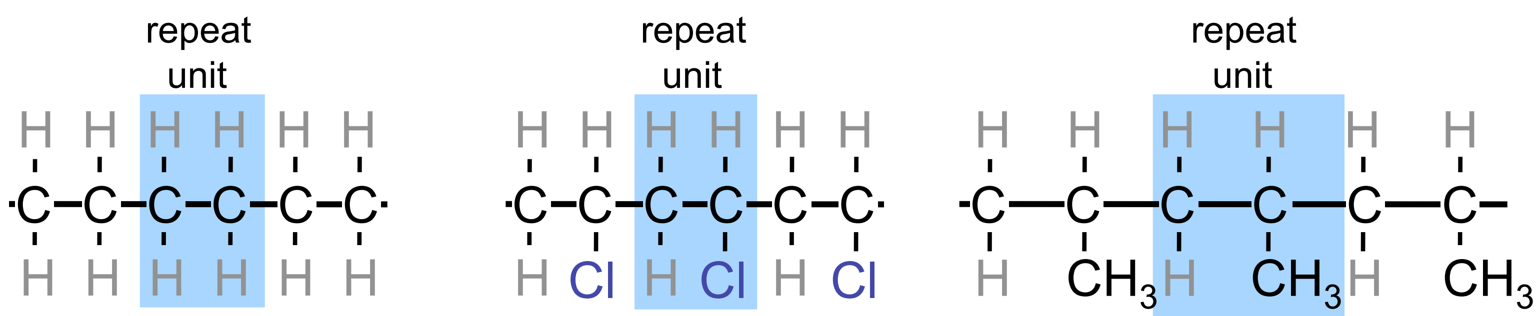
Polymers

Poly — many

mer — repeat unit

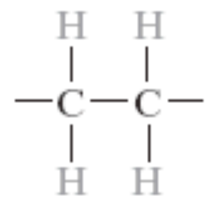
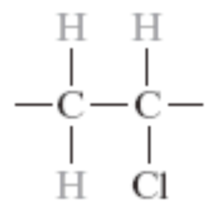
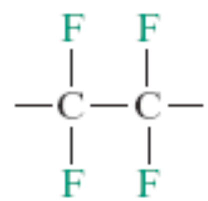
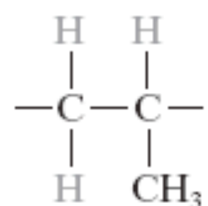


Polyethylene (PE) Polyvinyl chloride (PVC) Polypropylene (PP)

Adapted from Fig. 14.2, *Callister 7e.*

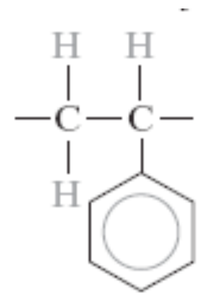
Bulk or commodity polymers

Table 14.3 **A Listing of Repeat Units for 10 of the More Common Polymeric Materials**

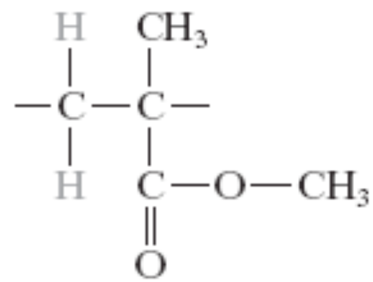
	Polymer	*Repeat Unit*
	Polyethylene (PE)	
	Poly(vinyl chloride) (PVC)	
	Polytetrafluoroethylene (PTFE)	
	Polypropylene (PP)	

Bulk or commodity polymers

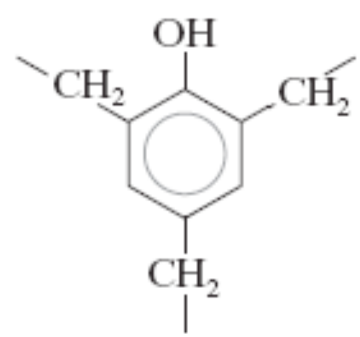
Polystyrene (PS)



Poly(methyl methacrylate) (PMMA)

