Chapter 16: Composites

ISSUES TO ADDRESS...

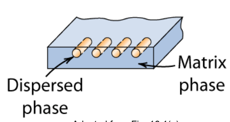
- What are the ______________________________?
- What are the ______________ of using composite materials?
- How do we predict the __________________ of the various types of composites?

Composite

- Combination of two or more __________ ____________
- Design goal: obtain a more desirable combination of properties (_______________ __________________)
  – e.g., low _________ and high strength

Terminology/Classification

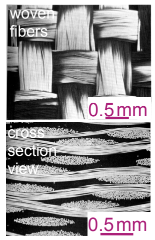
- ___________:
  -- Multiphase material that is artificially made.
- Phase types:
  -- _______ - is continuous
  -- Dispersed - is __________ and surrounded by matrix



Adapted from Fig. 16.1(a), *Callister & Rethwisch 8e.*

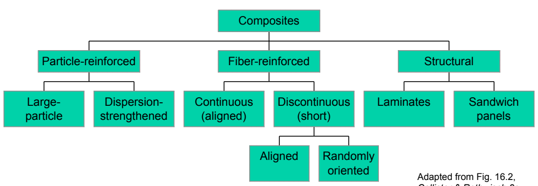
Terminology/Classification

- ________ phase:
  - -- Purposes are to:
    - - ______________________
    - - protect dispersed phase from environment
  - -- Types: MMC, CMC, PMC
    - metal ______ polymer
- Dispersed phase:
  - -- Purpose:
    - MMC: increase ______________.
    - CMC: increase K_{Ic}
    - PMC: increase E, σ_y, TS, creep resist.
  - -- Types: ________, 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.

Classification of Composites

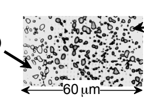


Adapted from Fig. 16.2, *Callister & Rethwisch 8e.*

Classification: Particle-Reinforced (i)

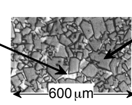
Particle-reinforced | Fiber-reinforced | Structural

- Examples:
  - - __________ steel — matrix: ferrite (α) (ductile); particles: cementite (Fe_3C) (brittle)



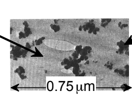
Adapted from Fig. 10.19, *Callister & Rethwisch 8e.* (Fig. 10.19 is copyright United States Steel Corporation, 1971.)

  - - WC/Co cemented carbide — matrix: cobalt (ductile, tough); particles: WC (brittle, hard)



Adapted from Fig. 16.4, *Callister & Rethwisch 8e.* (Fig. 16.4 is courtesy Carboloy Systems, Department, General Electric Company.)

  - - __________ __________ — matrix: rubber (compliant); particles: carbon black (stiff)



Adapted from Fig. 16.5, *Callister & Rethwisch 8e.* (Fig. 16.5 is courtesy Goodyear Tire and Rubber Company.)

Classification: Particle-Reinforced (ii)

Particle-reinforced | Fiber-reinforced | Structural

Concrete – ______________________________

- Why sand *and* gravel? Sand fills voids between _______ particles

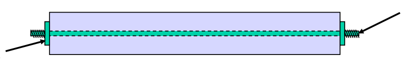
Reinforced concrete – _________ with steel rebar or remesh

- increases strength - even if cement matrix is cracked

____________ concrete

- Rebar/remesh placed under tension during setting of concrete
- ____
- To fracture concrete, applied tensile stress must exceed this compressive stress

_____________ – tighten nuts to place concrete under compression

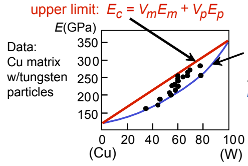


Classification: Particle-Reinforced (iii)

Particle-reinforced | Fiber-reinforced | Structural

- Elastic ____________ , E_c, of composites:
  -- two "__________" extremes:

upper limit: $E_c = V_m E_m + V_p E_p$



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

Adapted from Fig. 16.3, *Callister & Rethwisch 8e.* (Fig. 16.3 is from R.H. Krock, *ASTM Proc*, Vol. 63, 1963.)

- Application to other properties:
  -- Electrical __________, σ_e: Replace *E*'s in equations with σ_e's.
  -- ________ conductivity, *k*: Replace *E*'s in equations with *k*'s.

