Chapter 16: Composite Materials

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

Composites

- Combine materials with the objective of getting a more desirable combination of properties
  - Ex: get flexibility & weight of a polymer plus the strength of a ceramic

- Principle of combined action
  - Mixture gives "averaged" properties

Terminology/Classification

- Composites:
  -- Multiphase material w/significant proportions of each phase.
- Matrix:
  -- The continuous phase
  -- Purpose is to:
    - transfer stress to other phases
    - protect phases from environment

  -- Classification: MMC, CMC, PMC

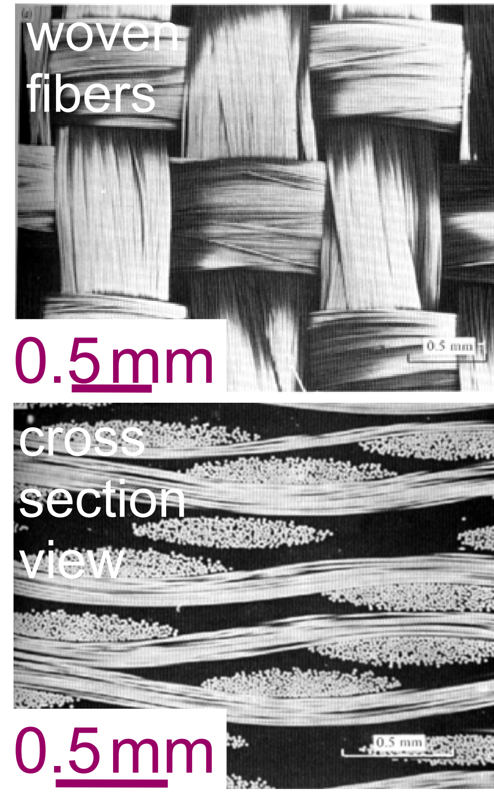
  metal ceramic polymer
- Dispersed phase:
  -- Purpose: enhance matrix properties.

  MMC: increase σ_y, *TS*, creep resist.

  CMC: increase *Kc*

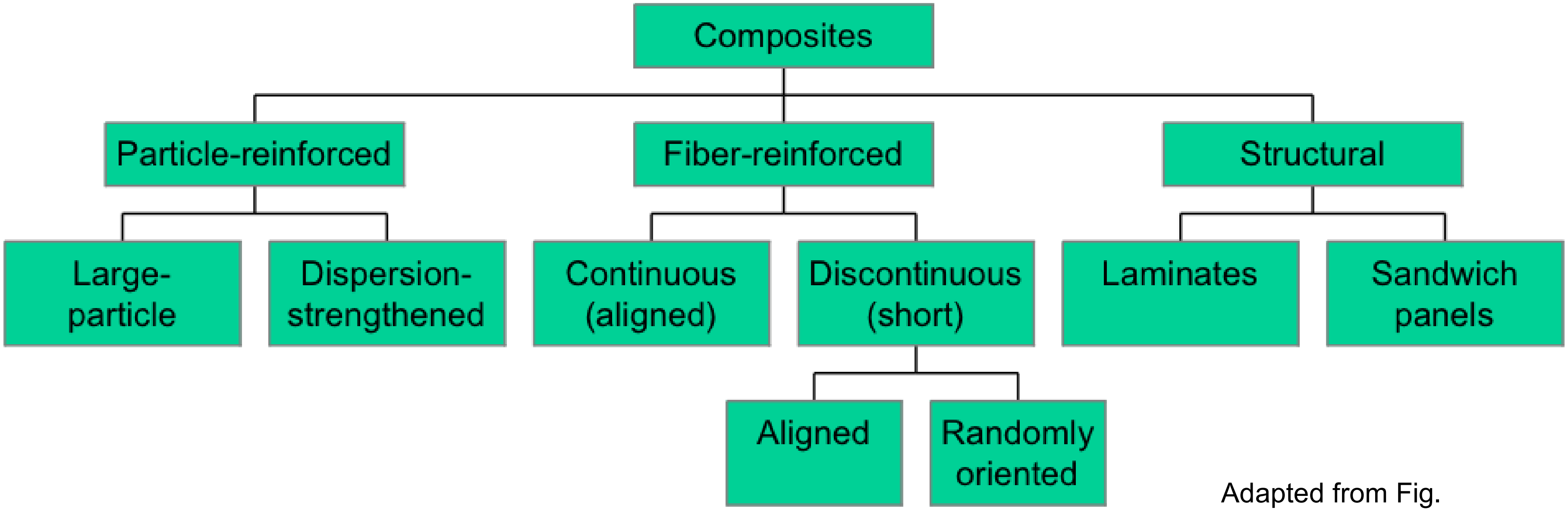
  PMC: increase *E*, σ_y, *TS*, creep resist.

