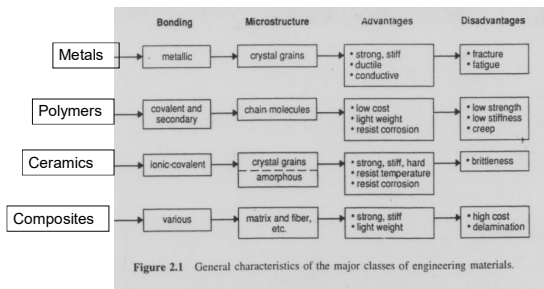


Chapter 1 Summary:



Composites consist of:

1. Combination of two or more materials □ Composite = matrix + fiber (filler):

- **Matrix:**
 - material component that surrounds the fiber.
 - Usually a **ductile, or tough, material w/ low density**
 - **Strength usually = 1/10 (or less) than that of fiber**
 - Examples include: thermoplastic or thermoset
 - Thermoset most common (epoxy, phenolic)
 - Serves to hold the fiber (filler) in a favorable orientation.

• **Fiber aka reinforcing material aka Filler:**

- **Materials that are strong with low densities**
 - Examples include glass, carbon or particles.

2. Designed to display a combination of the best characteristics of each material i.e. fiberglass acquires strength from glass and flexibility from the polymer.

3. Matrix and filler bonded together (adhesive) or mechanically locked together!

Where are composites used???????



CFRP – carbon fiber reinforced composite.



GFRP – glass fiber reinforced composite

Composites in industry

- Engineering applications

- Aerospace
- Automobile
- Pressure vessel and pipes

- Any place where high performance materials are desired



Turret Shield



Industrial Spring



Medical Table



Bullet proof shields

www.compositflex.com

Nature of Composites:

- Advantages:
 - High strength to weight ratio (low density high tensile strength) or high specific strength ratio!
 - 1020 HRS spec strength = 1 (E6 in)
 - Graphite/Epoxy, spec strength = 5 (E6 in)
 - High creep resistance
 - High tensile strength at elevated temperatures
 - High toughness
 - Generally perform better than steel or aluminum in applications where cyclic loads are encountered leading to potential fatigue failure (i.e. helicopter blades).
 - Impact loads or vibration – composites can be specially formulated with high toughness and high damping to reduce these load inputs.
 - Some composites can have much higher wear resistance than metals.
 - Corrosion resistance
 - Dimensional changes due to temp changes can be much less.
 - Anisotropic – bi-directional properties can be design advantage (i.e. helicopter blades)

Nature of Composites:

- Disadvantages (or limitations):
 - Material costs
 - Fabrication/ manufacturing difficulties
 - Repair can be difficult
 - Wider range of variability (statistical spread)
 - Operating temperature can be an issue for polymeric matrix (i.e. 500 F). Less an issue for metal matrix (2,700 F).
 - Properties non-isotropic makes design difficult!
 - Example – video test in line w/ fibers 10X stronger vs fibers oriented at an angle.
 - Inspection and testing typically more complex.

Classification of Composite Materials by Matrix

1. Metal matrix
2. Ceramic matrix
3. Polymer (Resin) matrix

Ceramic (Cermets)

Metal

Polymer (resin)

Most common – also called **fiber reinforced polymer**

Classification of Composite Materials by Matrix:

- **Polymer matrix composites or Fiber Reinforced Polymer (FRP)**
 - Fibers generally glass, carbon or kevlar
 - Matrix can be:
 - Thermoplastics: PE, Nylon, PS, PP, PC, PVC
 - Thermosets: Epoxy, polyester, phenolics
 - Have high strength and stiffness to weight ratio
 - Aerospace, sporting goods marine
 - Examples: GFRP aka fiberglass (polyester or epoxy and glass), CFRP (polyester or epoxy and carbon), KFRP (polyester or epoxy and Kevlar)

Filler = ? Matrix = ?

Layered Composites

Coordinate System
 Lamina – 1,2,3
 Laminate – x,y,z

Matrix- A homogeneous base material that forms the bulk of a composite material layer.

Fibers- Bonded or embedded reinforcing fibers that are usually responsible for the anisotropy of the composite.

