

Exam 2 Review Session

11/23

General Tips for Preparing!

1) Do the Sample Exam

If you fully understand the sample exam you should perform well

3) Look Over Past Lectures + Being Here

2) Look over previous HW Solutions

All solutions for past 7 HW are posted on canvas

4) Get a good night sleep

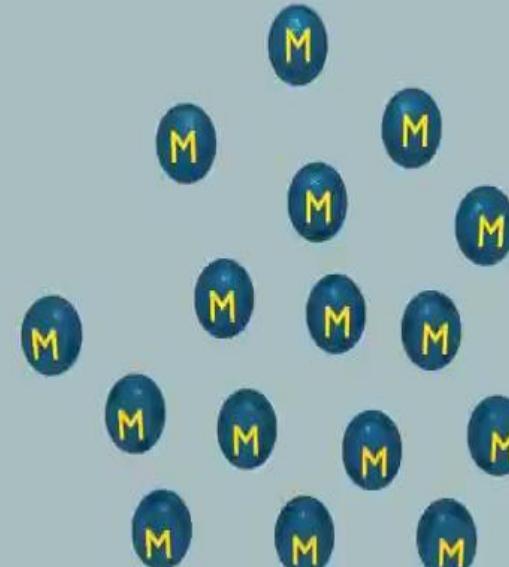
Relax you will do fine

*Polymer*s

Basic Concepts

Addition Polymerization

- **Monomers:** Small molecules that can be reacted into a polymer
 - This becomes the repeat unit
- **Polymer:** Many small molecules joined together, usually in a chain of some sort
- **Polymerization:** The type of reaction that can convert monomers into polymers ->



Polymers - Architecture

- The **Chain** is the most basic structure of a polymer
 - Polymers of the same material can vary by length, branching density, branch length, etc.
- Chains can take several configurations relative to their neighbors
 - Crystals occur when they are ordered
- Chains can be connected to their neighbors via cross-links
 - “Network solids”
- Non-chemically crosslinked chains interact through entanglements

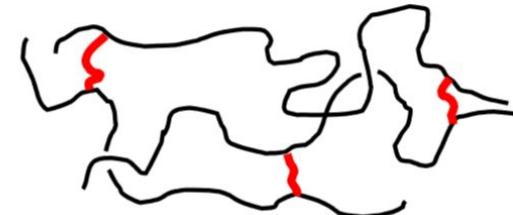
Linear Polymer



Branched Polymer

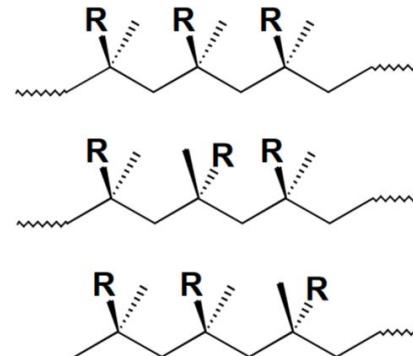


Network



Polymer Crystallinity

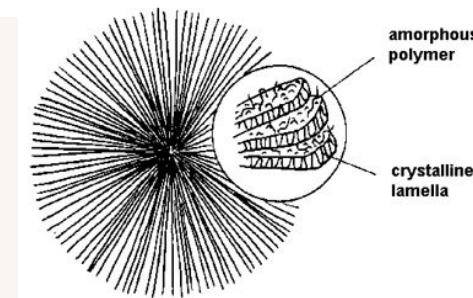
- **Crystallinity** occurs due to regularity and symmetry in the orientation of a polymer
- Polymers will tend to be either **semi-crystalline** or **amorphous** (e.g. It cannot crystalize)
- Key contributions
 - Presence of crosslinks
 - Prevents crystallization
 - Tacticity
 - Regularity promotes crystallization
 - Side group size
 - Large groups/branching hinder packing
- We'll cover packing in a couple slides



Isotactic

Syndiotactic

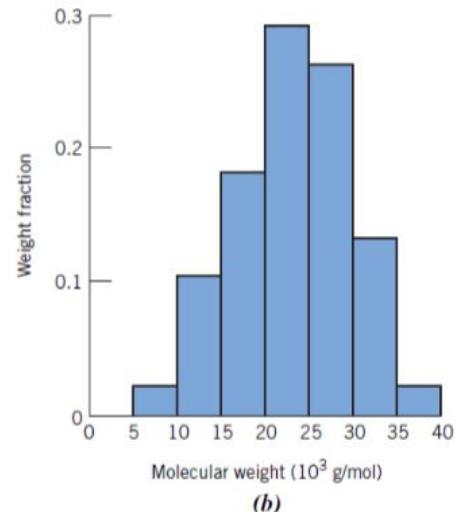
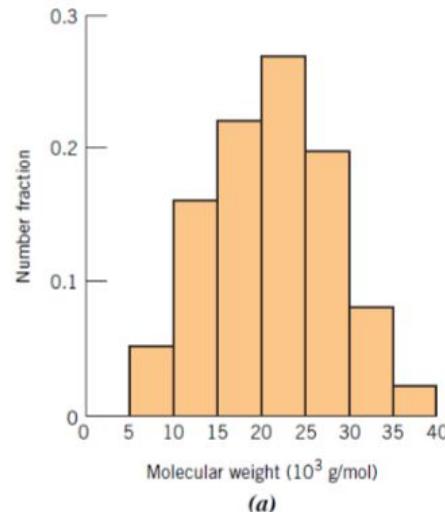
Heterotactic or
Atactic (random)



Molecular Weight

- The go-to measurement for a polymer
- Important determinant of behavior and properties
- Represents a distribution
 - Number average
 - Common average
 - Weight average
 - Factors longer chains more heavily
 - Dispersity
 - Ratio of the two averages
- All three together give a good understanding of the polymer and how it will likely behave

/ Polymer Structures



Molecular Weight Calculations

Number average (M_n): $\Sigma x_i m_i$

Weight average (M_w): $\Sigma w_i m_i$

$$w_i = x_i m_i / M_n$$

Degree of Polymerization (how many repeat units are in the chain): M_n/m

PDI (dispersity): M_w/M_n

- x_i = mole fraction of each weight class; w_i = weight fraction of each weight class; m_i = mean weight of each weight class; m = molar mass of 1 repeat unit