Classification: Fiber-Reinforced (i)

Particle-reinforced | Fiber-reinforced | Structural

- Fibers very strong in tension
  - Provide ______________________________
    ____
  - Ex: fiber-glass - continuous glass filaments in a polymer matrix
    - Glass fibers
      - strength and __________
    - Polymer matrix
      - holds fibers in place
      - _______________
      - transfers load to fibers

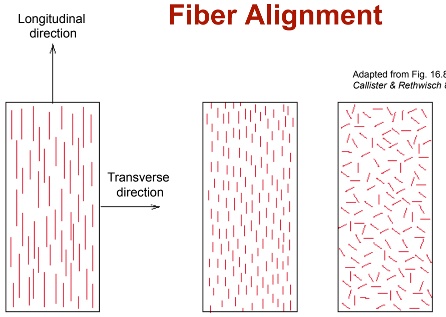
Classification: Fiber-Reinforced (ii)

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

- Fiber Types
  - ________ - ________________ - large length to diameter ratios
    - _______, silicon nitride, silicon carbide
    - high crystal ________ – extremely strong, strongest known
    - ________________ and difficult to disperse
  - _________
    - polycrystalline or amorphous
    - generally ________________________
    - Ex: alumina, aramid, E-glass, boron, UHMWPE
  - Wires
    - _________ – steel, molybdenum, tungsten

Chapter 16 - 10

Fiber Alignment



Adapted from Fig. 16.8, *Callister & Rethwisch 8e.*

aligned continuous | aligned discontinuous | random

Chapter 16 - 11

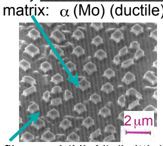
Classification: Fiber-Reinforced (iii)

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

- ________________________ fibers
- Examples:

-- Metal: γ'(Ni_3Al)-α(Mo) by ___________________.

matrix: α (Mo) (ductile)

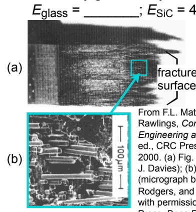


fibers: γ' (Ni_3Al) (brittle)

From W. Funk and E. Blank, "Creep deformation of Ni_3Al-Mo in-situ composites", *Metall. Trans. A* Vol. 19(4), pp. 987-998, 1988. Used with permission.

-- _________: Glass w/SiC fibers formed by glass slurry

E_{glass} = _______; E_{SiC} = 400 GPa.



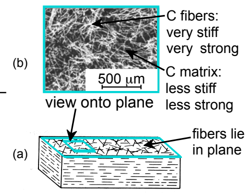
From F.L. Matthews and R.L. Rawlings, *Composite Materials; Engineering and Science*, Reprint ed., CRC Press, Boca Raton, FL, 2000. (a) Fig. 4.22, p. 145 (photo by J. Davies); (b) Fig. 11.20, p. 349 (micrograph by H.S. Kim, P.S. Rodgers, and R.D. Rawlings). Used with permission of CRC Press, Boca Raton, FL.

Chapter 16 - 12

Classification: Fiber-Reinforced (iv)

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

- ________________, random in 2 dimensions
- Example: ____________
  - -- fabrication process:
    - carbon fibers _________ in polymer resin matrix,
    - polymer resin __________ at up to 2500ºC.
  - -- uses: disk brakes, gas turbine exhaust flaps, missile nose cones.
- Other possibilities:
  - -- Discontinuous, random 3D
  - -- Discontinuous, aligned



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.

Chapter 16 - 13

Classification: Fiber-Reinforced (v)

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

- ____________________ for effective stiffening & strengthening:

fiber ______ tensile strength; fiber diameter

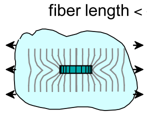
$$\text{fiber length} > \frac{\sigma_f d}{2\tau_c}$$

shear strength of fiber-matrix _________

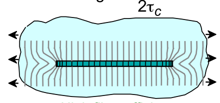
- Ex: For ____________, common fiber length > 15 mm needed
- For longer fibers, ______________ from matrix is more efficient

Short, thick fibers: fiber length $< \frac{\sigma_f d}{2\tau_c}$

Long, thin fibers: fiber length $> \frac{\sigma_f d}{2\tau_c}$



Low fiber efficiency



High fiber efficiency

Chapter 16 - 14

Composite Stiffness: Longitudinal Loading

______________ fibers - Estimate fiber-reinforced composite modulus of elasticity for ____________________

- ______________ deformation

$\sigma_c = \sigma_m V_m + \sigma_f V_f$ and ______________

volume fraction; ___________

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

E_{cl} = longitudinal ________

c = composite
f = fiber
m = matrix

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Composite Stiffness: Transverse Loading

- In transverse loading the fibers carry less of the load

$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$ and ____________

$$\therefore \quad \frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

E_{ct} = ____________ modulus

c = composite
f = fiber
m = matrix

Chapter 16 - 16

Composite Stiffness

Particle-reinforced | Fiber-reinforced | Structural

- Estimate of ________ for discontinuous fibers:
  - -- valid when fiber length < $15 \frac{\sigma_f d}{\tau_c}$
  - -- Elastic modulus in ________________:

$$E_{cd} = E_m V_m + K E_f V_f$$

________________:
- -- aligned: $K = 1$ (aligned parallel)
- -- aligned: $K = 0$ (aligned perpendicular)
- -- random 2D: $K = 3/8$ (2D isotropy)
- -- random 3D: $K = 1/5$ (3D isotropy)

Values from Table 16.3, *Callister & Rethwisch 8e.* (Source for Table 16.3 is H. Krenchel, *Fibre Reinforcement*, Copenhagen: Akademisk Forlag, 1964.)

