1 Lecture 4

Question 1 *What are Mechanical properties of a material reflect ?*

It reflects its response or deformation due to a certain load or force.

Question 2 *What factor to be considered in measuring mechanical properties ?*

Factors to be considered include the nature of the applied load and its duration, as well as the environmental conditions. It is possible for the load to be tensile, compressive, or shear, and its magnitude may be constant with time, or it may fluctuate continuously. Application time may be only a fraction of a second, or it may extend over a period of many years. Service temperature and humidity may also be important factors.

Question 3 *The most common mechanical test ?*

The tension test, where a specimen is put under pure axially oriented stress (axial tension). The machine simply keeps increasing the load while measuring the load vs elongation.

Question 4 *How to normalize the tension test regardless of the dimensions of the specimen and load ?*

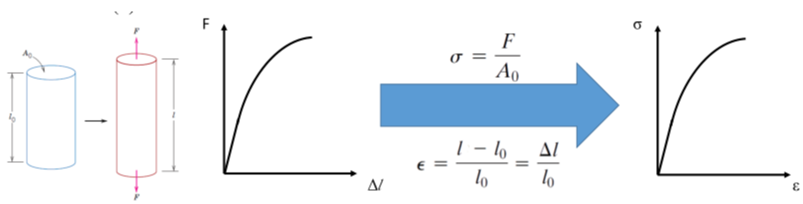
We divide the load by the **initial area** to get the stress

$$\sigma = \frac{L}{A_0}.$$

and we divide the elongation by the **initial length** to have the strain.

$$\epsilon = \frac{\Delta L}{L}.$$

So instead of the force-elongation curve we get what is called the stress-strain curve.



Question 5 *What do we get from the stress-strain curve ?*

We know the mechanical properties of the material such as: Modulus of Elasticity, Ductility, Resilience, Toughness, UTS, Yield Stress, Allowable stress. (stress or strength)

Question 6 *Describe the elastic behaviour ?*

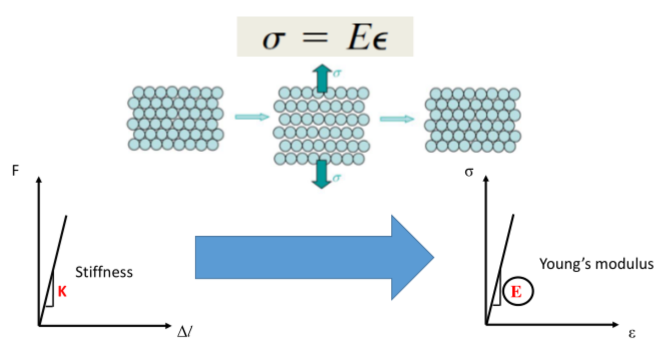
The elastic region or range, is when the tension is at relatively low levels where no bonds are broken, so the material returns to its original shape when The load is removed. Note that the elastic deformation presists only to strains of about 0.005 or (0.5%).

Question 7 *Where can we find the Yield Stress(Strength) of a material ?*

At the end of the elastic(linear) region.

Question 8 *What is young's modulus ? And how do we get it ?*

Young's modulus or the modulus of elasticity (E) is a measure of the material's stiffness. The greater the stiffer the material. We calculate it using the stress-strain graph's elastic region as it is the slope of the linear region.

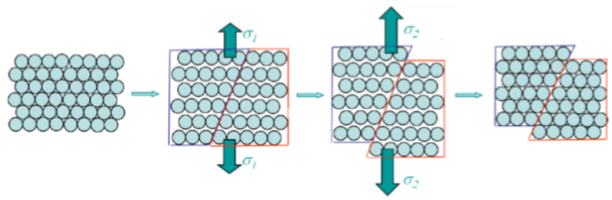


Question 9 *What are the most stiff elements/materials ?*

Ceramics. They have the highest E.

Question 10 *What it the plastic behaviour of a material ?*

After the 0.005 strain (yield strain) we get to the plastic region, where if the material is deformed in this region it won't get back to its original state or shape. Non-recoverable. In this region there is a slip that happens in the atoms planes.

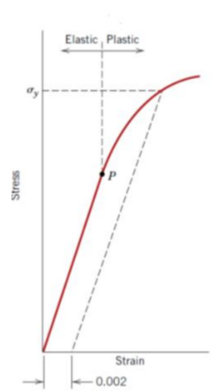


Question 11 *When does the plastic deformation occur?*

Exactly after the yield stress. σ_y. At a point P which is called the proportionality limit.

Question 12 *How to find the point P or the yield stressσ_y ?*

We go 0.002 (0.2%) offset, 0.002 of the total deformation (x-axis) and then make a straight line parallel to the elastic region's line. The point we hit is called the P.