Polymer Classes

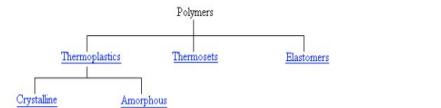
Elastomers: Key Requirements

Long polymer chains

Chains joined into a network structure

Network **above** T_g (high degree of flexibility)

Substantially amorphous



- Thermoplastics

Polystyrene
Polyvinylchloride

- Elastomers

Synthetic rubbers
Poly-cis-isoprene

- Thermosets

Phenolic Resins
Melamines
epoxies

(a) Linear

(b) Branched

(c) Cross-Linked

(d) Network

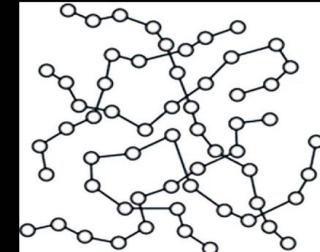
Polystyrene and PVC are examples of thermoplastics: can be re-processed into different shapes and products

Thermosets are 3-D, crosslinked networks. Cannot usually be reprocessed. Most elastomers are thermosets.

MSJChem
Tutorials for IB Chemistry

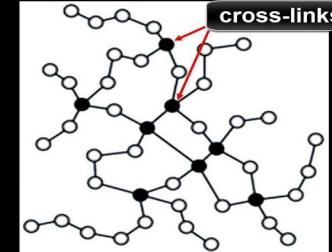
Polymers

Thermoplastic polymer



weak intermolecular forces between polymer chains

Thermosetting polymer



strong covalent bonds between polymer chains

Problem 1

For the following polymer combinations, Explain which material is more likely to be crystalline

- a. Isotactic PVC vs Atactic PVC
- b. Polyethylene vs Polypropylene
- c. Block Copolymer versus Graft Copolymer
- d. Rubber Elastomer versus Polycarbonate
- e. Thermoset or Thermoplastic

Solution

- a.) **Isotactic PVC** - due to the tacticity it is more likely to crystallize since atactic tacticity has a harder time lining up sidechain which lower crystallinity
- b.) **Polyethylene** - Polypropylene has a more complicated side chain compared to polyethylene that can increase chances of entanglement.
- c.) **Block Copolymer** - Grafting copolymer (branched polymer) have higher chances to entangle due to the extending branches of repeat units off of the main chain.
- d.) **Polycarbonate** - Elastomers by definition of the material are amorphous
- e.) **Thermoplastic** - Thermosets have complicated network and crossworking that complicated the crystallization process that is not found in the linear/branched structure of Thermoplastics.

Problem 2

Find the Weight average number of the polymer given the information below.

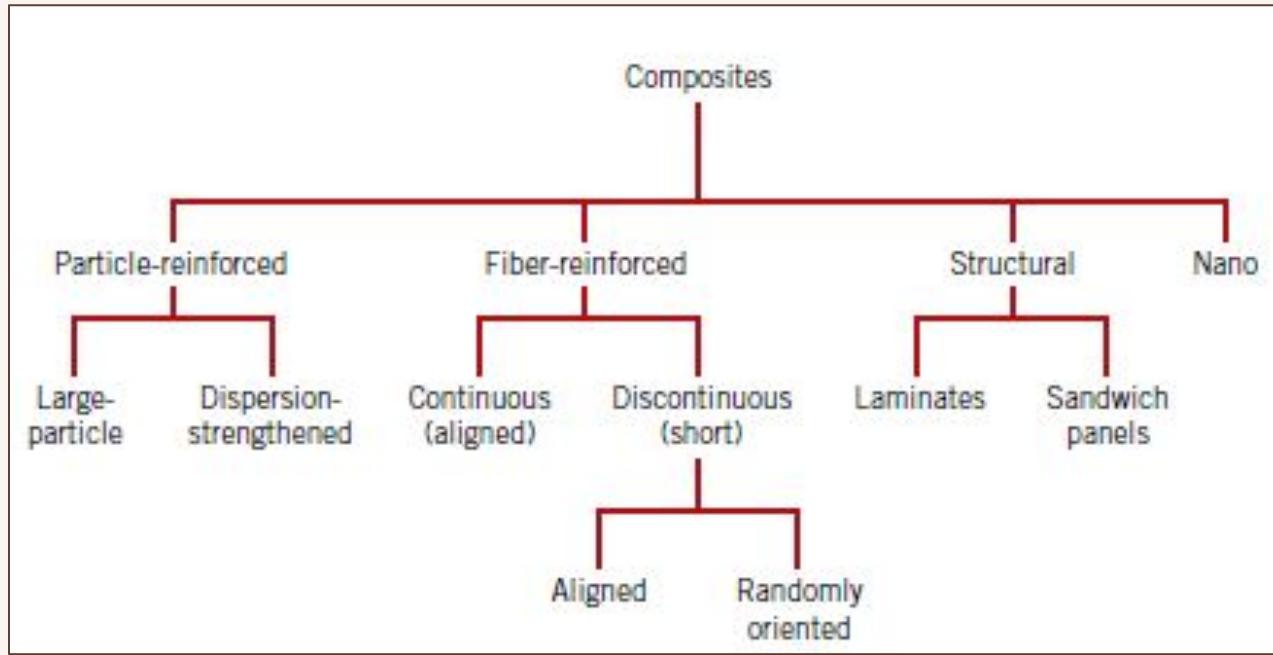
Average Molecular Weight	Weight fraction
22,000 g/mol	40%
26,000 g/mol	6%
42,000 g/mol	14%
53,000 g/mol	40%

Solution

2.) M	w _i	M _{w,i}	M _w
22,000 g/mol	40 %	22,000 · 4	8800 g/mol
26,000 g/mol	6 %	26,000 · 06	1560 g/mol
42,000 g/mol	14 %	42,000 · 14	5880 g/mol
53,000 g/mol	40 %	53,000 · 4	20800 g/mol