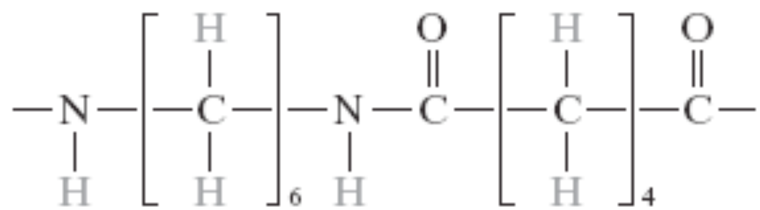
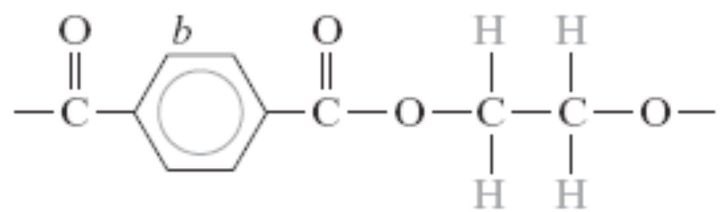
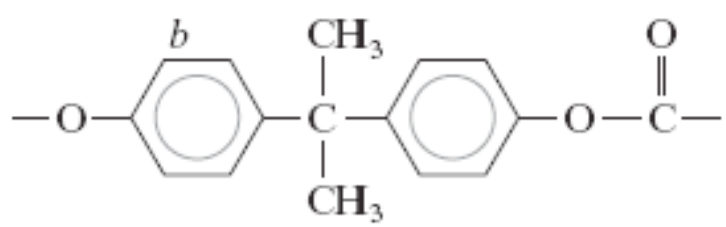


Phenol-formaldehyde (Bakelite)



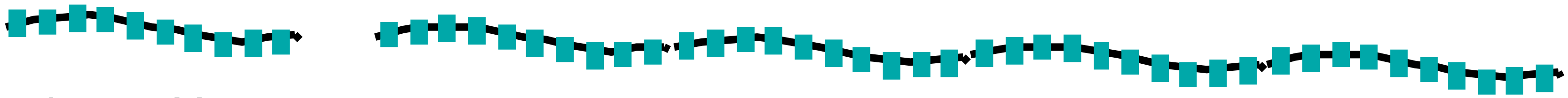
Bulk or commodity polymers

Table 14.3 A Listing of Repeat Units for 10 of the More Common Polymeric Materials

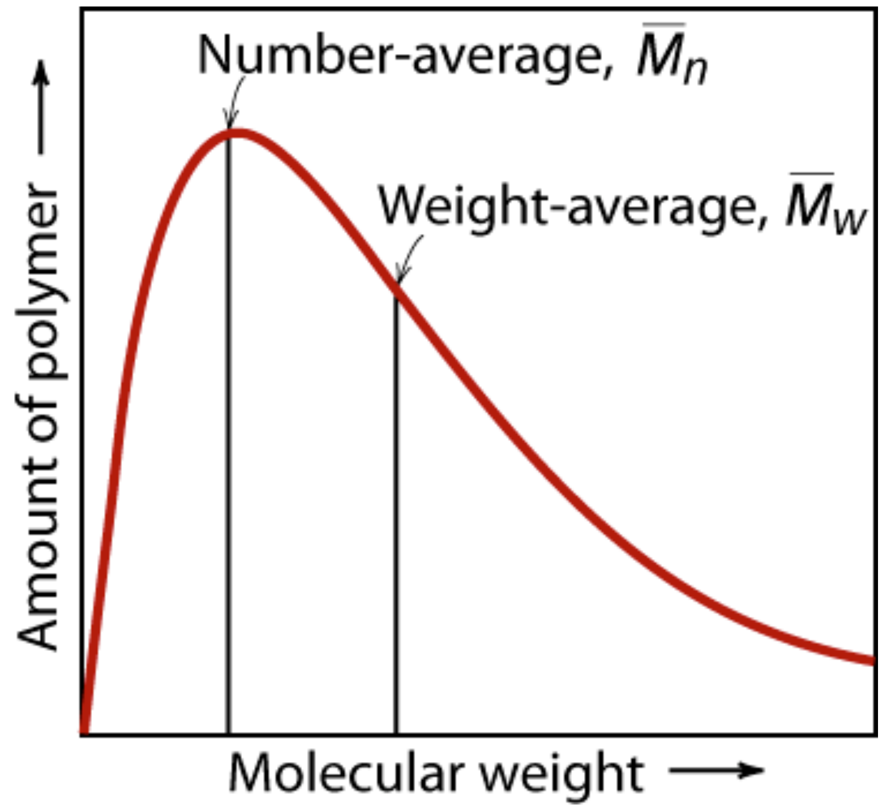
Polymer	*Repeat Unit*
Poly(hexamethylene adipamide) (nylon 6,6)	
Poly(ethylene terephthalate) (PET, a polyester)	
Polycarbonate (PC)	