Lamina- A composite material in sheet form usually referred to as a layer or ply. The material properties of a layer is usually determined through an equivalent homogenization (smearing) process.

Laminate- A stack of lamina joined together in arbitrary directions, referred to as a composite lay-up.

Ranking of Most Common Fibers for FRP

Property	Glass	Carbon	Kevlar
Strength	Worst	In - between	Best
Stiffness	Worst	Best	In - between
Cost	Best	Worst	In - between
Weight	Worst	Best	In-between

Manufacturing FRP (see video)

- Hand lay-up (http://www.youtube.com/watch?v=_GDQpnahtwk&list=PL9FC6FF2112573125&index=2)
- Filament winding or Pultrusion (http://www.youtube.com/watch?v=4MjHnZ80c_Y)
- Resin Transfer (or) Injection Molding (RTM)

<http://www.ckcomposites.com/>

<http://www.scaled.com/index.html>

Classification of Composite Materials by Matrix:

- **Metal matrix composites (MMC):**
 - Metal matrix: Al, Ti, Mg, Fe, Cu, Ni
 - Example: Al-SiC (silicon carbide)
 - Example: Al-Al₂O₃ (aluminum oxide)
 - High strength, high stiffness, abrasion resistance, dimensional stability, high temperature and toughness.

= matrix

Classification of Composite Materials by Matrix:

- **Ceramic matrix composites (CMC):**

- Silicon carbide-silicon carbide (SiC-SiC)
- Same material both matrix and filler BUT filler different form such as whiskers, chopped fibers or strands to achieve preferred properties.

 = matrix

Nature of Composites:

- The strength of the composite depends primarily on the amount, arrangement and type of fiber (or particle) reinforcement in the resin.
- Typically, the higher the reinforcement content, the greater the strength. In some cases, glass fibers are combined with other fibers, such as carbon or aramid (Kevlar29 and Kevlar49), to create a "hybrid" composite that combines the properties of more than one reinforcing material.

Classification of Composite by Filler Type:

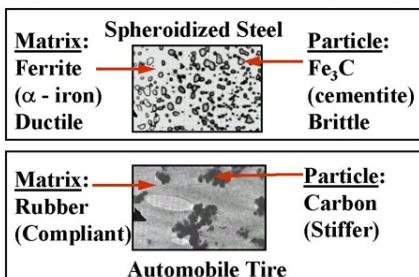
- Particle-reinforced composites
- **Fiber-reinforced composites**
- Structural composites

Particle Reinforced Composites:

- Particles used for reinforcing include:
 - ceramics and glasses such as small mineral particles,
 - metal particles such as aluminum,
 - and amorphous materials, including polymers and carbon black.
- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix.
- Particle reinforced composites support higher tensile, compressive and shear stresses
- Particles are also used to produce inexpensive composites.
- Examples:
 - automobile tire which has carbon black particles in a matrix of elastomeric polymer.
 - spheroidized steel where cementite is transformed into a spherical shape which improves the machinability of the material.
 - concrete where the aggregates (sand and gravel) are the particles and cement is the matrix.

Figure 1. Examples for particle-reinforced composites. (Spheroidized steel and automobile tire)

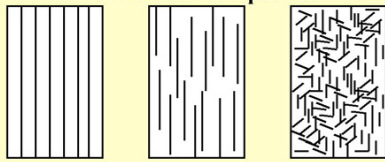
Particle Reinforced Composites



Fiber-reinforced Composites:

- Reinforcing fibers can be made of metals, ceramics, glasses, or polymers that have been turned into graphite and known as carbon fibers. Fibers increase the modulus of the matrix material. The strong covalent bonds along the fiber's length gives them a very high modulus in this direction because to break or extend the fiber the bonds must also be broken or moved. Fibers are difficult to process into composites which makes fiber-reinforced composites relatively expensive. Fiber-reinforced composites are used in some of the most advanced, and therefore most expensive, sports equipment, such as a triathlon racing bicycle frame which consists of carbon fibers in a thermoset polymer matrix. Body parts of race cars and some automobiles are composites made of glass fibers (or fiberglass) in a thermoset matrix.
- The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites. Applications involving totally multidirectional applied stresses normally use discontinuous fibers, which are randomly oriented in the matrix material. Consideration of orientation and fiber length for a particular composites depends on the level and nature of the applied stress as well as fabrication cost. Production rates for short-fiber composites (both aligned and randomly oriented) are rapid, and intricate shapes can be formed which are not possible with continuous fiber reinforcement.