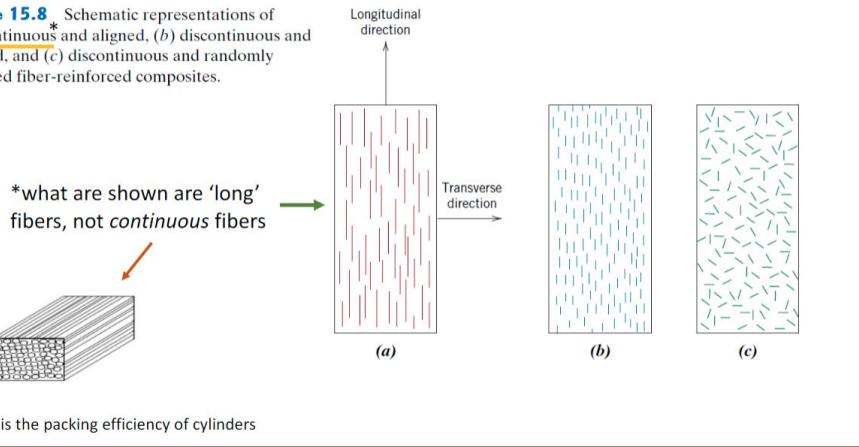
$$\overline{M_w} = \sum m_i w_i = 8800 + 1560 + 5880 + 20800$$
$$\overline{M_w} = 37,040 \text{ g/mol}$$

Composites



Matrix + Filler Phase

Figure 15.8 * Schematic representations of (a) continuous and aligned, (b) discontinuous and aligned, and (c) discontinuous and randomly oriented fiber-reinforced composites.



Benefits of Composites:

- Improve Strength and Strain
- Improve Toughness
- Increase/decrease thermal conductivity
- Electric conductivity.
- Permeability
- Fire resistance

What is needed for a successful Matrix?

1. Connecting source to distributed stress evenly to all fibers. (High Ductility & smaller strain than fibers)
2. Protect individual fibers from harsh mechanical forces and chemical reactions.
3. Protect individual brittle cracks between fibers and fibers preventing catastrophic failure under stress.

Understand How to Calculate Modulus!

Longitudinal Modulus of an Aligned, Continuous Fiber Composite 'Rule of Mixtures'

$$E_{cl} = E_m V_m + E_f V_f \quad (15.10a)$$

or

$$E_{cl} = E_m(1 - V_f) + E_f V_f \quad (15.10b)$$

E_m and E_f are moduli of matrix and fiber, respectively

V_m and V_f are volume fractions of matrix and fiber, respectively

Transverse Modulus of an Aligned, Continuous Fiber Composite

$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f} \quad (15.15)$$

which reduces to

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m} = \frac{E_m E_f}{(1 - V_f) E_f + V_f E_m} \quad (15.16)$$

Longitudinal Modulus: Stress is applied along the direction where the fibers are aligned

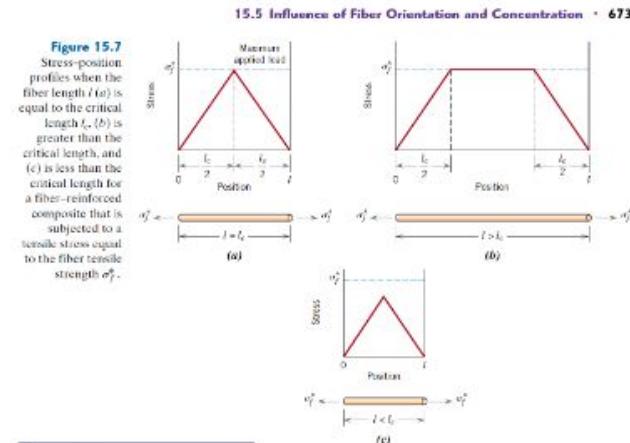
Rule of Mixtures: We can use the modulus of the matrix and the filler to approximate a total modulus for the composite

Transverse Modulus: Stress is applied perpendicular to the direction where the fibers are aligned

Continued

- Longitudinal strength is dominated by fiber strength.
 - Transverse strength; these factors include properties
 - the fiber and matrix individually,
 - the fiber–matrix bond strength,
 - The presence of voids.
-
- 1)** Fiber Length
 - 2)** Dispersion of Filler
 - 3)** Fiber Orientation (aligned vs random vs discontinuous)
 - 4)** Fiber Geometry

Fiber Length Dependency



$$l_c = \sigma_f d / 2\tau_c$$

where

d = fiber diameter

τ_c = fiber-matrix bond strength

σ_f = fiber yield strength

Fibre length

We have already mentioned that fibres are only effective when loaded along their length. It is seldom practicable to apply loads to fibres in composites by direct tension. Normally the load is applied to the matrix, and this load is transferred through shear through the interface to the fibre.

As an example of this principle, it is easy to apply a substantial axial load to a long pencil by gripping with both hands in pulling along the axis of the pencil. But with a short pencil there is not much length over which a grip can be achieved, and trying to apply too much axial force via the fingers merely results in the pencil slipping away by shear.

With very long fibres, the load can be effectively transferred by this shear mechanism, and apart from a region near the ends of the fibres, most of the fibre is stressed to take its full share of the external load, which is the main objective. But for short fibre lengths, there may be insufficient length over which the shear can be transferred (Figure 1.18). The minimum effective length depends on the aspect ratio (length/diameter ratio) of the fibre and the strength of the fibres and the interface. For many glass fibre/plastics composites the critical fibre length is typically only a few hundred micrometres.

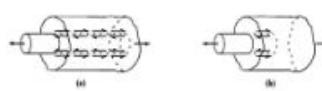
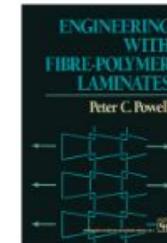


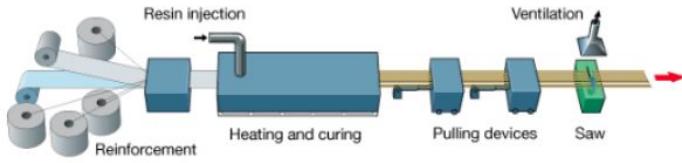
Figure 1.18 The interface transfers load from matrix to fibre: (a) sufficient length; (b) insufficient length.