Chapter 16 - 17

Composite Strength

Particle-reinforced | Fiber-reinforced | Structural

- Estimate of σ^*_{cd} for ______________ fibers:

1. When ________

$$\sigma^*_{cd'} = \sigma^*_f V_f \left(1 - \frac{l_c}{2l}\right) + \sigma'_m (1 - V_f)$$

2. When ________

$$\sigma^*_{cd'} = \frac{l\tau_c}{d} V_f + \sigma'_m (1 - V_f)$$

Chapter 16 - 18

Composite Production Methods (i)

____
- Continuous fibers pulled through resin tank to impregnate fibers with ______________
- Impregnated fibers pass through steel die that preforms to the desired shape
- Preformed stock passes through a curing die that is
  - ______________________
  - ______________________

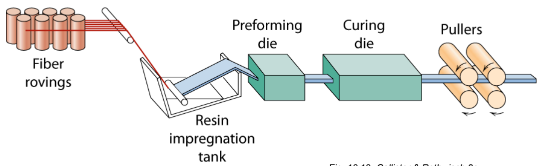
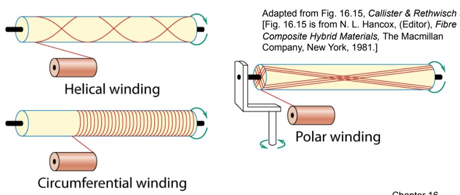


Fig. 16.13, *Callister & Rethwisch 8e.*

Composite Production Methods (ii)

- Filament Winding
  - Continuous reinforcing fibers are accurately positioned in a predetermined pattern to form ______________
  - Fibers are fed through a resin bath to impregnate with ______________
  - Impregnated fibers are continuously wound (typically automatically) onto a ______________
  - After appropriate number of layers added, curing is carried out either in an oven or at room temperature
  - ______________________

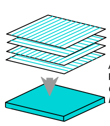
Adapted from Fig. 16.15, *Callister & Rethwisch 8e.* [Fig. 16.15 is from N. L. Hancox, (Editor), *Fibre Composite Hybrid Materials*, The Macmillan Company, New York, 1981.]



Classification: Structural

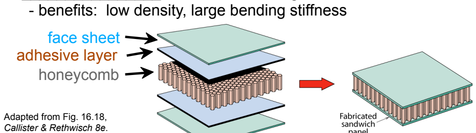
Particle-reinforced | Fiber-reinforced | Structural

- Laminates -
  - -- stacked and bonded ______________ sheets
    - stacking sequence: e.g., 0º/90º
    - benefit: ______________________



Adapted from Fig. 16.16, *Callister & Rethwisch 8e.*

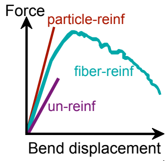
- ______________
  - -- ______________ between two facing sheets
    - benefits: low density, large bending stiffness

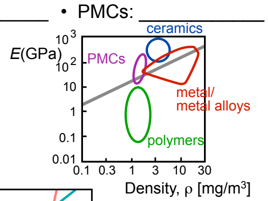


Adapted from Fig. 16.18, *Callister & Rethwisch 8e.* (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

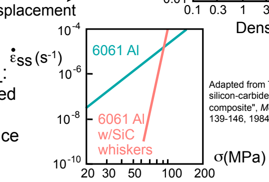
Composite Benefits

- CMCs: Increased ___________
- PMCs: ___________





- ________: 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.

Chapter 16 - 22

Summary

- Composites types are designated by:
  - -- the matrix material (CMC, MMC, PMC)
  - -- the reinforcement (particles, fibers, structural)
- Composite property benefits:
  - -- MMC: enhanced E, σ^*, creep performance
  - -- CMC: enhanced K_{Ic}
  - -- PMC: enhanced E/ρ, σ_y, TS/ρ
- Particulate-reinforced:
  - -- Types: large-particle and dispersion-strengthened
  - -- Properties are isotropic
- Fiber-reinforced:
  - -- Types: continuous (aligned)
    discontinuous (aligned or random)
  - -- Properties can be isotropic or anisotropic
- Structural:
  - -- Laminates and sandwich panels

Chapter 16 - 23