Fiber Orientations in Fiber Reinforced Composites



Continuous and aligned fibers Discontinuous and aligned fibers Discontinuous and randomly oriented fibers

Note: Fiber composite manufacturers often rotate layers of fibers to avoid directional variations in the modulus.

The modulus of the entire composite, matrix plus reinforcer, is governed by the rule of mixtures:

LONGITUDINAL LOADING

ISO-STRAIN CONDITION: Deformation of matrix and fibers is the same.

Force parallel to fiber direction

$$S_c = S_m * V_m + S_f * V_f$$

$$E_c = E_m * V_m + E_f * V_f$$

S = Tensile Strength
E = Modulus of Elasticity
V = Volume Fraction
m = Matrix
f = Fiber
c = Composite

TRANSVERSE LOADING

ISO-STRESS CONDITION: Matrix and fibers are under the same stress. ($S_m = S_f = S_c$)

Force perpendicular to fiber direction

$$E_c = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

S = Tensile Strength
E = Modulus of Elasticity
V = Volume Fraction
m = Matrix
f = Fiber
c = Composite

Stiff and Strong!!

See case study at end!!

Soft and Weak!

Structural Composites:

- The properties of structural composites depend on:
 - Constituents
 - Geometrical design

Structural Composites:

- Common structural composite types are:
 - Laminar:** Is composed of two-dimensional sheets or panels that have a preferred high strength direction such as is found in wood and continuous and aligned fiber-reinforced plastics. The layers are stacked and cemented together such that the orientation of the high-strength direction varies with each successive layer. One example of a relatively complex structure is modern ski and another example is plywood.

Structural Composites:

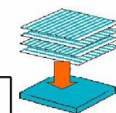
- Common structural composite types are:
 - Sandwich Panels:** Consist of two strong outer sheets which are called face sheets and may be made of aluminum alloys, fiber reinforced plastics, titanium alloys, steel. Face sheets carry most of the loading and stresses. Core may be a honeycomb structure which has less density than the face sheets and resists perpendicular stresses and provides shear rigidity. Sandwich panels can be used in variety of applications which include roofs, floors, walls of buildings and in aircraft, for wings, fuselage and tailplane skins.

Show example (ref: bh user's conference)