Different Ways to Make Composites

Composite Fabrication: A Few Approaches

Pultrusion



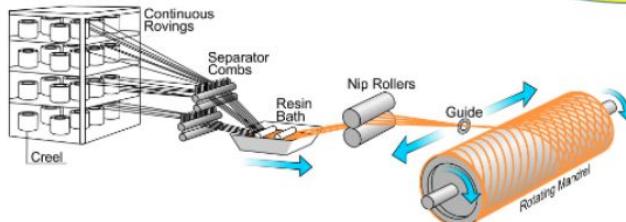
<https://fiberline.com/pultrusion>

Wet Compression Molding



<https://www.compositesworld.com/blog/post/wet-compression-molding>

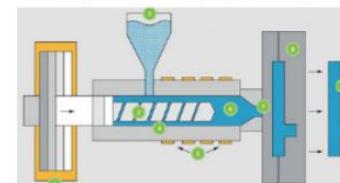
Filament Winding



<http://www.nuplex.com/composites/processes/filament-winding>

Consider resin rheology

Injection Molding



<https://www.machinedesign.com/materials/basics/rapid-injection-molding>

Problem 1

When designing a material, I want to create a composite with a longitudinal Modulus of 25.5 GPA. The only filler I have around me is Polycarbonate with a modulus of 2.38 GPA. The Magnesium I am using to make this matrix has a modulus of 45 GPA. What volume fraction of filler must I use to get Composite Modulus I need?

Solution

Problem 1

$$E_{CL} = 25.5 \text{ GPA}$$

$$E_f = 2.38 \text{ GPA}$$

$$E_m = 45 \text{ GPA}$$

$$V_f = ?$$

$$E_{CL} = E_f V_f + E_m V_m \rightarrow V_m + V_f = 1$$

$$E_{CL} = E_f V_f + E_m (1 - V_f)$$

$$E_{CL} = E_f V_f + E_m - E_m V_f$$

$$E_{CL} - E_m = E_f - E_m (V_f)$$

$$V_f = \frac{E_{CL} - E_m}{E_f - E_m}$$

$$V_f = \frac{25.5 \text{ GPA} - 45 \text{ GPA}}{2.38 \text{ GPA} - 45 \text{ GPA}}$$

$$V_f = 45.75\%$$

Mechanical Properties of Materials

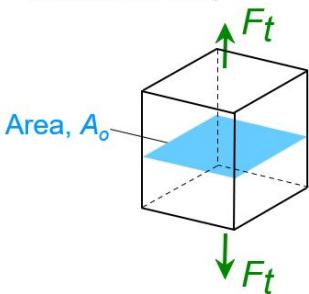
Key Objectives

- **Stress** and **strain**... What are their physical definitions and why are they used instead of load and deformation?
- **Elastic behavior**... When loads are small, how much deformation occurs? What types of materials will deform the least?
- **Plastic behavior**... At what points does permanent deformation occur? What materials are the least susceptible to permanent deformation?
- **Toughness** and **ductility**... What are they and how do we measure them?

Engineering Stress and Strain

Stress

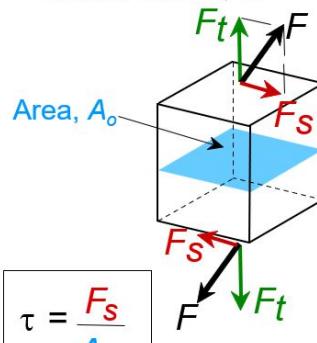
- Tensile stress, σ :



$$\sigma = \frac{F_t}{A_o} = \frac{\text{lb}_f}{\text{in}^2} \text{ or } \frac{\text{N}}{\text{m}^2}$$

original area before loading

- Shear stress, τ :



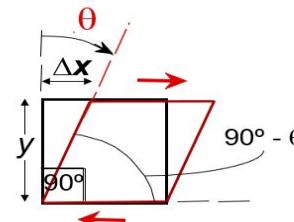
$$\tau = \frac{F_s}{A_o}$$

∴ Stress has units:
 N/m^2 or lb_f/in^2

- Tensile strain:

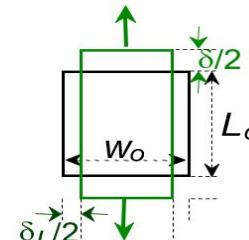
$$\epsilon = \frac{\delta}{L_o}$$

- Shear strain:



Strain

- Lateral strain:



$$\epsilon_L = -\frac{\delta_L}{W_o}$$

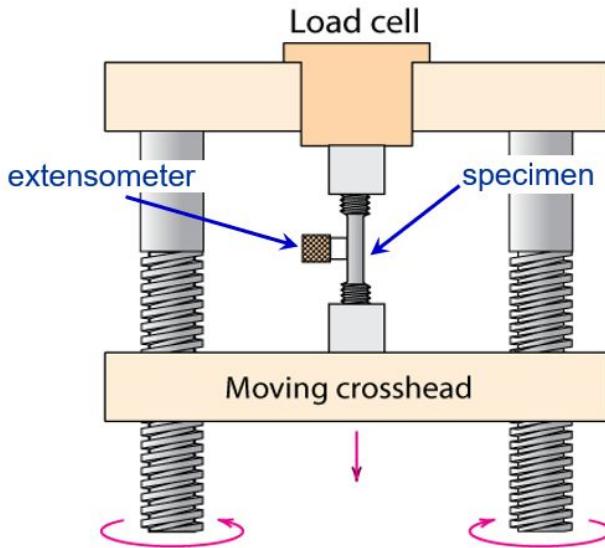
$$\gamma = \Delta x/y = \tan \theta$$

Strain is always dimensionless.

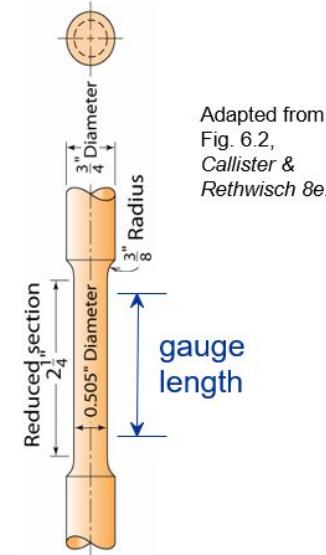
Adapted from Fig. 6.1(a) and (c), Callister & Rethwisch 8e.

Stress-Strain Testing

- Typical tensile test machine



- Typical tensile specimen



Adapted from
Fig. 6.2,
Callister &
Rethwisch 8e.