  -- Classification: Particle, fiber, structural



Reprinted with permission from D. Hull and T.W. Clyne, *An Introduction to Composite Materials*, 2nd ed., Cambridge University Press, New York, 1996, Fig. 3.6, p. 47.

Composite Survey



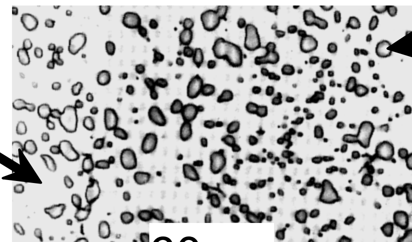
Adapted from Fig. 16.2, *Callister 7e*.

Composite Survey: Particle-I

Particle-reinforced | Fiber-reinforced | Structural

- Examples:
  - Spheroidite steel

matrix: ferrite (α) (ductile)

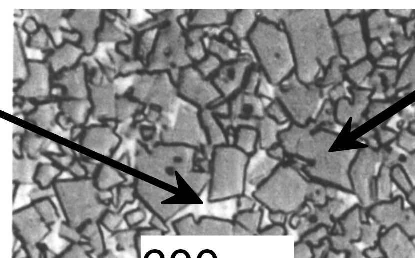


particles: cementite (Fe_3C) (brittle)

Adapted from Fig. 10.19, *Callister 7e*. (Fig. 10.19 is copyright United States Steel Corporation, 1971.)

  - WC/Co cemented carbide

matrix: cobalt (ductile)
V_m: 10-15 vol%!

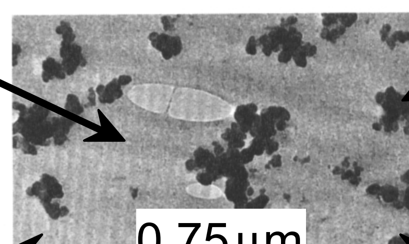


particles: WC (brittle, hard)

Adapted from Fig. 16.4, *Callister 7e*. (Fig. 16.4 is courtesy Carboloy Systems, Department, General Electric Company.)

  - Automobile tires

matrix: rubber (compliant)



particles: C (stiffer)

Adapted from Fig. 16.5, *Callister 7e*. (Fig. 16.5 is courtesy Goodyear Tire and Rubber Company.)

Composite Survey: Particle-III

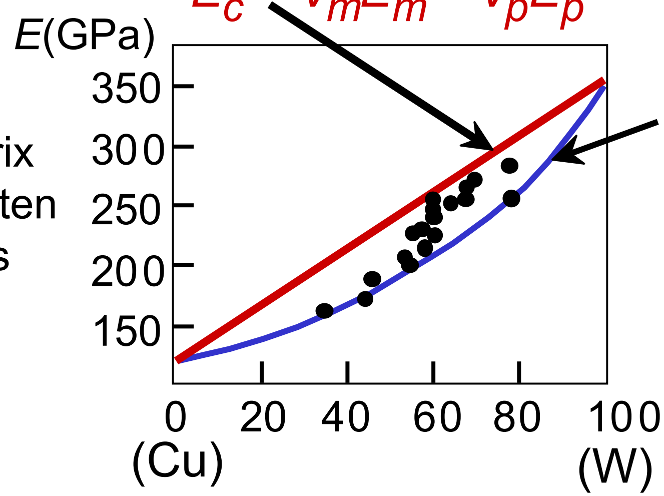
Particle-reinforced | Fiber-reinforced | Structural

- Elastic modulus, E_c, of composites:
  - -- two approaches.

upper limit: "rule of mixtures"

$$E_c = V_m E_m + V_p E_p$$

Data:
Cu matrix
w/tungsten
particles



vol% tungsten

lower limit:

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

Adapted from Fig. 16.3, *Callister 7e*. (Fig. 16.3 is from R.H. Krock, *ASTM Proc*, Vol. 63, 1963.)