Structural Composites

Stacked and bonded fiber-reinforced sheets

-stacking sequence: e.g., 0/90
 -benefit: balanced, in-plane stiffness

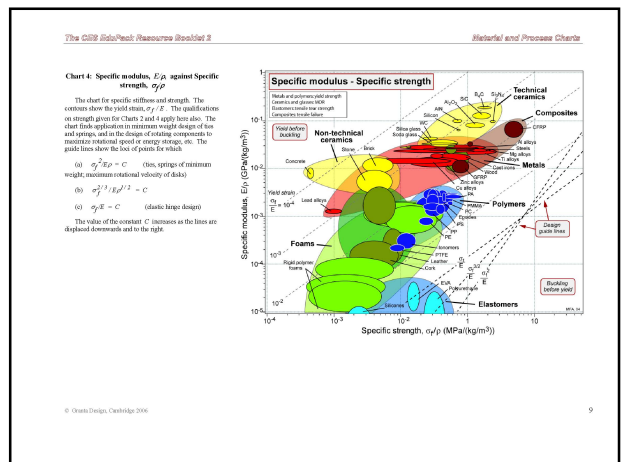
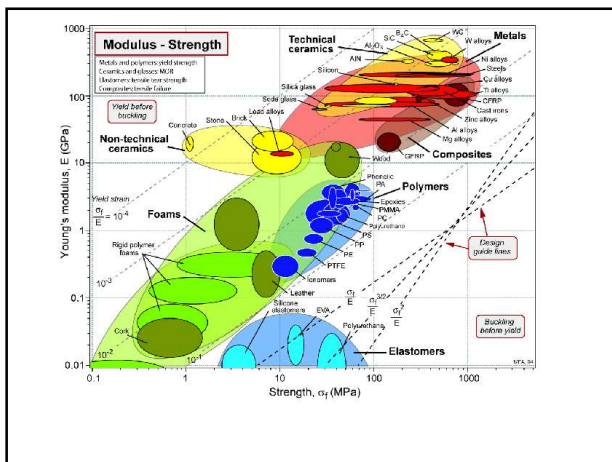
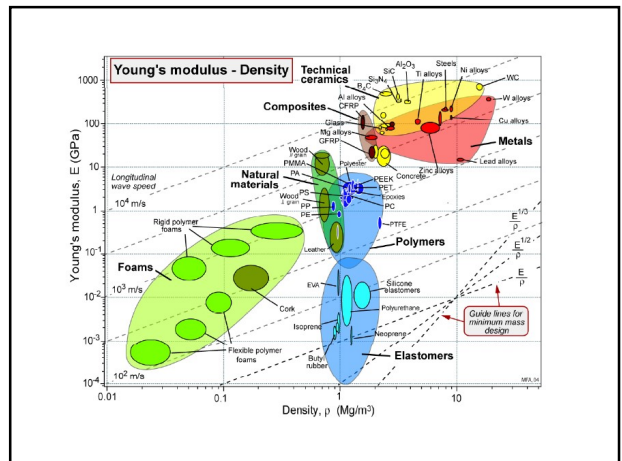
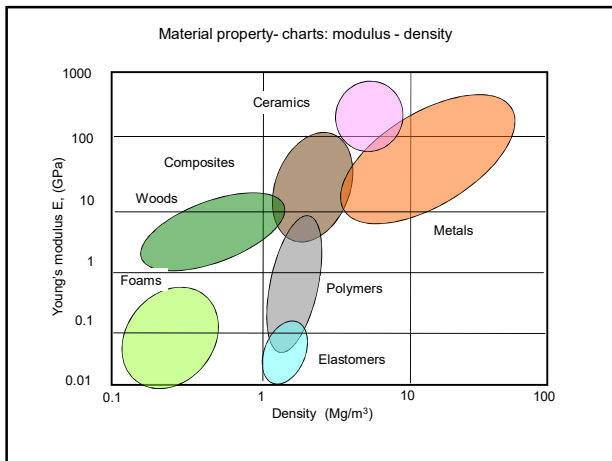


Sandwich panels

-low density honeycomb core
 -benefit: small weight, large bend stiffness

face sheet
 adhesive layer
 honeycomb

Fabricated sandwich panel



Neat Links!!!

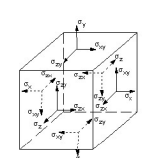
- <http://www.scaled.com/index.html>
- http://composite.about.com/ql/dynamic/offsite.htm?site=http%3A%2F%2Fpoisson.me.dal.ca%2Fdesign_projects%2F96_97%2Fcomposite%2F
- http://en.wikipedia.org/wiki/Composite_material
- http://www.youtube.com/watch?v=_GDqxnahwbk&list=PL9FC6FF2112573125&index=2

Good manufacturing videos

REMAINING SLIDES REFERENCE ONLY – No need to print out!!!!

Case Study: Generating Properties for FE Analysis of Composites

- **Orthotropic material data requires nine values to be fully described**
 - Three Young's moduli (E_x, E_y, E_z)
 - Three Poissons ratio ($\nu_{xy}, \nu_{yz}, \nu_{xz}$)



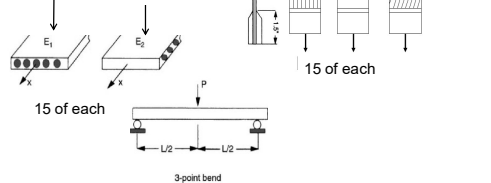
$$\begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_z \\ \epsilon_{xy} \\ \epsilon_{yz} \\ \epsilon_{xz} \end{bmatrix} = \begin{bmatrix} 1/E_x & 0 & 0 & 0 & 0 & 0 \\ -\nu_{yx}/E_y & 1/E_y & 0 & 0 & 0 & 0 \\ -\nu_{zx}/E_z & 0 & 1/E_z & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{xy} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{yz} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{xz} \end{bmatrix} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{bmatrix}$$

symm

Project work completed

- Tested 75 specimens

- 3 different volume fractions.
 - Tensile test at 0°, 90°, 10° off axis
 - 3 point bend test at 0° and 90°
- Applied over 150 strain gages
- Applied 120 tabs for tensile specimens