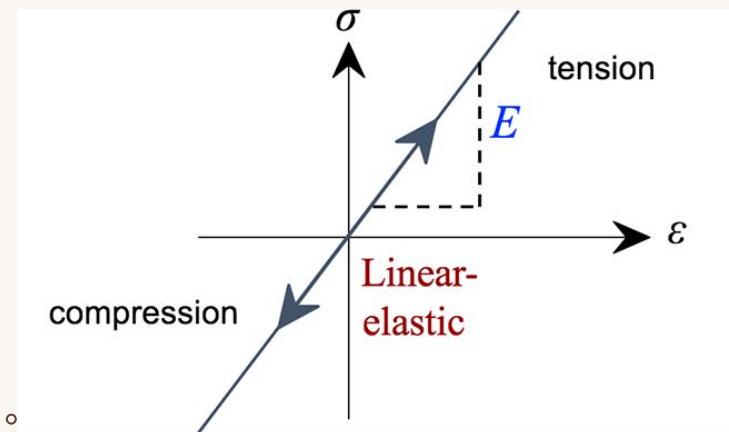
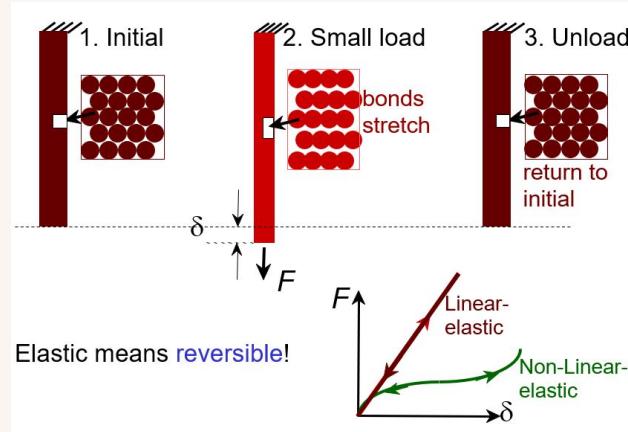
Adapted from Fig. 6.3, Callister & Rethwisch 8e. (Fig. 6.3 is taken from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, p. 2, John Wiley and Sons, New York, 1965.)

Tensile Testing Demonstration



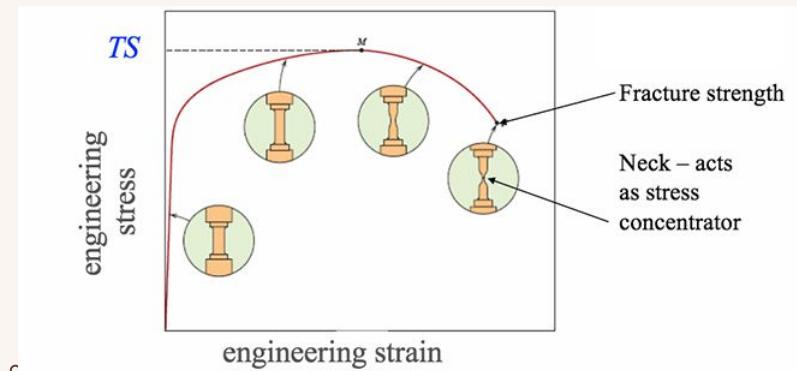
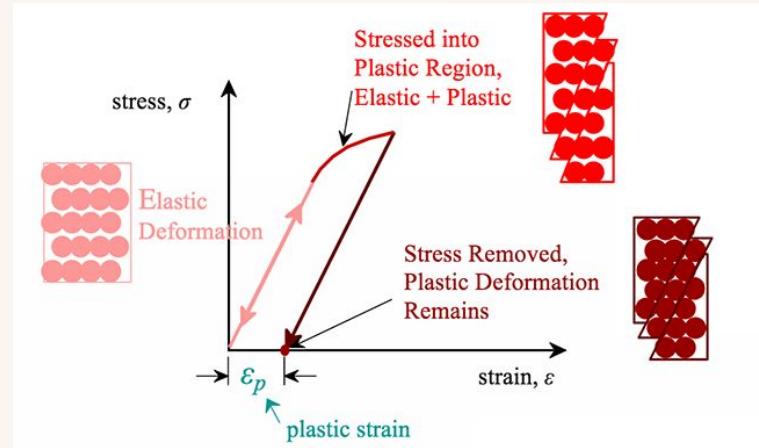
Elastic Region

- Elastic deformation occurs in the region where the material can be deformed and subsequently return to its original configuration upon releasing the load (small tensile load). Mathematically, this is defined as Hooke's Law, and E is the proportionality constant, known as Young's modulus; that is, the slope of the stress-strain curve in the linear region is the **modulus of elasticity**.
- In general, a larger modulus of elasticity suggests a stronger bond. Different materials will exhibit different elastic moduli depending on the varying atomic structures.



Plastic Region

- After some point of elastic deformation, the strain is no longer proportional to the applied stress and deformation becomes **permanent**. The material has moved into the plastic deformation regime, and the **yield strength**, determined by a parallel line offset of 0.002 strain, defines the transition of the material from elastic to plastic deformation.
- As stress is increased past the yield strength, the curve proceeds to a maximum at which point it curves downward toward the fracture point. The maximum is the **tensile strength** and the **fracture point** is the point at which the material ultimately breaks.

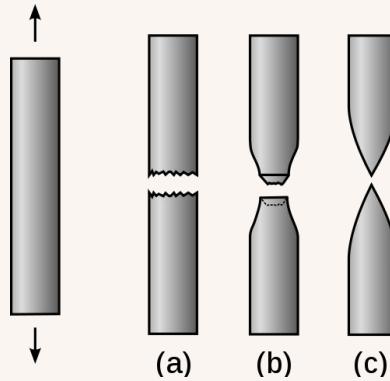
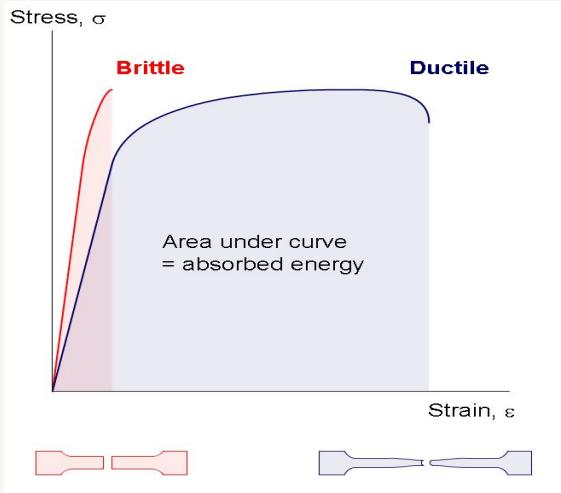


Ductility

- **Ductility** is the ability of a material to be drawn or plastically deformed with minimal fracture, i.e., how malleable the material is.