Question 13 *What is the UTS?*

The ultimate tensile strength, is the stress at the maximum point on the engineering stress-strain curve. After which Necking happens and then the stress decreases as the force decreases and the original area is constant.

Question 14 *What to choose when designing a material to be your safety guideline ?*

We choose the yield strength instead of the ETs and of course divide it by the safety factor in order to get the allowable stress.

$$\sigma_{all} = \frac{\sigma_y}{FS}.$$

Question 15 *What is Ductility and Brittles ?*

it is a measure of the degree of plastic deformation that has been sustained at fracture . The material that experiences significant plastic deformation until fracture is said to be **ductile** . (long plastic deformation region). While the material that exhibits only less than 5% or no plastic deformation is said to be **brittle.**

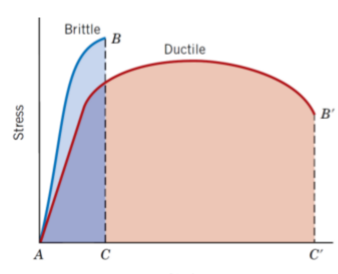
Question 16 *How to calculate Ductility ?*

Well, it is a percent. Percent elongation or percent reduction in area.

$$\%\text{EL} = \left(\frac{l_f - l_0}{l_0}\right) \times 100$$

$$\%\text{RA} = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$

Where the subscript 0 refers to the initial value while the subscript f refers to the final value at fracture



Question 17 *What is Resilience ?*

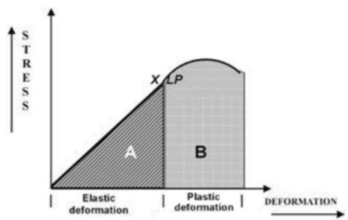
it is the capacity of the material to absorb energy while being deformed elastically. And upon unloading this energy is released. It represents the energy per unit volume (Makes sense).

Question 18 *How to measure Resilience ?*

Using the modulus of resilience U_r

$$U_r = \frac{1}{2}\sigma_y \epsilon_y = \frac{1}{2}\sigma_y(\frac{\sigma_y}{E}) = \frac{\sigma_y^2}{2E} J/m^3.$$

It is like Spring Energy. The area under the Elastic region Curve



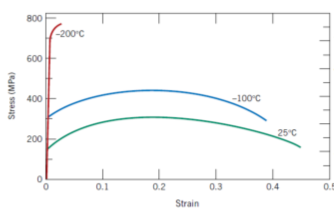
Areas indicating resilience (A) and toughness (A+B) of a material

Question 19 *What is toughness ?*

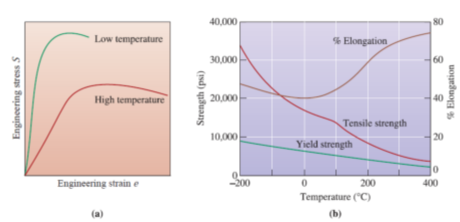
is the ability of the material to absorb energy and plastically deform before fracturing. Like resilience.

Question 20 *What is the effect of temperature on mechanical properties ?*

We notice from the following graphs that decreasing the temperature decreases the ductility and hence decreases the toughness, but increases the strength of the material.



The effect of temperature on stress-strain behavior of iron



The effect of temperature (a) on the stress-strain curve and (b) on the tensile properties of an

Question 21 *What is the True stress-strain curve ?*

Instead of the engineering stress-strain curve we have what is called the true stress-strain curve, in which the stress is computed by dividing the current force with the instant's cross sectional area not the original area.

$$\sigma = \frac{F}{A_i}.$$

Question 22 *Compare the engineering VS the true stress-strain curve ?*

in the engineering one, after the M point (at which UTS exists), the metal becomes weaker. But this is not true, in face it is increasing in strength. The cross section is decreasing so the stress becomes higher.

Question 23 *But why does the curve go lower in the engineering one?*

It is part of the experiment, we choose a certain strain rate to pull the specimen with, So the force needed to pull the specimen decreases with time as the area becomes smaller significantly when necking occurs. The machine decreases the force in order to have the same strain rate.

Question 24 *How to calculate the true stress in the curve ?*

$$\sigma_T = \frac{F}{A_i}.$$

Question 25 *How to calculate the true strain ?*

$$Elongation = \epsilon_T = \Sigma d\epsilon = \Sigma \frac{dl}{l} = \int_{l_0}^{l} \frac{dl}{l} = ln(l) - ln(l_0) = ln(\frac{l}{l_0}).$$

Question 26 *The relationship between the true and engineering stress-strain curves ?*

We can assume that the volume of the specimen is the same (constant) as it deforms **(but this is before the necking)** so:

$$A_0 l_0 = Al.$$

and Hence:

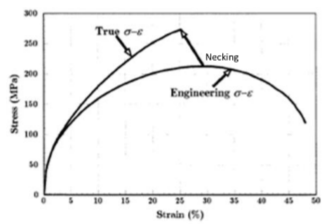
$$\sigma_T = \frac{F}{A} = \frac{Fl}{A_0 l_0} = \frac{\sigma l}{l_0}.$$

$$l = l_0 + \Delta l.$$

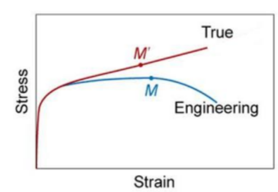
$$\sigma_T = \sigma(1 + \frac{\Delta l}{l}) = \sigma(1 + \epsilon).$$

and Again

$$\epsilon_T = ln(1 + \epsilon).$$



True stress-strain computed till necking



True stress-strain computed till necking and continued via measurements of instantaneous area and length till fracture

Question 27 *Define true strain*

The instantaneous elongation per unit length of the specimen.

Question 28 *Compare true and engineering stresses and strains.*

The true stress is higher than the Engg. stress, while the true strain is smaller than the Egg. Strain.

Question 29 *The relationship between true stress and strain?*

$$\sigma_T = K\epsilon_T^n.$$

This is called the flow stress, K and n are constants and they vary from one metal or alloy to the other. N is called the strain hardening exponent, it is less than 1.

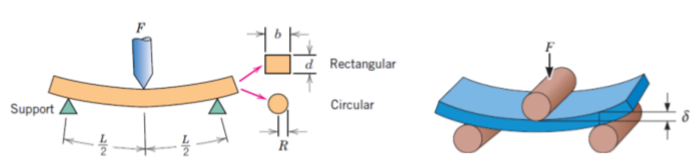
2 Lecture 5

Question 30 *What other tests can we use to find mechanical properties ?*

Three point bend test - impact test - hardness test

Question 31 *Why normal tensile test cannot easily be done on brittle materials ?*

1. it is difficult to prepare and test specimens having the required geometry.
2. it is difficult to grip brittle materials without fracturing them.
3. ceramics fail after only about 0.1% strain, which necessitates that tensile specimens be perfectly aligned to avoid the presence of bending stresses



Question 32 *what is the flexural strength ?*

flexural strength or bend strength or modulus of rupture, is the stress at fracture using the three point bend test. It is an important parameter for brittle materials.

For a rectangular cross section, the flexural strength (σ_{fs}) is given by

$$\sigma_{fs} = \frac{3F_f L}{2bd^2}$$

Where F_f is the force at which the sample fractures
For a circular cross section, the flexural strength (σ_{fs}) is given by

$$\sigma_{fs} = \frac{F_f L}{\pi R^3}$$

Question 33 *What does fracture strength depend on ?*

it depends on the specimen size ? Increasing the volume will increase the probability of existence of a crack and thus decrease the flexural strength.

Question 34 *Flexural strength for brittle materials Vs fracture strength from tensile test.*

The fracture strength using the 3point bend test is mush greater than it is measured using tensile test.

Question 35 *But why ?*

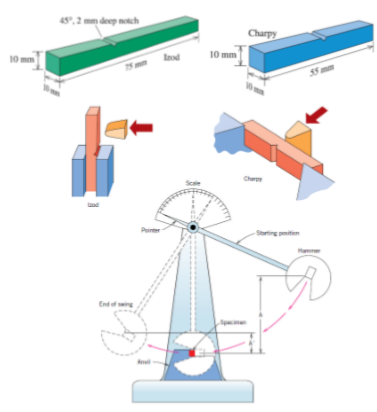
This phenomenon may be explained by differences in specimen volume that are exposed to tensile stresses: The entirety of a tensile specimen is under tensile stress, whereas only some volume fraction of a flexural specimen is subjected to tensile stresses—those regions in the vicinity of the specimen surface opposite to the point of load application .

Question 36 *how different the results of 3point test*

The flexural strength has units of stress. The results of the bend test are similar to the stress-strain curves; however, the stress is plotted versus deflection rather than versus strain since we actually care more about strength rather than ductility.

Question 37 *What happens in the impact test ?*

a material is subjected to a sudden intense blow from a weighted pendulum hammer related from a cocked position at a fixed height, strain rate is extremely rapid ($10^3 s^{-1}$). It measures the amount of absorbed energy till fracture. It is similar to toughness but in high strain rates compared to those with the tensile test.

