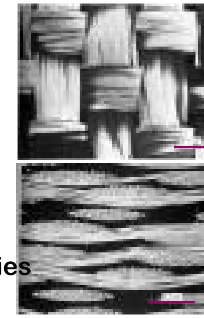
Chapter 17: Composite Materials

Issues to address...

- What are the classes and types?
- Why are composites used instead of metals, ceramics, or polymers?
- How do we estimate composite stiffness and strength?
- What are some typical applications?

Terminology/Classification

- **Composite Definition:**
  multiphase material w/significant proportions of ea. phase
- **Matrix:**
  -The continuous phase
  -Purpose:
    transfer σ to other phases
    protect phases from environ.
  -Classification: MMC, CMC, PMC
    metal ceramic polymer
- **Dispersed Phase:**
  -Purpose: enhance matrix properties
    MMC: increase σ_y, TS, creep
    CMC: increase K_c
    PMC: increase E, σ_y, TS, creep
  -Classification: Particle-reinf, fiber-reinf, lamellar



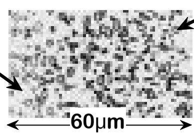
Hull, "An Intro. to Composite Materials, Fig. 4.6

Particle-Reinforced

- Examples:

-spheroidite steel

matrix: ferrite (α) (ductile)



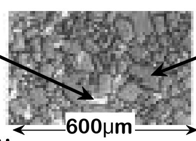
particles: cementite (Fe_3C) (brittle)

Callister, Fig. 10.10

-WC/Co cemented carbide

matrix: cobalt (ductile)

V_m: 10-15vol%!

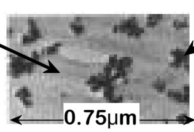


particles: WC (brittle, hard)

Callister, Fig. 17.4

-Automobile tires

matrix: rubber (compliant)



particles: C (stiffer)

Callister, Fig. 17.5

Particle-Reinforced: Elastic Modulus

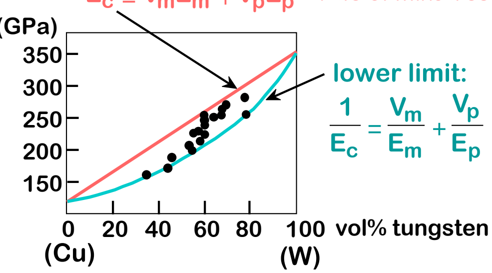
- E_c depends on volume fractions V_p and V_m:

upper limit:

$$E_c = V_m E_m + V_p E_p$$ "rule of mixtures"

Cu matrix w/tungsten particles

Callister, Fig. 17.3



lower limit:

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_p}{E_p}$$

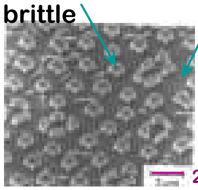
- Application to other properties
  Electrical conductivity, σ_e: replace E by σ_e.
  Thermal conductivity, k: replace E by k.

Fiber-Reinforced-I

- Aligned Continuous:

fibers: $\gamma'(Ni_3Al)$ brittle

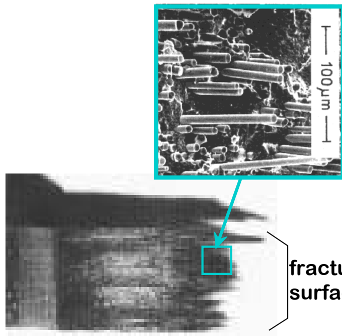
matrix: α (Mo) ductile



Metal: $\gamma'(Ni_3Al)$-α(Mo)

Process: eutectic solidification

Fig. 3.5, Matthews & Rawlings: Composite Materials: Engineering and Science



fracture surface

Glass w/SiC fibers

Process: glass slurry

E_{glass} = 76GPa

E_{SiC} = 400GPa

Figs. 4.22, 11.20, Matthews & Rawlings

Fiber-Reinforced-II

- Discontinuous, random 2D:

Carbon-Carbon

Process: fiber/pitch, followed by burnout at up to 2500°C

Uses: disk brakes, gas turbine exhaust flaps, nose cones

very stiff, strong C fibers

view onto plane

less stiff less strong C matrix

fibers lie in plane

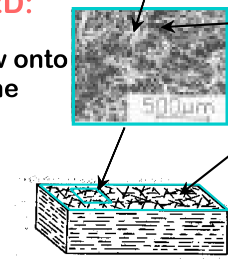


Fig. 4.24a,b: Matthews & Rawlings

- Other variations:

Discontinuous, random 3D

Discontinuous 1D

Critical fiber length

- For effective stiffening and strengthening:

$$\text{fiber length} > 15\frac{\sigma_f d}{\tau_c}$$

fiber strength (σ_f); fiber diameter (d); shear strength of fiber/matrix interface (τ_c)

- Example: For fiberglass, fiber length > 15mm is needed.
- Why? Longer fibers carry stress more efficiently

Shorter, thicker fiber:

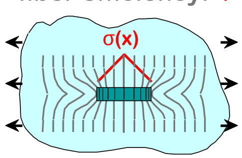
fiber length $> 15\frac{\sigma_f d}{\tau_c}$

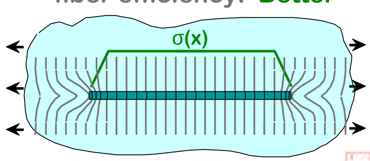
fiber efficiency: Poor

Longer, thinner fiber:

fiber length $< 15\frac{\sigma_f d}{\tau_c}$

fiber efficiency: Better





Fiber Composite Properties

- Valid when fiber length $>> 15\frac{\sigma_f d}{\tau_c}$

Elastic modulus in fiber direction:

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

efficiency factor

aligned 1D: K=1 (anisotropic)

random 2D: K=3/8 (2D isotropy)

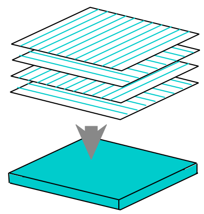
random 3D: K=1/5 (3D isotropy)

TS in fiber direction:

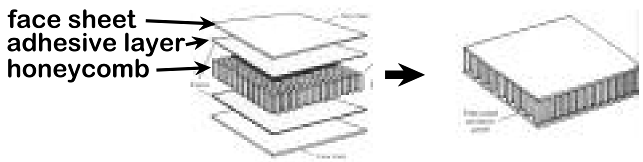
$$(TS)_c = (TS)_m V_m + (TS)_f V_f \quad \text{(aligned 1D)}$$

Laminar 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 bending stiffness



Callister, Fig. 17.16

Composite Benefits

- CMCs: Increased toughness

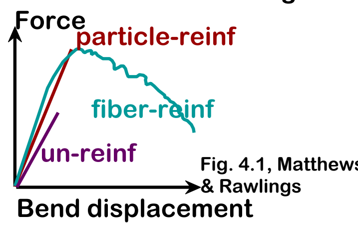
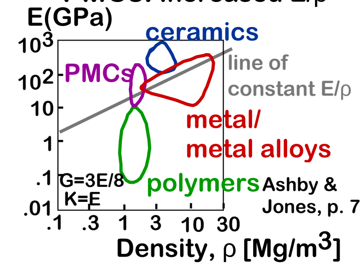
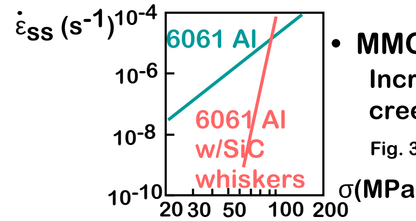


Fig. 4.1, Matthews & Rawlings

- PMCs: Increased E/ρ



Ashby & Jones, p. 7



- MMCs
  - Increased creep resistance

Fig. 3.27, Matthews & Rawlings