightarrow 3 slip systems
low probability of slip and generally brittle

Substitution and
Impurity

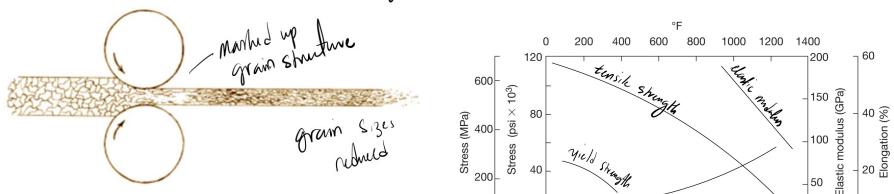




$$S_{\text{int}} = 3 \cdot S(\text{Hg}) \quad \text{Handnum} = c S_{\text{int}}$$



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Influence of Structure

Dependent on structure

- hardness, yield strength,
distortion modulus

- electrical conductor

Elastic properties
melting point

Density
Specific heat
Coefficient of thermal expansion

upper & lower yield point

A point at which maximum load or stress required

Initial plastic deformation of material - Upper yield point
 A point at which minimum load or stress required to maintain the plastic behavior of material - lower yield point.

As material solidifies individual crystals nucleate at random positions and orientations throughout

- Metals: Dislocation motion easier

- Metals: insulation/motion easier.
 - non directional bonding
 - lots of slip planes
 - Covalent Ceramics** → Silicon wafers
glass
diamond
 - Strongly directional bond
 - make slip much more difficult
 - makes material more brittle
 - Ionic Ceramics** → NaCl
 - Strongest bond type
 - need to overcome charge balance as well as breaking ionic bonds

Cannot process with deformation
Ductile/Malleable

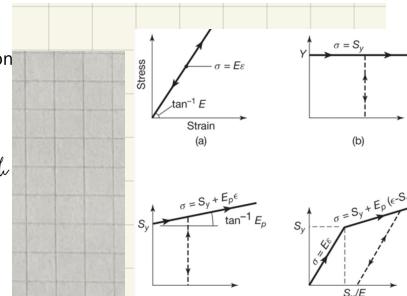


Figure 2.7
 Schematic illustration of various types of idealized stress-strain curves. (a) Perfectly elastic; (b) rigid, perfectly plastic; (c) elastic, perfectly plastic; (d) rigid, linearly strain hardening; and (e) elastic, linearly strain hardening. The broken lines and arrows indicate unloading and reloading during the test.

1. A **perfectly elastic material** displays linear behavior with slope E . The behavior of brittle materials, such as common glass, most ceramics, and some cast irons, may be represented by the curve shown in Fig. 2.7a. There is a limit to the stress the material can sustain, after which it fractures. Permanent deformation, if any, is negligible.
 2. A **rigid, perfectly plastic** material has, by definition, an infinite value of elastic modulus, E . Once the stress reaches the yield strength, S_y , it continues to undergo deformation at the same stress level; that is, there is no strain hardening. When the load is released, the material has undergone permanent deformation; there is no elastic recovery. (Fig. 2.7b).
 3. The behavior of an **elastic, perfectly plastic** material is a combination of the first two: It has a finite elastic modulus, no strain hardening, and it undergoes elastic recovery when the load is released. (Fig. 2.7c).
 4. A **rigid, linearly strain-hardening** curve model assumes that the elastic strains are negligible, and that the strain-hardening behavior is defined by a straight line with a slope equal to the **plastic modulus**, E_p . Such materials have no elastic recovery upon unloading. (Fig. 2.7d).
 5. An **elastic, linearly strain-hardening** curve (Fig. 2.7e) uses an elastic portion with slope E , and a linear plastic portion with a plastic modulus, E_p ,

→ Important for HCP (limited # of slip systems)
twinning refers to the process of producing a mirror image by a grain about the plain of twinning during deformation.

$$\text{Theoretical shear strength of metals, } \tau_{\max} = \frac{G}{2\pi}$$

$$\text{Theoretical tensile strength of metals, } \sigma_{\max} = \sqrt{\frac{E\gamma}{a}} \approx \frac{E}{10}$$

$$\text{Hall-Petch equation } S_Y = S_{Y_i} + kd^{-1/2}$$

Inherent strength
Grain boundary constant

$$\text{ASTM grain-size number, } N = 2^{n-1}$$

$$\text{Fracture strength vs. crack length, } S_f \propto \frac{1}{\sqrt{\text{Crack length}}}$$

1. A minimum amount of deformation is needed to cause recrystallization.

2. The smaller the degree of deformation, the higher the temperature required to cause recrystallization.

3. Increasing the annealing time decreases the recrystallization temperature. However, temperature is far more important than time. Doubling the annealing time is approximately equivalent to increasing the annealing temperature 10°C.