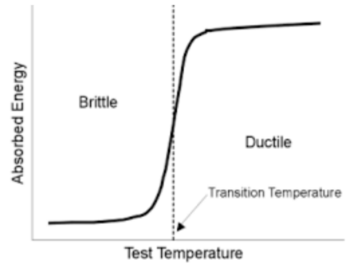


the specimen is positioned at the base as shown. Upon release, a knife edge mounted on the pendulum strikes and fractures the specimen at the notch, which acts as a point of stress concentration for this high- velocity impact blow. The pendulum continues its swing, rising to a maximum height h, which is lower than h. The energy absorption, computed from the difference between h and h, is a measure of the impact energy.

$$E = mg\Delta h = mg(h - h').$$

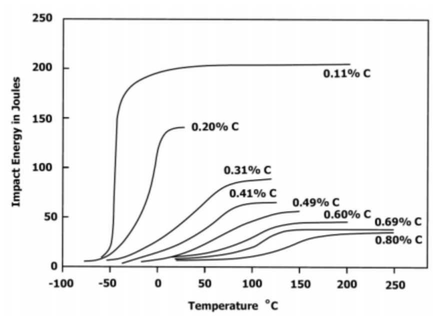
Question 38 *What else does impact test measure ?*

besides the absorbed energy, it also determines whether a material experiences a **ductile-to-brittle transition** with decreasing temperature or not. If so, what is the range of temperatures over which it occurs ?



Question 39 *Ductile vs Brittle material in energy absorption ?*

Ductile materials absorb higher energy until fracture compared to brittle materials. Below is a graph that shows the change in impact energy absorbed by carbon steels depending on the carbon content.

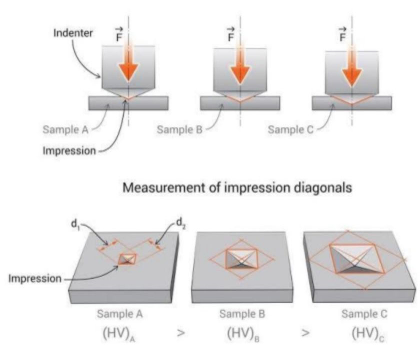


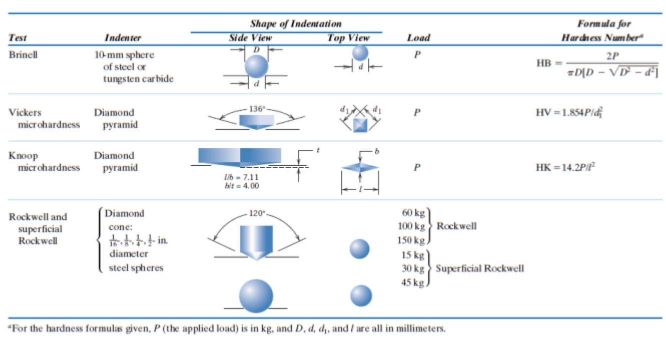
Question 40 *What is Hardness ?*

Hardness is the resistance of the material to localized plastic deformation (like a small dent, or a scratch depending on context).

Question 41 *Describe the Hardness test ?*

In a modern hardness test, a small indenter is forced into the surface of a material to be tested under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured and related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number. Most common hardness tests are the Rockwell, Vicker and Brinell tests. Hardness numbers are used primarily as a qualitative basis for comparison of materials.





Test	*Indenter*	*Shape of Indentation* *Side View*	*Top View*	*Load*	*Formula for Hardness Number*[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid	136°		P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid	$l/b = 7.11$ $b/t = 4.00$		P	$HK = 14.2P/l^2$
Rockwell and superficial Rockwell	Diamond cone: $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in. diameter steel spheres	120°		60 kg, 100 kg, 150 kg: Rockwell; 15 kg, 30 kg, 45 kg: Superficial Rockwell	

[a]For the hardness formulas given, P (the applied load) is in kg, and D, d, d_1, and l are all in millimeters.

Question 42 *Hardness and tensile stress/strength ?*

The harder the material the stronger it is. and there is a relation between them.

$$TS(\text{MPa}) = 3.45 \times \text{HB}$$

$$TS(\text{psi}) = 500 \times \text{HB}$$

Question 43 *What are the advantages of Hardness test over other tests ?*

1. They are simple and inexpensive—typically, no special specimen need be prepared, and the testing apparatus

2. is relatively inexpensive. The test is non-destructive—the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.

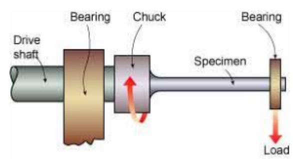
3. Other mechanical properties often may be estimated from hardness data, such as tensile strength

Question 44 *What is fatigue ?*

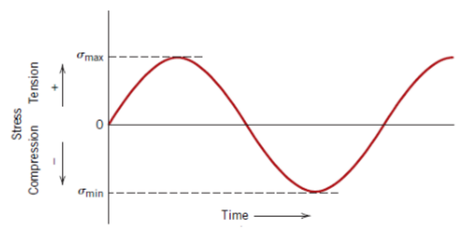
Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft, machine components). Under these circumstances, it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. The applied stress (positive and negative) may be axial (tension–compression), flexural (bending), or torsional (twisting) in nature. This is the first **time-dependent** behavior discussed.