Molecular weight

- Molecular weight, M_i: Mass of a mole of chains.



Lower M higher M

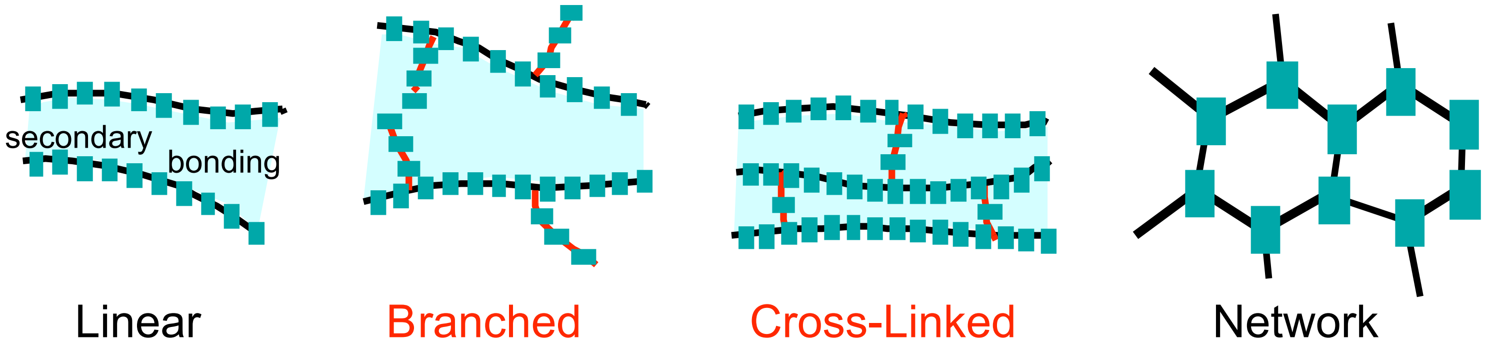


$\overline{M}_w$ is more sensitive to higher molecular weights

Adapted from Fig. 14.4, *Callister 7e.*

Molecular structures

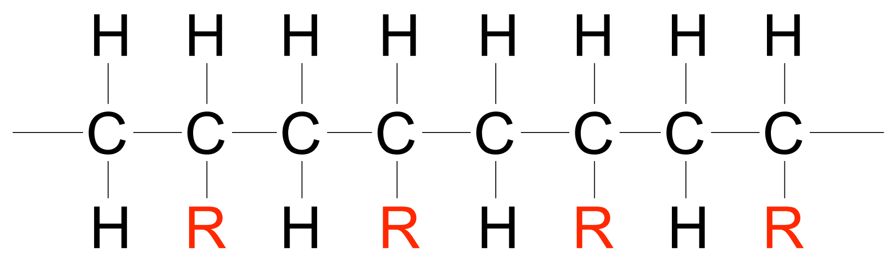
- Covalent chain configurations and strength:

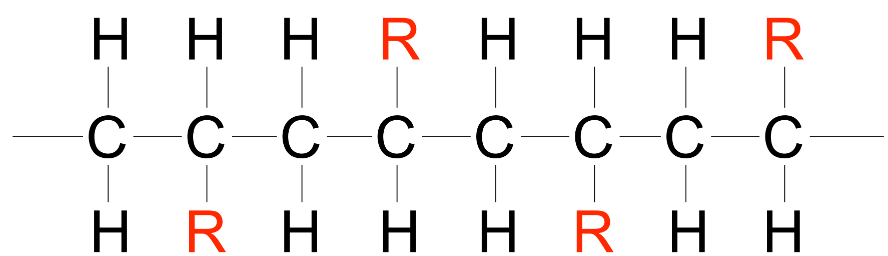


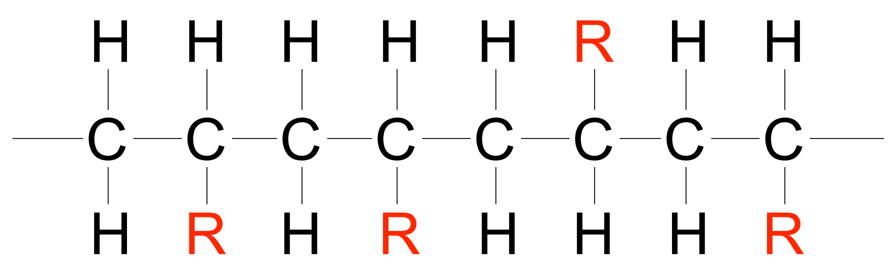
Adapted from Fig. 14.7, *Callister 7e.*

Tacticity

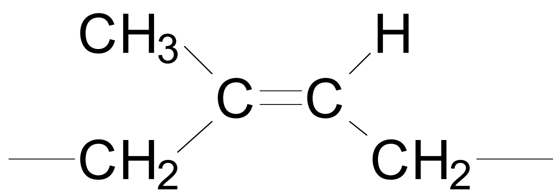
Tacticity – stereoregularity of chain







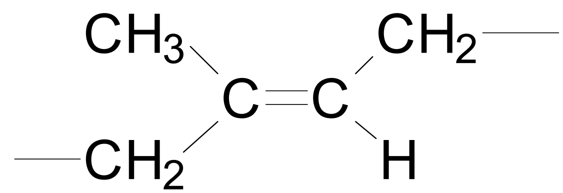
Cis and trans isomerism



cis

cis-isoprene
(natural rubber)