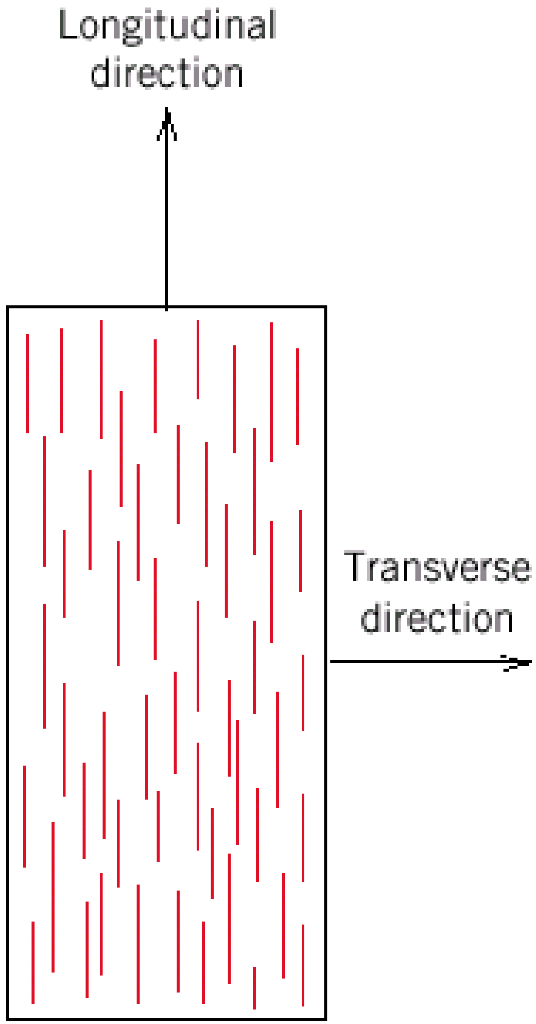
- Application to other properties:
  - -- Electrical conductivity, σ_e: Replace *E* in equations with σ_e.
  - -- Thermal conductivity, *k*: Replace *E* in equations with *k*.

Composite Survey: Fiber-I

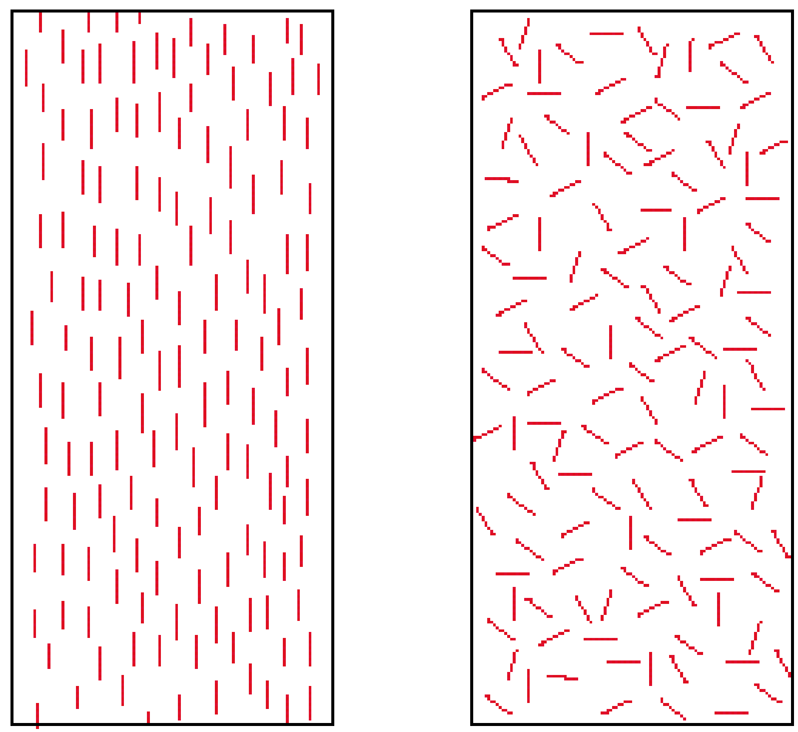
Particle-reinforced | **Fiber-reinforced** | Structural

- Fibers very strong
  - Provide significant strength improvement to material
  - Ex: fiber-glass
    - Continuous glass filaments in a polymer matrix
    - Strength due to fibers
    - Polymer simply holds them in place

Fiber Alignment



Adapted from Fig. 16.8, *Callister 7e*.