4. The final grain size depends chiefly on the degree of deformation and to a lesser extent on the annealing temperature. The greater the degree of deformation and the lower the annealing temperature, the smaller the recrystallized grain size.

5. The larger the original grain size, the greater the amount of cold work required to produce an equivalent recrystallization temperature.

6. The recrystallization temperature decreases with increasing purity of the metal. Solid-solution alloying additions always raise the recrystallization temperature.

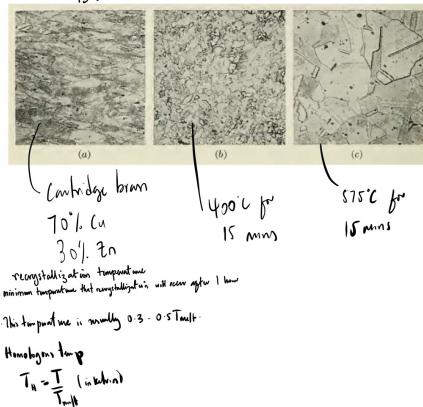
7. The amount of deformation required to produce equivalent recrystallization behavior increases with increased temperature of working.

8. For a given reduction in cross section, different metalworking processes, such as rolling, drawing, etc., produce somewhat different effective

deformations. Therefore, identical recrystallization behavior may not be obtained.

- Large grain size is generally associated with low strength, low hardness, high ductility.

Growth



heat & diffusion solid solution strengthening

4 Strengthening mechanism - precipitation hardening, strain hardening, grain size strengthening, solid solution strengthening.

Six main variables influence recrystallization behavior. Amount of prior deformation ② temperature ③ time ④ initial grain size ⑤ composition ⑥ amount of recovery or polygonization prior to the start of recrystallization.

What effects does recrystallization have on the properties of metal? By recrystallizing, the density of crystal deformations, called dislocation, is decreased. This is due to the recrystallization process "repairing the defects in the crystal structure".

A metal undergoing recrystallization will also typically have a lower strength and higher ductility characteristics than its original form.

3.16 Explain why the strength of a polycrystalline metal at room temperature decreases as its grain size increases

Since strength is directly proportional to the entanglements of dislocations that take place with each other and with grain boundaries. Also, more is the grain size less will be the grainboundary area per unit volume. Therefore, for metals with large grains fewer entanglements are generated at grain boundaries and thus have lower strength. Hence, we can say that the strength of a polycrystalline metal at room temperature decreases as its grain size increases

3.9 Describe why different crystal structures exhibit different strengths and ductilities.

Ductility of the material is directly proportional to the number of the slip systems. Along with it, plastic behaviour of the material can be estimated with the help of number of active slip systems. As an example, a hcp material has few grains oriented in reference to a slip system and thus to start plastic deformation high stresses are required because of having few slip systems and are brittle whereas because of having many slip system a fcc material requires lower stresses for the same and thus have moderate strength and good ductility.

$$\text{Brinell} = \frac{P}{A_{surf}}$$

$$\text{Meyer} = \frac{P}{A_{surf}}$$

$$\text{Agrej}$$

What is the relationship between nucleation rate and the number of grains per unit volume of a metal?

There is a very close relationship between nucleation rate and the number of grains per unit volume. Grain size depends upon the number of sites in which crystal form and the rate at which they grow. Commonly, small grains are formed due to rapid cooling whereas slow cooling gives larger crystals.

$$d = \frac{0.254}{\sqrt{N}} \quad N = 2^{n-1}$$

$$N = \# \text{ of grains @ 1000x}$$

$$d = \frac{L}{N}$$

grain diameter / Number of intersections