bulky groups on same side of chain



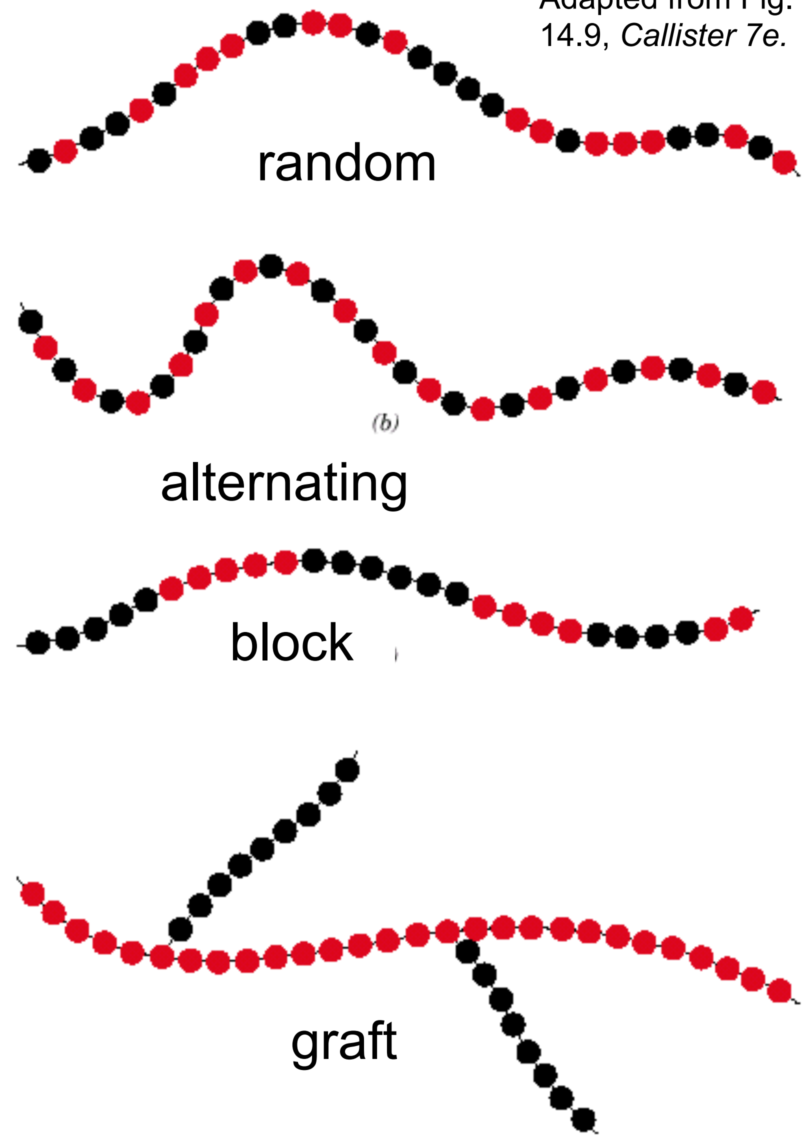
trans

trans-isoprene
(gutta percha)

