Goals for this unit

• Survey composite materials (Ch. 14)
  – Fiber reinforced materials
    » Natural (*wood, foam, coral*)
    » Synthetic (*fiber reinforcement, concert, foams*)
  – Large aggregate composites
  – Several special types

• Understand properties of composites
  – Averaging schemes
  – Mechanical properties

➢ Multifunctional materials (*from properties of individual phases*)
Classification of Composites

Composites

Particulate
- Large Particle
- Dispersion Strenthened

Fiber
- Continuous
- Discontinuous
  - Aligned
  - Random

Structural
- Laminates
- Sandwich Panels

Synthetic Fiber-Reinforced Composites

- One of the most common composite types
  - Micron scale reinforcing fibers (stronger/stiffer)
    » Glass fibers
    » Higher moduli fibers (“advanced composites”)
  - Matrix material is frequently a polymer
    (weaker/softer/less brittle/inexpensive)

- Continuous
- Chopped
- Weaved
Fiberglass Fibers

» Glass fiber-reinforced polymer
» Different compositions of glass (consider electrical, thermal, chemical and mechanical properties)

- Strong interfacial bond between fibers and matrix to transfer loads effectively between phases

Advanced Composites

• Higher moduli fibers than glass
• Matrix can be polymer, ceramic or metal
  – PMCs, CMCs, MMCs
• Many materials were developed for military applications (e.g. “stealth” structures)
• Conversion to other markets
  – Marine, aviation, civil engineering structures, automotive components, sporting goods (costs still quite high)
14.3 Property Averaging

- Properties of composite represent some average of the constituent properties.
- The “average” is extremely sensitive to geometry:
  - parallel to fibers
  - perpendicular to fibers
  - in a uniformly dispersed aggregate.
Composite properties are intermediate between two materials

Stage I - elastic deformation with intermediate
Stage II - matrix yields
Failure - Non-catastrophic. When fibers fracture, you now have new fiber length and matrix is still present

Volume Fraction in Fiber Composites

- Elastic modulus is dependent on the volume fraction of fibers
- “Rule of mixtures” equation (again)
  - $E$ - elastic modulus, $V$ - volume fraction, $m$ - matrix, $f$ - fiber
  - upper bound
    
    \[
    E_c = E_m V_m + E_f V_f
    \]
  - lower bound
    
    \[
    E_c = \frac{E_m E_f}{E_f V_m + E_m V_f}
    \]
Rule of Mixtures

$$E_c = E_m V_m + E_f V_f$$

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

Tensile Strength

- In longitudinal direction, the tensile strength is given by the equation below if we assume the fibers will fail before the matrix:

$$\sigma^*_{c} = \sigma^*_{m} V_m + \sigma^*_{f} V_f$$
Example

- Calculate the composite modulus for polyester reinforced with 60 vol% E-glass under iso-strain conditions.
  - \( E_{\text{polyester}} = 6.9 \times 10^3 \text{ MPa} \)
  - \( E_{\text{E-glass}} = 72.4 \times 10^3 \text{ MPa} \)

\[
E_c = (0.4)(6.9x10^3 \text{ MPa}) + (0.6)(72.4x10^3 \text{ MPa}) = 46.2 \times 10^3 \text{ MPa}
\]

Influence of Fiber Length

- Mechanical properties depend on:
  - mechanical properties of the fiber
  - how much load the matrix can transmit to the fiber
  - depends on the interfacial bond between the fiber and the matrix

- Critical fiber length - depends on
  - fiber diameter, fiber tensile strength
  - fiber/matrix bond strength
Influence of Fiber Length

Critical fiber length - $L_c$
- “Continuous” fibers
  $L >> 15 L_c$
- “Short” fibers are anything shorter 15 $L_c$

$$L_c = \frac{\sigma_f d}{2\tau_c}$$

where
- $d$ = fiber diameter
- $\tau_c$ = fiber-matrix bond strength
- $\sigma_f$ = fiber yield strength

![Figure 17.7 Stress-strain profile when fiber length $L_f$ is equal to the critical length $L_c$: (a) $L_f$ is greater than the critical length, and (b) $L_f$ is less than the critical length for a fiber-reinforced composite that is subjected to a tensile stress equal to the fiber tensile strength $\sigma_f$.

Interfacial Bond Strength

- In polymer matrix and metal matrix composites (PMCs and MMCs), it is important that interfacial bond strength be high, because fibers are the stronger phase.
- In ceramic matrix composites (CMCs), the matrix is strong but brittle, so desirable for interfacial bond strength to be low (“fiber pullout” is desired to increase toughness or resistance to fracture.)
Large Aggregate Composites

- Particles reinforce the matrix phase
- Most common example is concrete
  - rock (coarse) and sand (fine) aggregates
    - usually chosen from locally available deposits
  - aluminosilicate (cement) matrix
    - Portland cement (Ca-aluminosilicates)
- Weight of concrete used each year exceeds that of all metals combined

\[
\begin{align*}
\text{Upper Bound} & \quad E_c = E_m V_m + E_p V_p \\
\text{Lower Bound} & \quad E_c = \frac{E_m E_p}{E_m V_m + E_p V_p}
\end{align*}
\]
Sandwich Panel

Composites Summary

- Reinforced composite materials include fiber (both natural and synthetic) and particulate (aggregate) reinforced composites
- Property averaging schemes depend on the quantities, shape and orientation of reinforcement phase

*Reading: relevant sections of Ch. 14