Question 45 *The fatigue test.*

The most common type of test conducted in a laboratory setting employs a rotating– bending beam: alternating tension and compression stresses of equal magnitude are imposed on the specimen as it is simultaneously bent and rotated. In this case, R = -1.



Data are plotted as stress versus the logarithm of the number N of cycles to failure for each of the specimens. The S parameter is normally taken as either maximum stress (σ_{max}) or stress amplitude (σ_a) forming what is called the S-N curve.



$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

The range of stress is *defined as:*

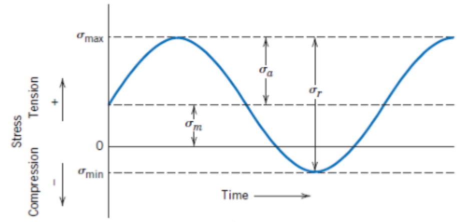
$$\sigma_r = \sigma_{max} - \sigma_{min}$$

The stress amplitude is *defined as:*

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

Finally, the *stress ratio R is defined as*

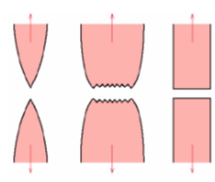
$$R = \frac{\sigma_{min}}{\sigma_{max}}$$



3 Lecture 6

Question 46 *When does the brittle/ductile behaviour exist ?*

Ones the elastic limit is exceeded, the bonds between the atoms break and the material behaves either in a ductile or brittle manner



A. Very ductile
B. Moderately ductile fracture
C. Brittle fracture

Question 47 *Explain plastic deformation:*

In ductile materials, the component continue to deform as the force is applied until fracture, this deformation is irreversible.

Question 48 *Do brittle material show plastic deformation ?*

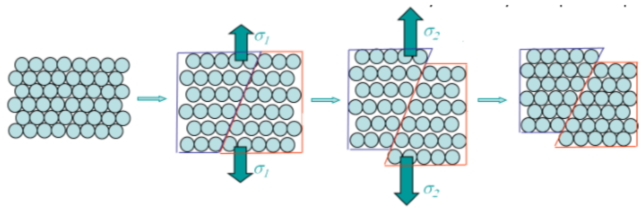
Yes, they do, yet this is not significant it is only small amount. As the applied tensile stress breaks the bonds between the atoms and divides the component into two pieces by **cleavage**. Brittle materials fail in **tension**

Question 49 *What is ductility ?*

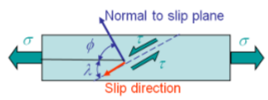
it is basically the motion of dislocations that causes plastic deformation before fracture.

Question 50 *What is the cause of plastic deformation ?*

It's basically caused by the slip of one plane of atoms relative to another in **SHEAR**.

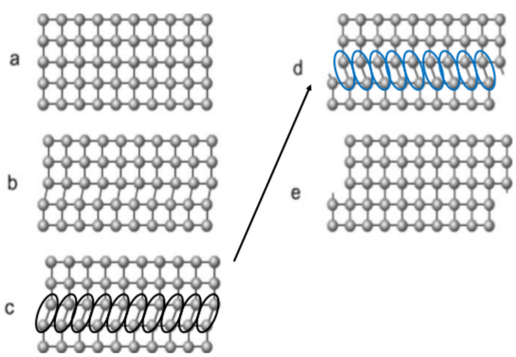


Basically the normal stress is resolved to shear and normal components along the several planes of atoms. When the shear component along a certain plane exceeds a critical value (that depends on the planar density), slip occurs. Slipping of atoms is the basically what translated to plastic deformation that we see with the naked eye



Question 51 *Explain slip in perfect crystals ?*

it involves breaking and forming of bonds between the atoms while the planes move along one another. This slipping requires so much energy.



This happens in perfect crystals that have no dislocations. (Hypothetical situation)

Question 52 *Define Real-life slip ?*

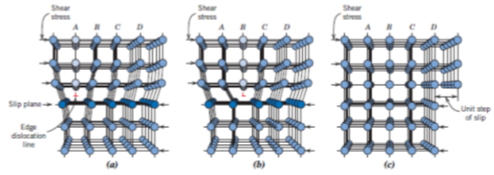
in also involves forming and breaking bonds but it is one at a time. That's why we call it dislocation slip/glide. It makes plastic deformation easier to occur, as the energy needed to break one bond at a time is lower than that needed to break a whole plane of bonds, look at the following figure.

Question 53 *What are the carriers of plasticity ?*

Dislocations are the carriers of plasticity, because in real life there are no perfect crystals.