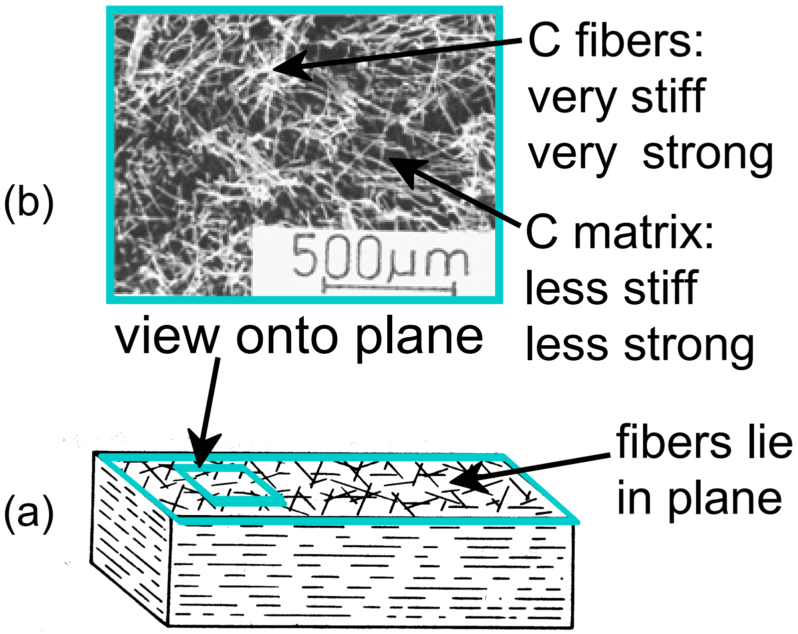
aligned
continuous

aligned random
discontinuous

Composite Survey: Fiber-IV

Particle-reinforced | **Fiber-reinforced** | Structural

- Discontinuous, random 2D fibers
- Example: Carbon-Carbon
  - -- process: fiber/pitch, then burn out at up to 2500ºC.
  - -- uses: disk brakes, gas turbine exhaust flaps, nose cones.



- Other variations:
  - -- Discontinuous, random 3D
  - -- Discontinuous, 1D

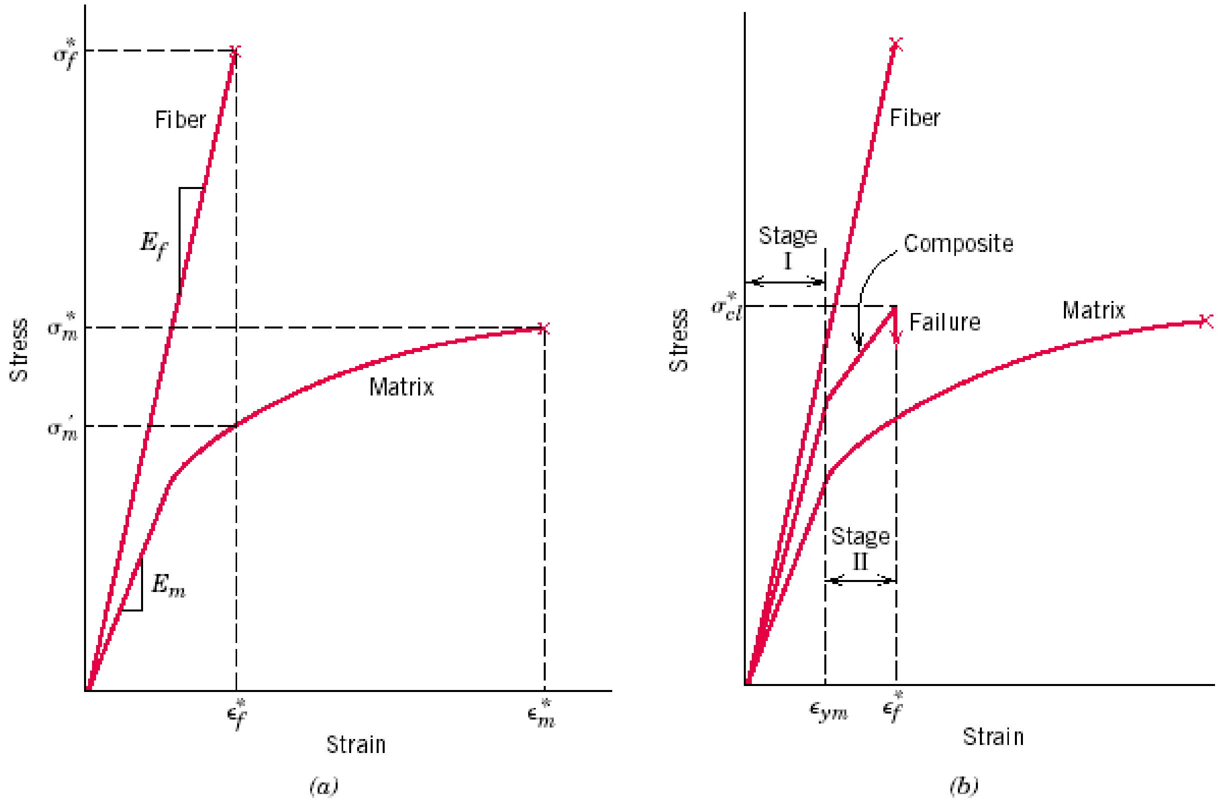
Adapted from F.L. Matthews and R.L. Rawlings, *Composite Materials; Engineering and Science*, Reprint ed., CRC Press, Boca Raton, FL, 2000. (a) Fig. 4.24(a), p. 151; (b) Fig. 4.24(b) p. 151. (Courtesy I.J. Davies) Reproduced with permission of CRC Press, Boca Raton, FL.