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$

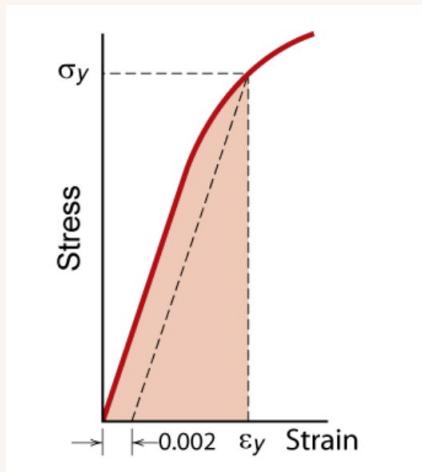
$$\%RA = \frac{A_o - A_f}{A_o} \times 100$$



- Ductility can be quantified by reading the value of strain at fracture on the stress-strain plot or by doing a percent reduction in area calculation.

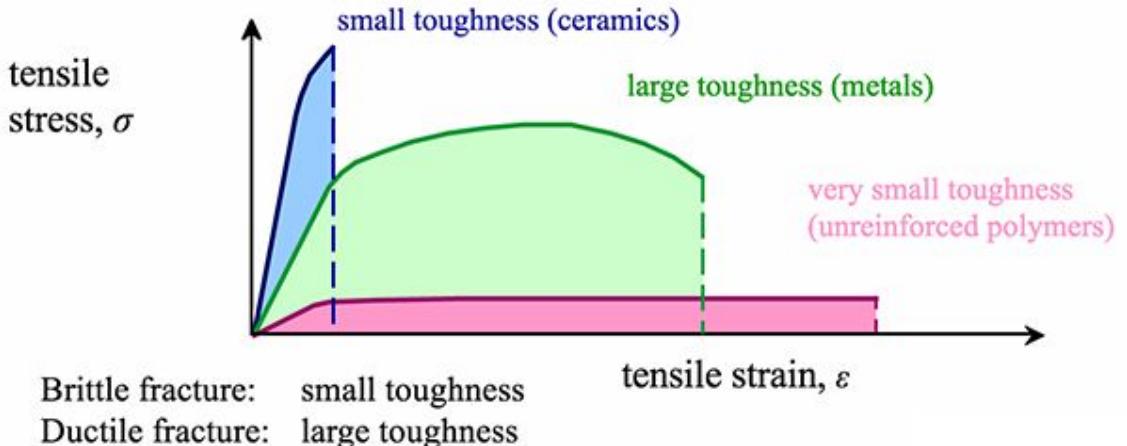
Resilience

- In effect, **resilience** is the ability of a material to store energy, which is best achieved in the elastic region. Computationally, resilience represents the area under the engineering stress-strain curve taken to yielding.



Toughness

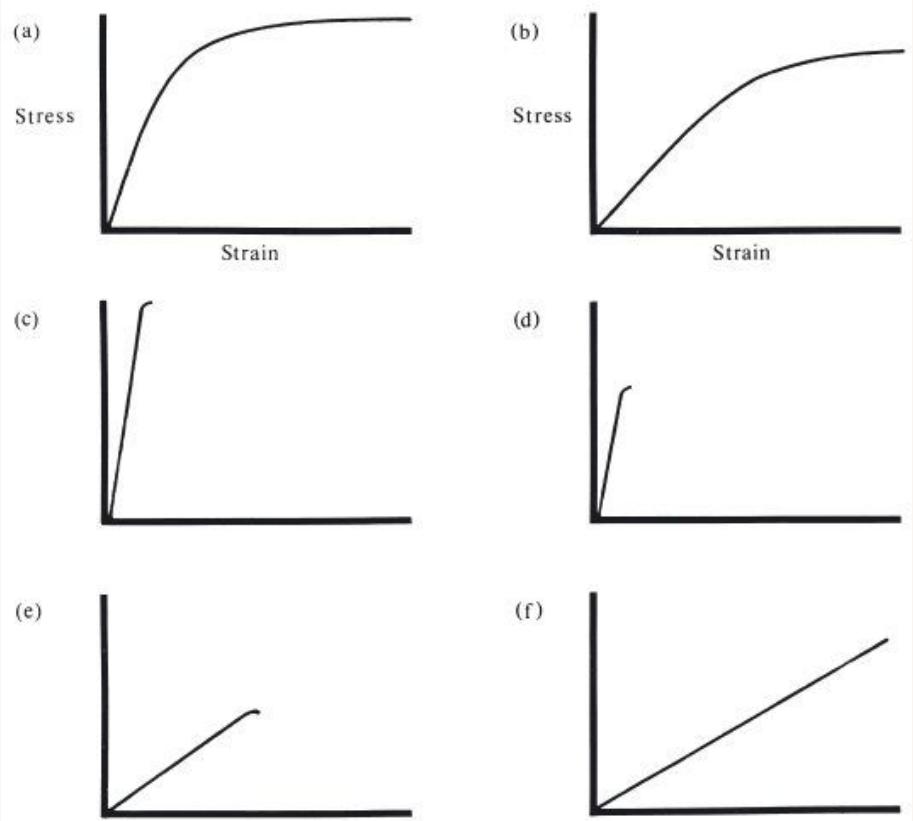
- **Toughness** is how much energy can be absorbed and still maintain integrity of the material. For example, consider the case of a car in a demolition derby. The car is allowed to continue the competition as long as it is capable of moving. It does not matter how many hits and how much destruction has been done to the car, but rather as long as the car can move it can stay in the competition. The toughness of the car is based on how many hits and how much damage the car can sustain and continue in the competition. In the case of materials, the amount of energy that the material can absorb plastically before fracturing is the toughness