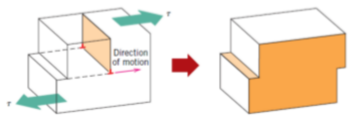
Question 54 *What happens to the number of dislocations during plastic deformation ?*

The number of dislocation increase dramatically !



Question 55 *Define the* ***Slip system*** *?*

It's a system that consists of slip plane and a slip direction. The process by which plastic deformation happens itself is called slip.



Question 56 *What are slip planes and directions ?*

Slip planes are planes which have the highest planar density, and slip direction are those which have the highest linear density.

Question 57 *Slip occurs first on which type of planes and directions ?*

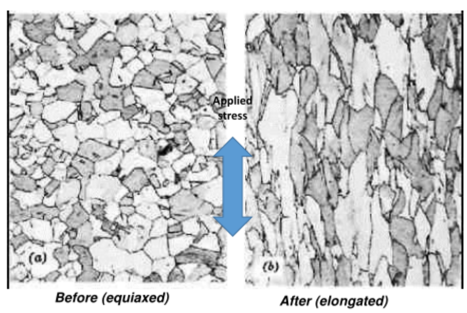
a smooth plane is the one in which atoms are dense and close together, and thus has higher planar density. So smooth planes are easier to slip.

Question 58 *For an FCC material what is the plane that has the highest planar density, or what is the slip plane ?*

it is (111). and the directions along the sides of this plane are the slip directions.

Question 59 *Ductility in polycrystalline materials ?*

Before deformation, the grains are **equiaxed** or have approximately the same dimensions in all direction. After deformation, grains are elongated in a direction parallel to the load/applied stress direction. (Only that direction). Polycrystalline materials are much stronger than their equivalent single crystalline and thus require higher stresses to initiate slip and yielding.



Question 60 *What is the relation between ductility and bond types in materials ?*

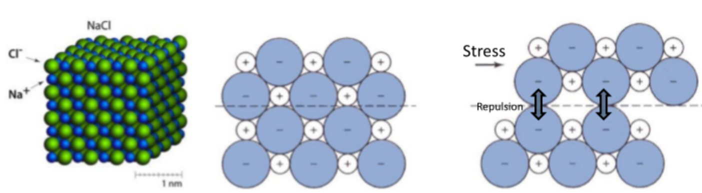
We know that covalent bonds ¿ Ionic ¿ Metallic in Strength. And thus covalent metals such as Silicon and diamond are less ductile than ionic ones such as ceramics .

Question 61 *Relation between ductility and strength of a material ?*

The more ductile the material the weaker. And the less ductile the stronger. Inverse relationship.

Question 62 *Why ceramics such as (NaCl) are brittle ?*

because their lattice is consisted of charged ions. Once slip starts and bonds are broken, ions of the same charge come in contact and they don not form any bonds due to repulsion. This leads to brittle fracture since once slip starts to occur, ions repel and fracture happens



Question 63 *How to Strengthen one material ?*

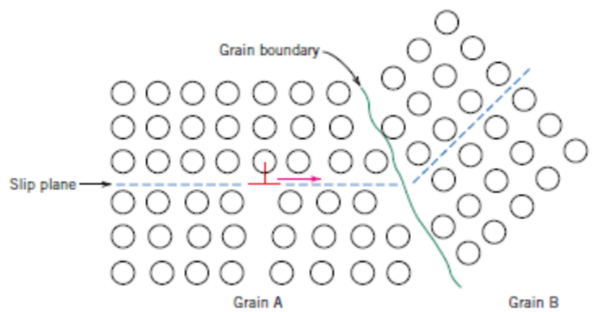
Strength (yield and tensile) are related to the ease with which plastic deformation can occur. So reducing the movement of dislocations, will increase the strength and thus decrease the ductility. **Restricting or hindering dislocation motion renders a material harder and stronger.**

Question 64 *What are the strengthening mechanisms ?*

- Grain size reduction
- Solid solution strengthening
- Strain hardening

Question 65 *What happens in grain size reduction technique ?*

We know that grain boundaries are a barrier to the dislocation movement, so in order to decrease dislocation and thus ductility and thus increase strength we increase the grain boundaries by reducing the grain size.



Small angle grain boundaries are not very effective in blocking dislocations. High-angle grain boundaries block slip and increase strength of they material .

Question 66 *How to increase the area of grain boundaries to better impede motion ?*

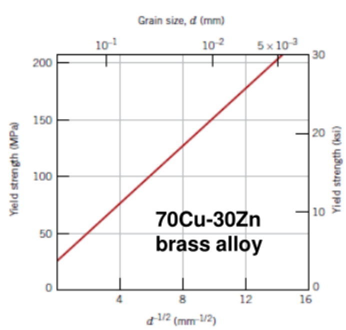
The finer the grains the larger the area of grain boundaries .