Fiber-reinforced composites

- **Stress-strain relation for brittle fiber and ductile matrix**
- **Elastic modulus in longitudinal**

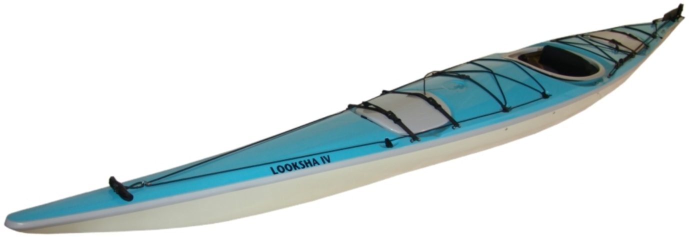
$$E_{cl} = E_m V_m + E_f V_f$$

- **Elastic modulus for transverse loading**



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

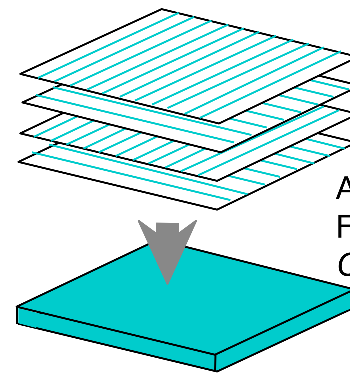
Fiber Composites



Composite Survey: Structural

Particle-reinforced | Fiber-reinforced | **Structural**

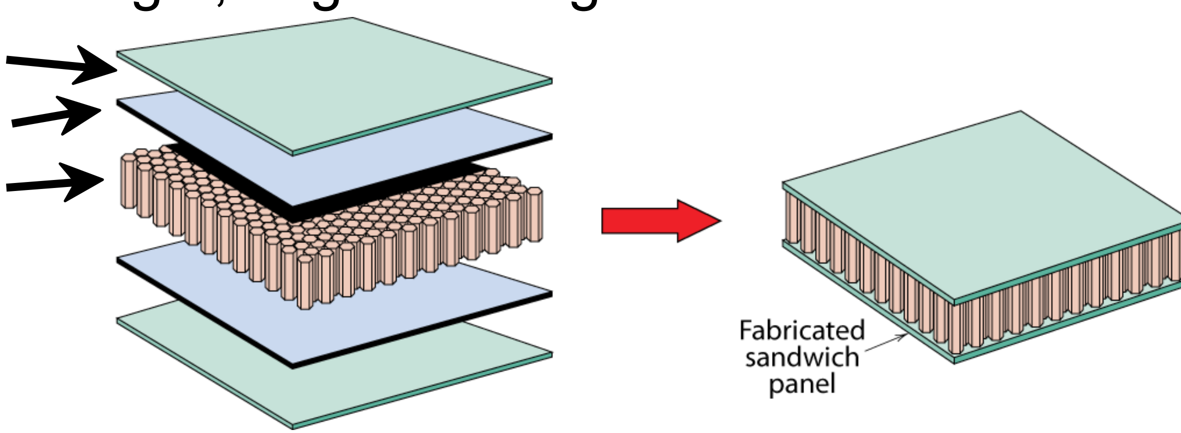
- Stacked and bonded fiber-reinforced sheets
  - -- stacking sequence: e.g., 0º/90º
  - -- benefit: balanced, in-plane stiffness



Adapted from Fig. 16.16, *Callister 7e*.