Summary

Term	Meaning	Graphically
Stiff	How much stress we need to strain a material. Proportional to Young's modulus of elasticity	Samples with higher slopes are more stiff
Brittle	Undergoes little to no plastic deformation	The sample fractures right after linear region
Ductile	Undergoes significant plastic deformation.	The sample fractures before. Large strain before fracture
Toughness	How much energy can the sample take before it fractures	Area under curve before fracture. Large area = high toughness
Yield strength	The maximum stress before plastic deformation and after elastic deformation	Stress at the end of the linear region

Term	Meaning	Graphically
Maximum strength	Maximum strength before necking and after plastic deformation	Maximum stress of the stress-strain curve
Resilience (Bonus...)	Amount of energy before undergoing plastic deformation	Area under linear region of stress-strain curve. You can calculate it

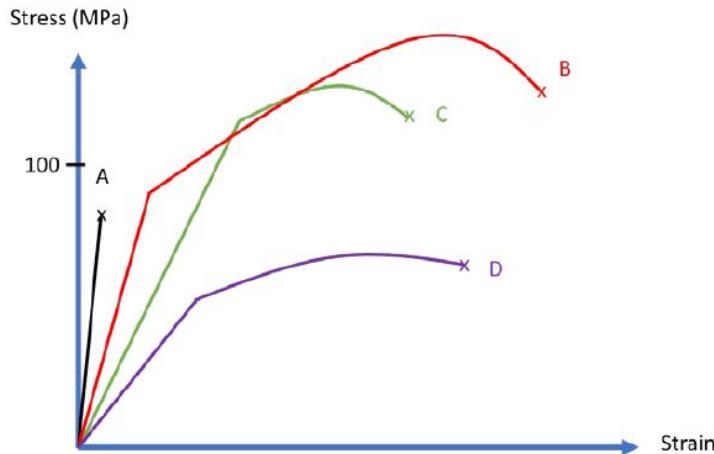


Six different types of stress-strain graphs. These may be used to characterise materials as follows: (a) rigid, strong, tough, ductile; (b) flexible, tough; (c) rigid, strong, brittle; (d) rigid, weak, brittle; (e) flexible, weak, brittle; (f) flexible, resilient.

Example Problems

Problem 1

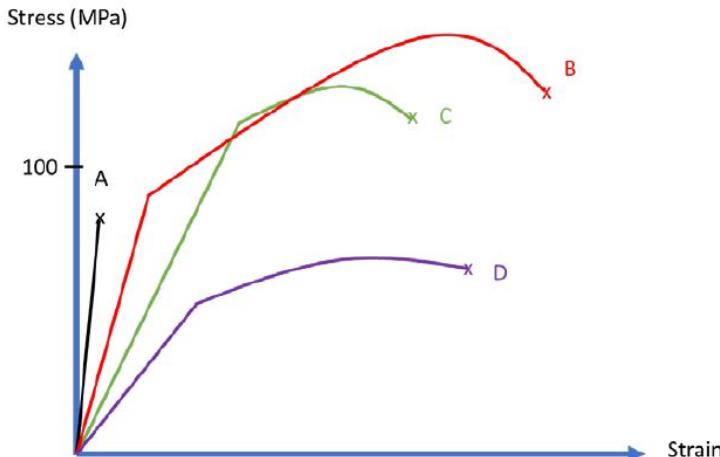
- 1- Based on the stress-strain diagram (X-marks the fracture) below which material has:
- Greatest stiffness
 - Largest fracture toughness
 - Lowest ductility



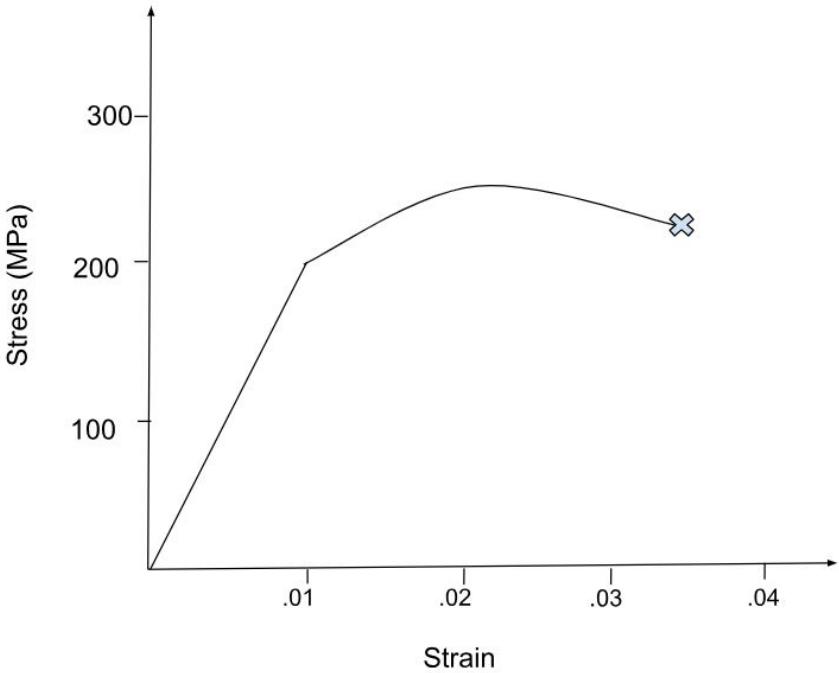
Problem 1 (Solution)

1- Based on the stress-strain diagram (X-marks the fracture) below which material has:

- a. Greatest stiffness A
- b. Largest fracture toughness B
- c. Lowest ductility A



Problem 2



Find the following Values on the graph:

- a. Young's modulus
- b. Tensile Strength
- c. Fracture Strain
- d. Yield Point
- e. Total energy in the elastic region.