Question 67 *What is the Hall-Petch equation ?*

it is the relation that relates yield strength and grain size d.

$$\sigma_y = \sigma_0 + k_y(d) - 0.5.$$

where σ_o and k are constants for a particular material, d is the average grain diameter.

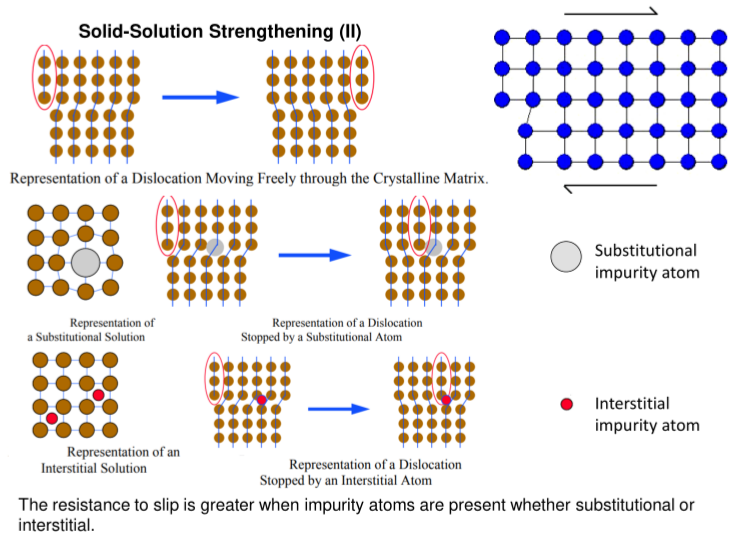


Question 68 *What are solid solutions ?*

means a commination of two solid or in other words an alloy :). Alloys are usually stringer than pure metals of the solvent.

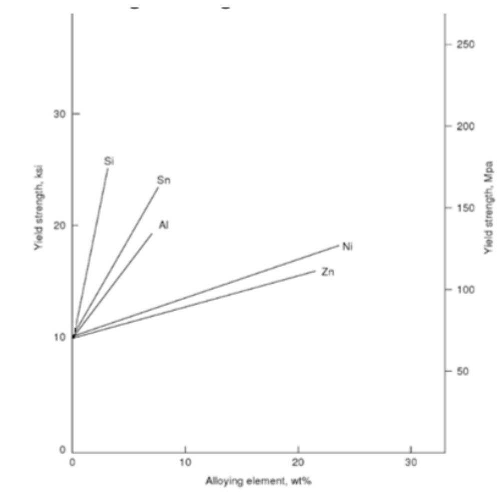
Question 69 *What happens in Solid-solution strengthening ?*

We use interstitial or substitutional impurities/defects to cause lattice distortion and as a result it hinders the dislocation movement.

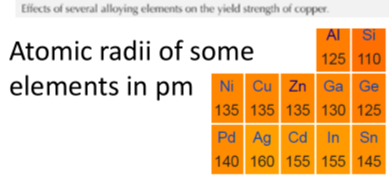


Question 70 *What makes the solid-solution technique make higher strength ?*

The more the difference between impurity and base material atom sizes (radii), the higher the strengthening. And the higher concentration of the impurity atoms the higher the strength. Look at the following copper materials treated with different impurities.



Effects of several alloying elements on the yield strength of copper.



The greatest strength happened with Silicon as the difference in radii is so large.

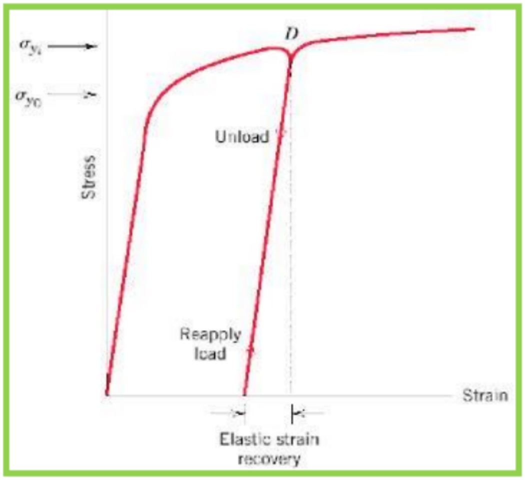
Question 71 *What happens in the Strain Hardening/Work Hardening/Cold Working?*

Ductile materials become more stronger when they are deformed plastically at temperatures below the melting point. We do this strain hardening in order to increase the dislocation density with applied stress. In this technique we do mechanical forces (like forging) in low temperatures below melting point. Th average distance between dislocations decrease and dislocations start blocking the motion of each other.