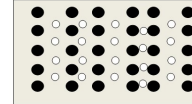


Project work completed

- Researched Mechanics of Composites

- To obtain theoretical data we used the Rule of Mixtures

- Why the rule of mixtures?



Beige = Resin
Black = Fibers
White = Voids

Typical Material Properties

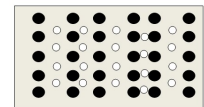
- **Grafil 34-700 carbon fiber tows**
 - Tensile tow strength $\sigma = 700$ ksi
 - Tensile Modulus $E = 34,000$ ksi
 - Density $\rho = .065$ lbm/in³
- **Newport 301 Epoxy Resin**
 - Tensile strength $\sigma = 8300$ psi
 - Tensile Modulus $E = 460$ ksi
 - Shear Modulus $G = 500$ ksi
 - Density $\rho = .0441$ lbm/in³



NEWPORT
ADHESIVES AND COMPOSITES, INC.
A subsidiary of MITSUBISHI RAYON CO., LTD.

Rule of Mixtures (cont.)

- F = Fibers
- R = Resin
- C = Composites
- V_F = Fiber volume fraction
 - Density
 - Longitudinal Modulus
 - Transverse Modulus



Beige = Resin
Black = Fibers
White = Voids

$$V_F = \frac{V_F}{V_C}$$

$$\rho_C = \rho_F \cdot V_F + \rho_R \cdot (1 - V_F)$$

$$E_1 = E_F \cdot V_F + E_R \cdot (1 + V_F)$$

$$E_2 = \frac{E_F \cdot E_R}{E_R \cdot V_F + E_F \cdot (1 - V_F)}$$

Rule of Mixtures (cont.)

- In Plane Shear Modulus
- Major Poisson's ratio

- Longitudinal Strength $G_{12} = \frac{G_F \cdot G_R}{G_R \cdot V_F + G_F \cdot (1 - V_F)}$

$$\nu_{12} = \nu_F \cdot V_F + \nu_R \cdot (1 - V_F)$$

$$\sigma_C = \sigma_F \cdot V_F + \sigma_R \cdot (1 - V_F)$$

Rule of Mixtures (cont.)

- This gives :

- E_1, E_2, G_{12} & ν_{12}

- The remaining missing values can be approximated using an assumption of transverse isotropy (Mil-Handbook-17)

- $E_3 = E_2, G_{21} = G_{32}, \nu_{21} = \nu_{32}$

- Out of plane Shear Modulus

- $G_{21} = (E_2) / (2(1 + \nu_{21}))$

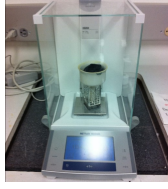
- Estimate or measure ν_{21}

Finding Volume Fraction



Composite Specimen in Nitric Acid

$$v_f = \frac{W_f / \rho_f}{W_c / \rho_c}$$



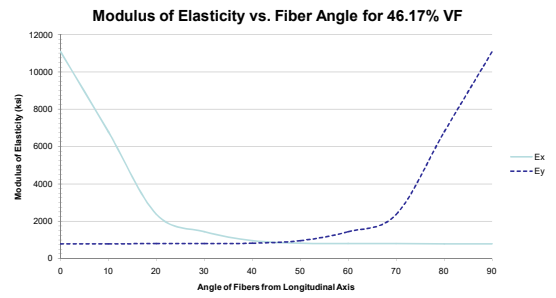
Determining mass of fibers after acid bath

$$v_v = 1 - \rho \left[\frac{m_f}{\rho_f} + \frac{m_m}{\rho_m} \right]$$



Fibers in bookner

Modulus Based on Fiber Angle



See material summary sheet!!