bulky groups on opposite sides of chain

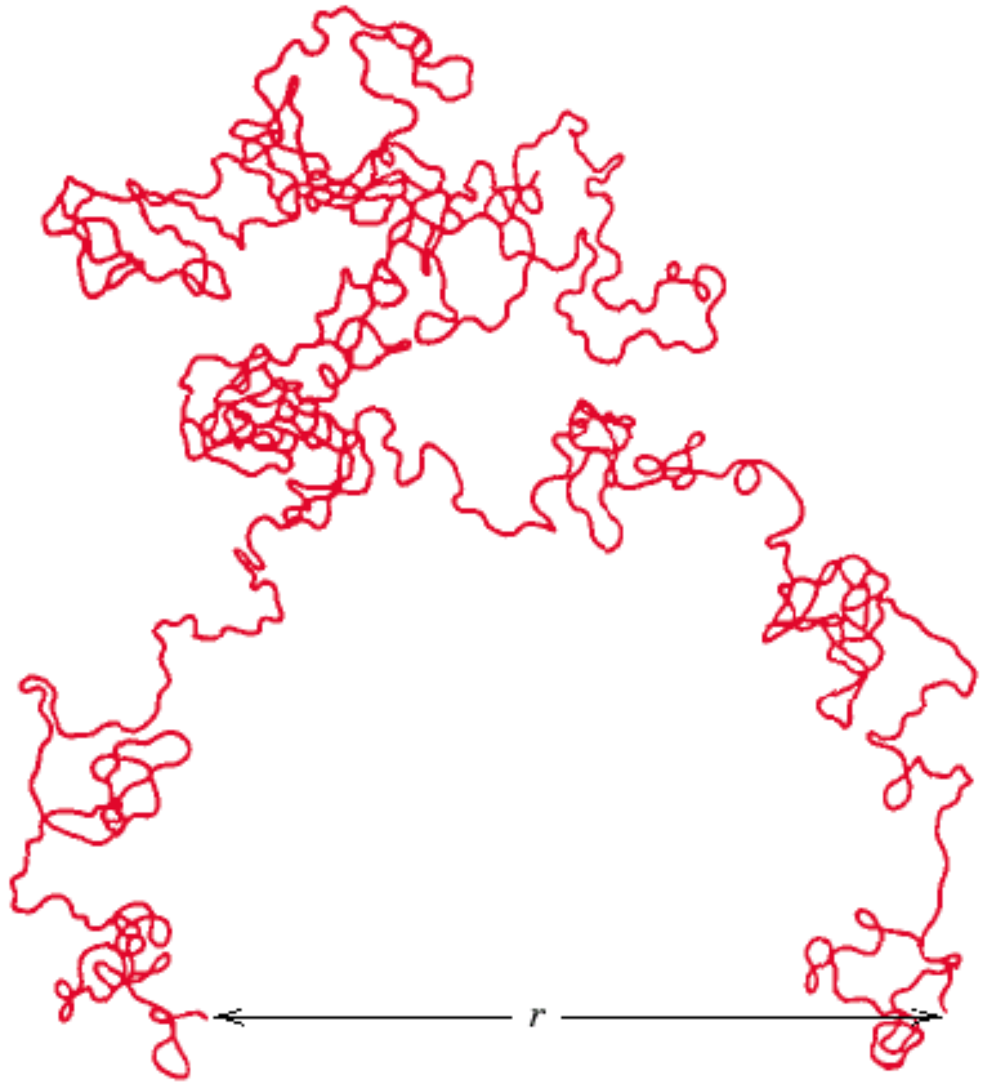
Copolymers

Adapted from Fig. 14.9, *Callister 7e.*



A –   B –

End to end distance



Adapted from Fig. 14.6, *Callister 7e.*

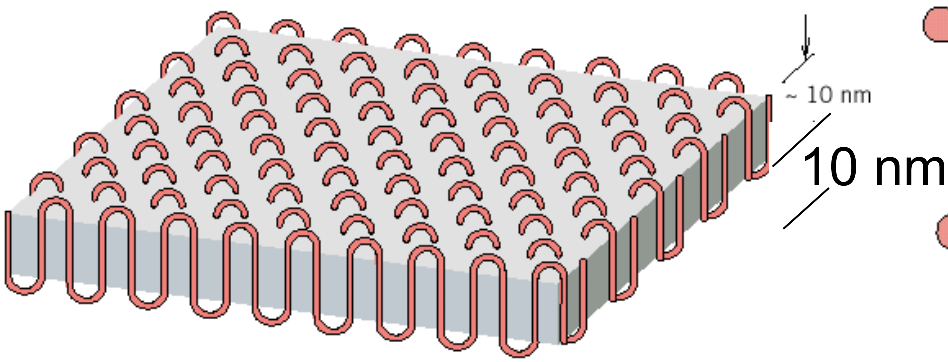
Polymer crystalline structure

Ex: polyethylene unit cell

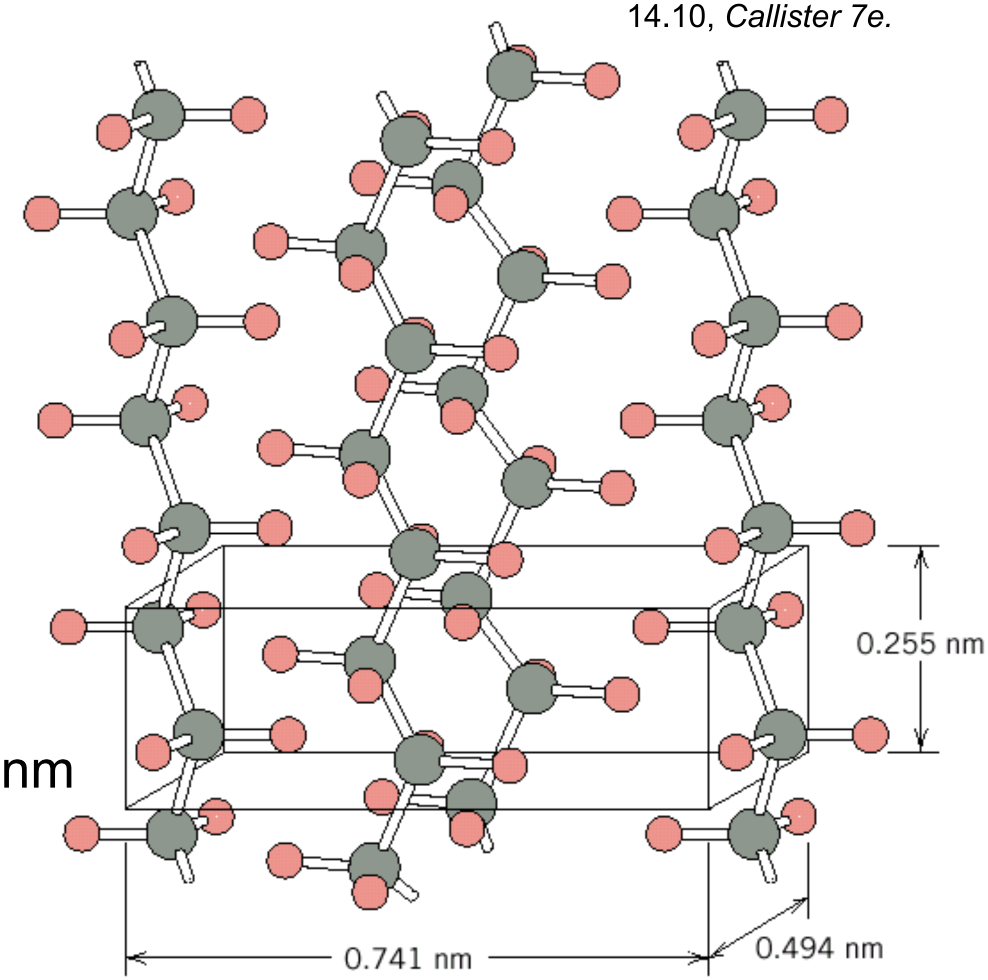
Crystals must contain the polymer chains in some way