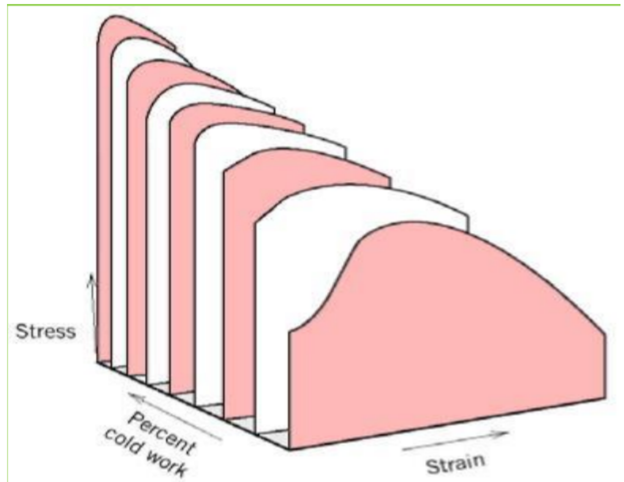
Question 72 *Calculate the percent cold work (%CW).*

$$\%CW = (\frac{A_0 - A_d}{A_0}) * 100.$$

%CW is just another measure of the degree of plastic deformation, in addition to strain.



New yield strength σ_{y_0} is higher than the initial yield strength, σ_{y_1}. The reason for this effect - strain hardening.



Yield strength and hardness are increasing as a result of strain hardening but ductility is decreasing (material becomes more brittle but strong).

Question 73 *What if we needed to do some Strain hardening to a material that is strain hardened ?*

We need first a heat treatment in 3 processes.

- Recovery
- Recrystallization
- Grain Growth (may or may not be a step)

This is a resonation to the state before the hard working.

Question 74 *What does heating do to a material in general ?*

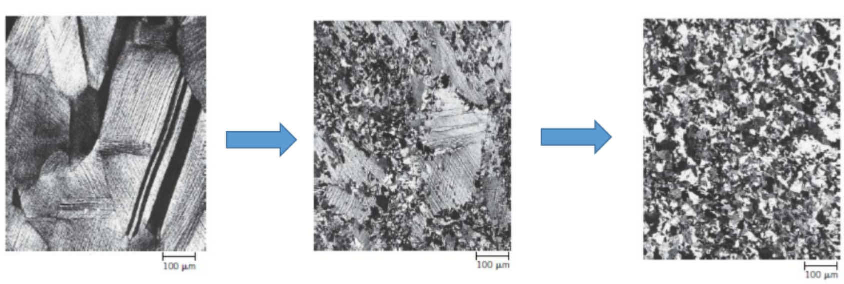
Heating in general allows materials to relief internal stresses/strains and annihilate (destroy) defects. Defects in general are distortions leading to stresses and strains. If atoms are given enough energy (through heating), they tend to move (diffuse) in a away that annihilates defects and associated stresses to a certain extent.

Question 75 *Discuss recovery :*

Heating $\rightarrow$ increased diffusion $\rightarrow$ enhanced dislocation motion $\rightarrow$ decrease in dislocation density by annihilation and rearrangement $\rightarrow$ relieve of the internal strain

Question 76 *Discuss Recrystallization:*

After recover some grains may be still strained. Those strained grained of cold-worked metal can be replaced, upon heating, by other strain-free (equiaxed) grains with low density of dislocations. Recrystallization is the nucleation and growth of new grains until they consume the while material. It depends on temperatures and time.



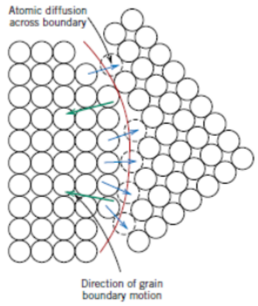
During recrystallization, grain-boundary motion occurs as the new grain form and then grow.

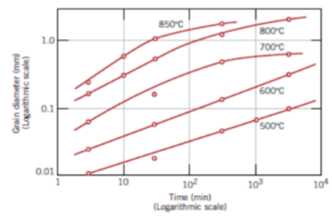
Question 77 *What is the Recrystallization temperature ?*

temperature at which the process is complete in one hour. It is typically 1/3 to 1/2 of the melting temperature (can be as high as 0.7 Tm in some alloys).

Question 78 *Discuss grain growth :*

If deformed polycrystalline material is maintained at annealing temperature following complete recrystallization, then further grain growth occurs.





The logarithm of grain diameter versus the logarithm of time for grain growth in brass at several temperatures.

Question 79 *What is the driving force in grain growth ?*

Driving force is reduction of grain boundary area. Big grains grow at the expense of the small ones.

Question 80 *Do grain growth happens only after recrystallization or deformation ?*

No, Grain growth during annealing occurs in all polycrystalline materials (i.e. they do not have to be deformed or recrystallized first).

Question 81 *What causes boundary motion ?*

Boundary motion occurs by diffusion of atoms across the grain boundary.