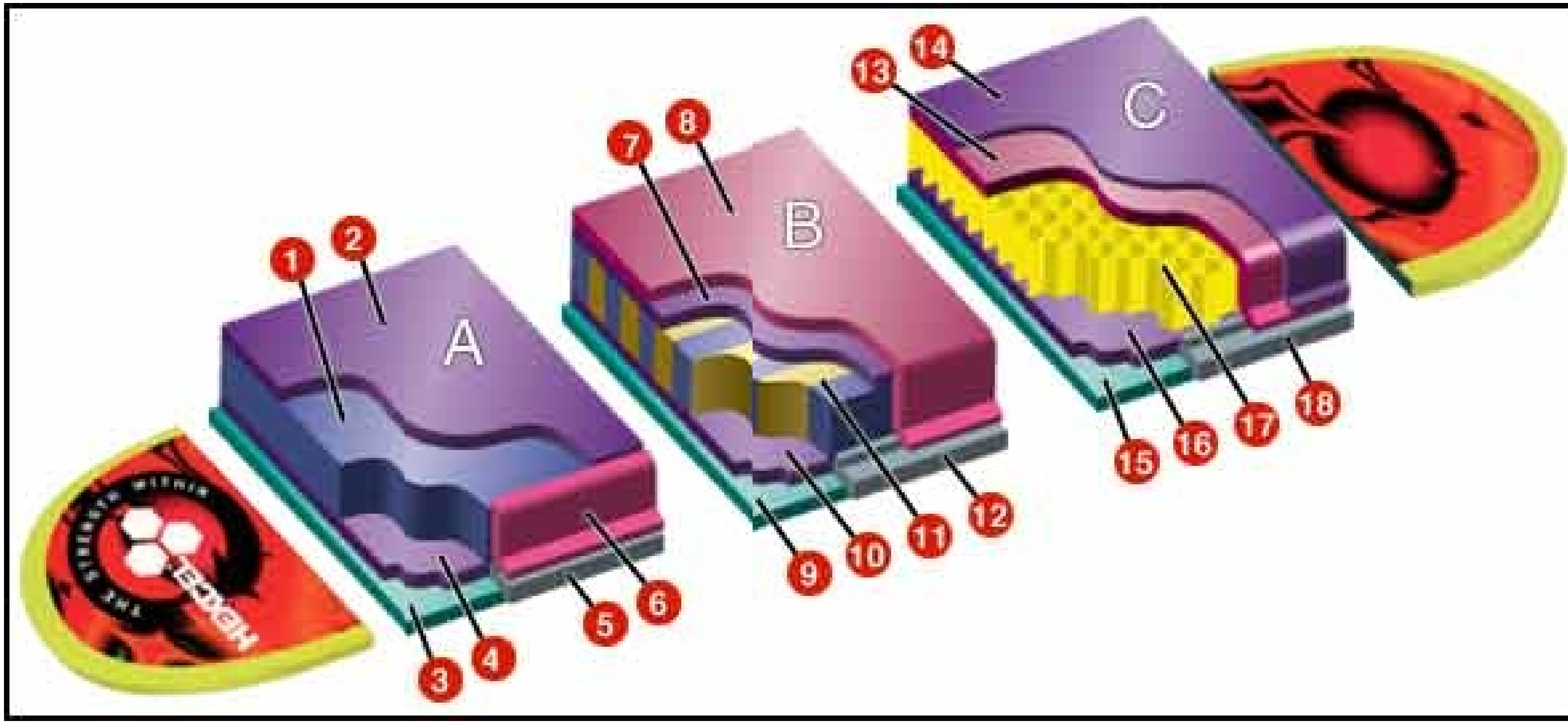
- Sandwich panels
  - -- low density, honeycomb core
  - -- benefit: small weight, large bending stiffness

face sheet
adhesive layer
honeycomb



Adapted from Fig. 16.18, *Callister 7e*. (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

Snowboards

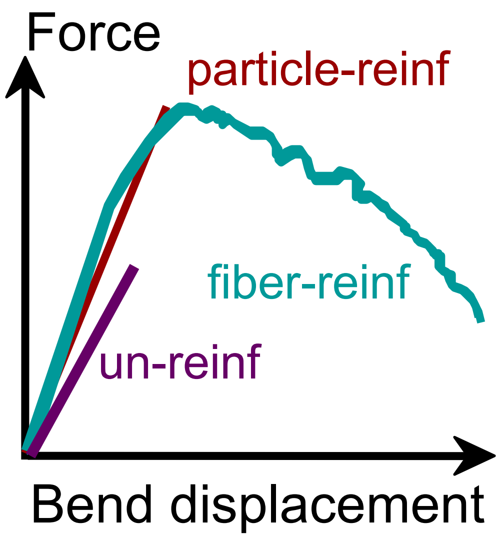


1 Honeycomb/ Polyurethane core 2 Epoxy/Glass, Carbon or Hybrid Top Laminate 3 PE Running Surface: 4 Epoxy/Glass, Carbon or Hybrid Bottom Laminate: 5 Profile Steel Edge: 6 Sidewall (ABS) : 7 Top Laminate 8 Decorative Thermoplastic Cap Foil 9 PE Running Surface: www.hexcel.com