Solution

Problem 2

a.) $\sigma = E \epsilon \Rightarrow E = \sigma / \epsilon$ $\sigma = 200 \text{ MPa}$
 $E = 200 / .01 = 20,000 \text{ MPa} = \boxed{20 \text{ GPA}}$

b.) $\boxed{\sigma_F = 250 \text{ MPa}}$

c.) $\epsilon @ \sigma_F$
 $\epsilon_p = .035$

d.) $200 \text{ MPa} @ \epsilon = .01$

e.) Total energy of elastic region = Area under
elastic Region

Use triangle formula

$$\frac{1}{2} b \cdot h \rightarrow \frac{1}{2} \epsilon_y \sigma_y$$

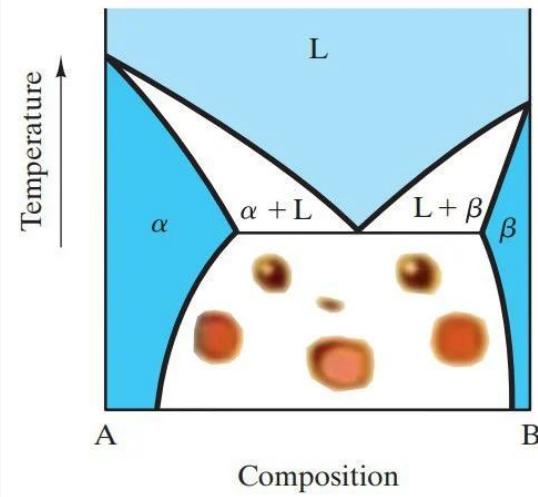
$$\frac{1}{2} (.01)(200 \text{ MPa}) = \boxed{11}$$

Phase diagrams

me: doesn't study phase diagrams

me: does badly on the quiz

me:



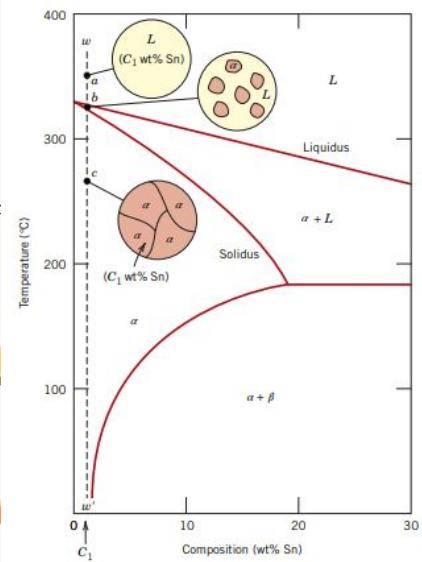
- **Phase** is a region of uniform and physical and chemical properties
 - **Misconception** : Alpha/Beta/Gamma/Liquid/etc.. are phases, lead and tin are not !
- **Phase diagram** : map that shows the conditions (**P, T, V, etc...**) that allow the existence of different phases (Solid, liquid, alpha solid solution) at equilibrium (No change as time passes)
- Anyone remembers those terms ? :
 - Isotherms (Phase boundary)
 - Isomorphous

Make sure that you can :

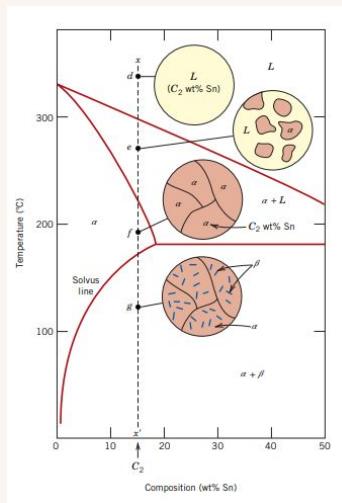
- Identify the phases at a given temperature and concentration
- Calculate the weight composition of the phases present at a given temperature and concentration using the lever rule
- Identify the weight composition of the constituents of the pure phases present at a given temperature and concentration using isotherms
 - Can you tell the difference between the last two bullet points ?
- **This is almost an exhaustive list of the things you could be asked for on the phase diagram topic**

Microstructural development

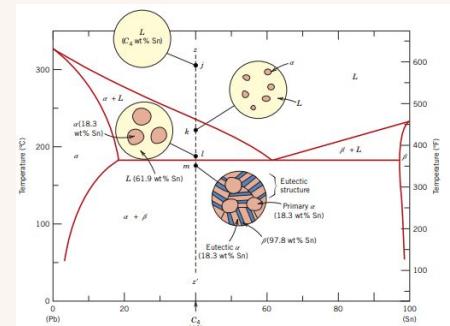
But there is a one caveat : **Microstructural development**



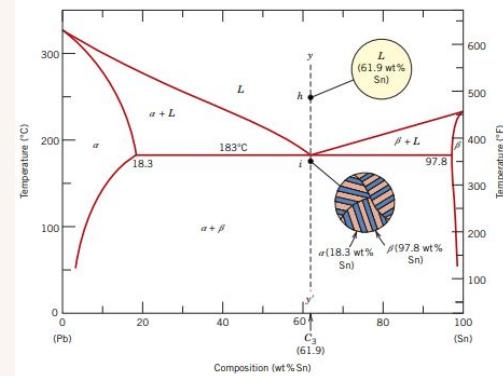
Case 1 : Lower than max solubility



Case 2 : higher than max solubility at room temperature but lower than max solubility limit



Case 3 : Right at eutectic temperature



Case 4 : between 2 and 3

Cracks (The practical guide)

Cracking

- Brittle materials have fracture strengths that are much lower than the theoretical ones (based on bonding energy calculations)
 - Griffith : Oh, we missed cracks
- Cracks act as stress raisers
 - This is observable in brittle fracture of materials
 - a is length of crack | ρ_t is radius of curvature
 - K shows how big is concentration stress
- Are cracks more significant at tensile or compressive Stress ? Why can glass handle compression better than Tensile stress)

$$K_t = \frac{\sigma_m}{\sigma_0} = 2 \left(\frac{a}{\rho_t} \right)^{1/2}$$

$$\sigma_m = 2\sigma_0 \left(\frac{a}{\rho_t} \right)^{1/2}$$



eliephant

Strengthening mechanics :

- All these basically involve applying some process that can make normal glass do a little bit better
- Gorilla glass (Ion exchange)
 - Adding Potassium atoms that replaces Sodium atoms, Potassium atoms are larger
- Tempered glass
 - Applying a cool gas to the surface of heated glass, creates kind of coating on the glass. The surface experiences compressive forces making it stronger and reducing impact of cracks

*Thanks For Coming
Out*

ANY QUESTIONS?