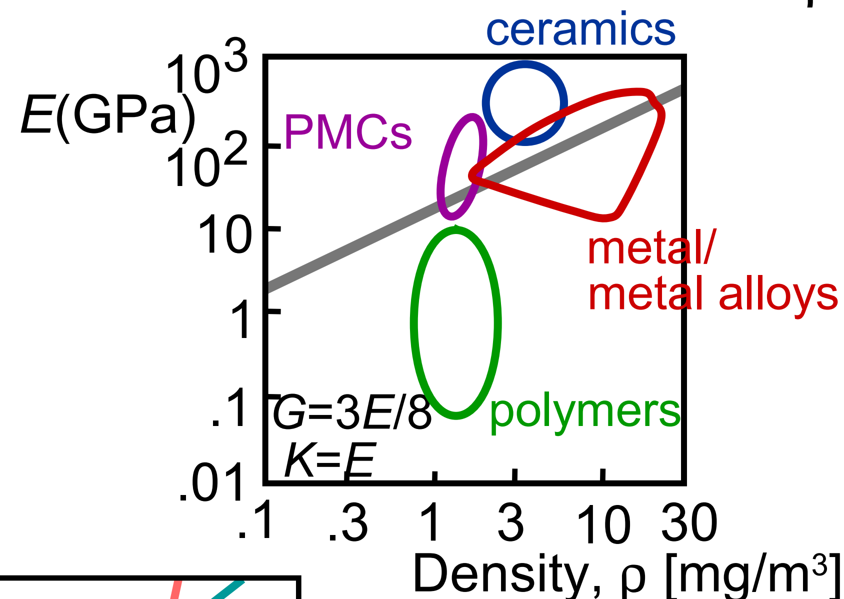
10 Glass, Carbon, or Hybrid Prepreg: 11 Honeycomb, polyurethane or wood core (PUR/ wood combination demonstrated here): 12 Steel Edge : 13 Prepreg: 14 Decorative Thermoplastic Cap Foil: 15 PE running surfaces: 16 Glass, Carbon or Hybrid Prepreg: 17 Honeycomb/ Polyurethane core: 18 Steel Edge:

Composite Benefits

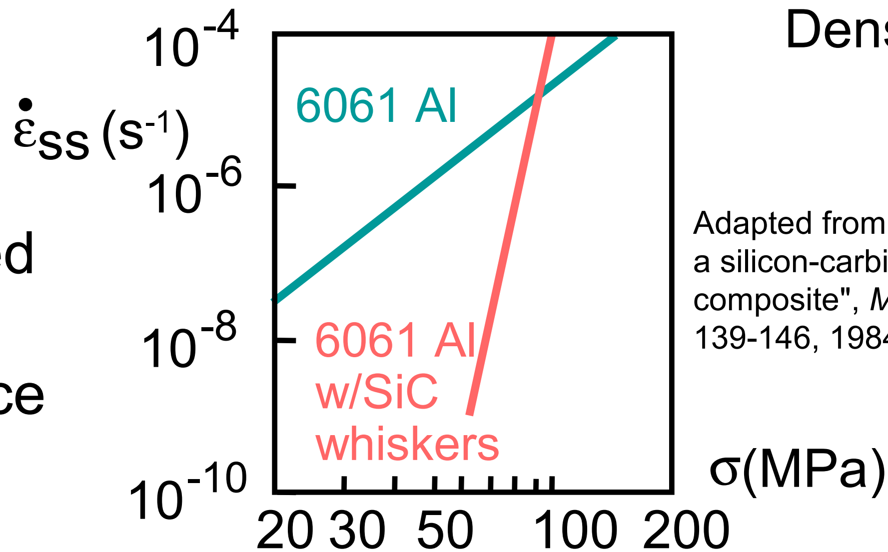
- CMCs: Increased toughness



- PMCs: Increased E/ρ

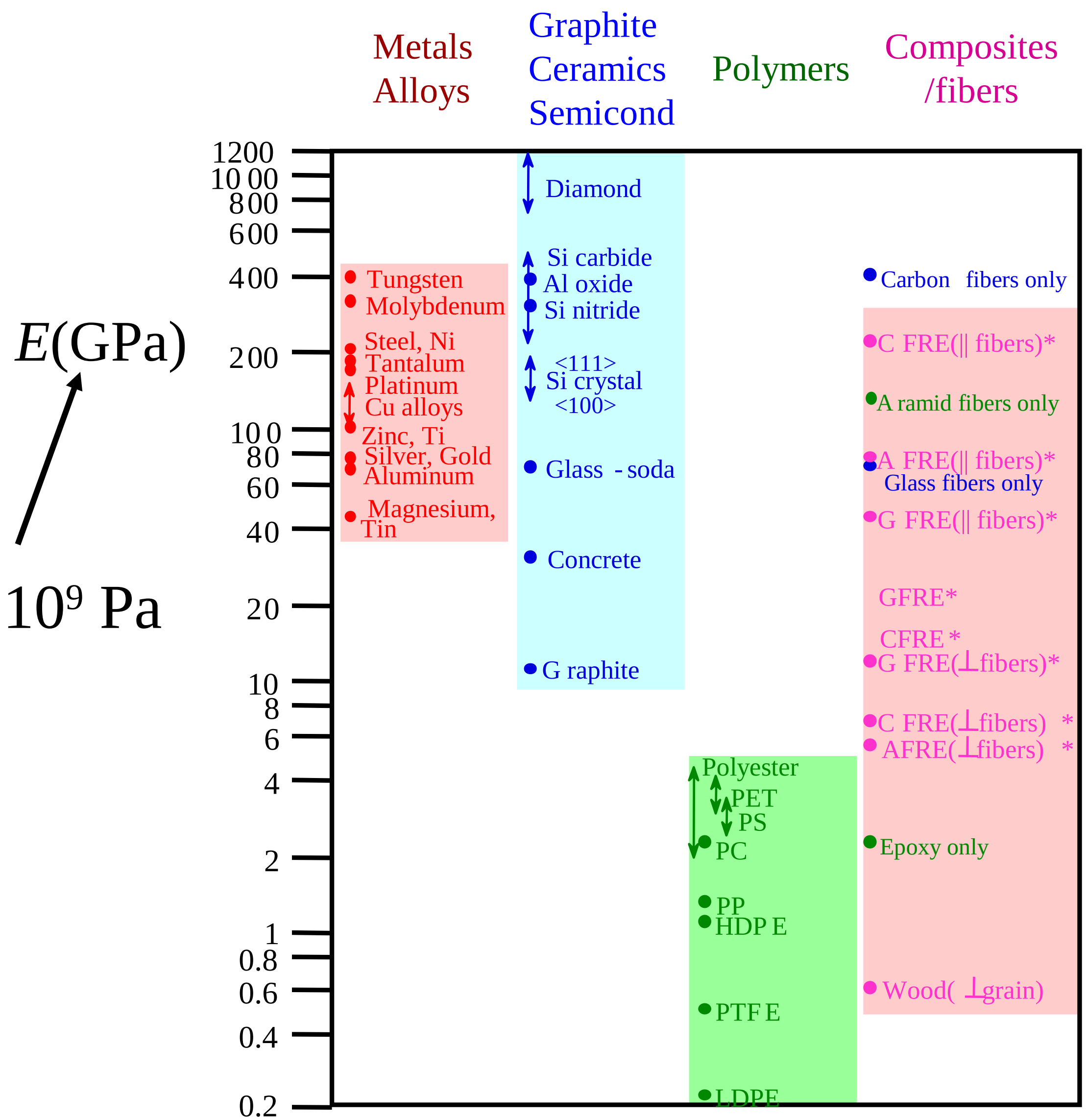


- MMCs:
  Increased creep resistance



Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans. A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

Young's Moduli: Comparison



Based on data in Table B2, *Callister 7e*.

Composite data based on reinforced epoxy with 60 vol% of aligned carbon (CFRE), aramid (AFRE), or glass (GFRE) fibers.

Summary

- Composites are classified according to:
  -- the matrix material, dispersed phase
  -- the reinforcement geometry (particles, fibers, layers).

- Composites enhance matrix properties

- Particulate-reinforced:
  -- Elastic modulus can be estimated.
  -- Properties are isotropic.
- Fiber-reinforced:
  -- Elastic modulus and *TS* can be estimated along fiber dir.
  -- Properties can be isotropic or anisotropic.
- Structural:
  -- Based on build-up of sandwiches in layered form.