Chain folded structure

Adapted from Fig. 14.12, *Callister 7e.*



Adapted from Fig. 14.10, *Callister 7e.*



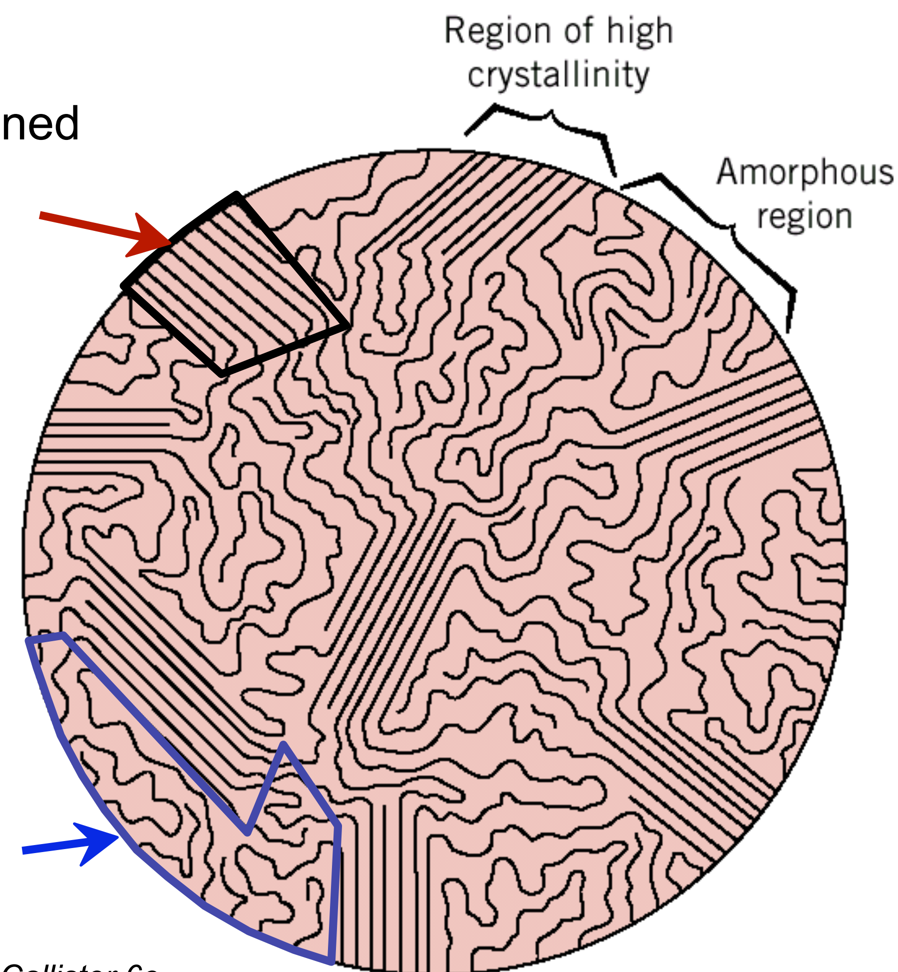
Polymer crystalline structure

Polymers rarely 100% crystalline

Too difficult to get all those chains aligned

crystalline
region

- % Crystallinity: % of material
  that is crystalline.
  -- *TS* and *E* often increase
  with % crystallinity.
  -- Annealing causes
  crystalline regions
  to grow. % crystallinity
  increases.

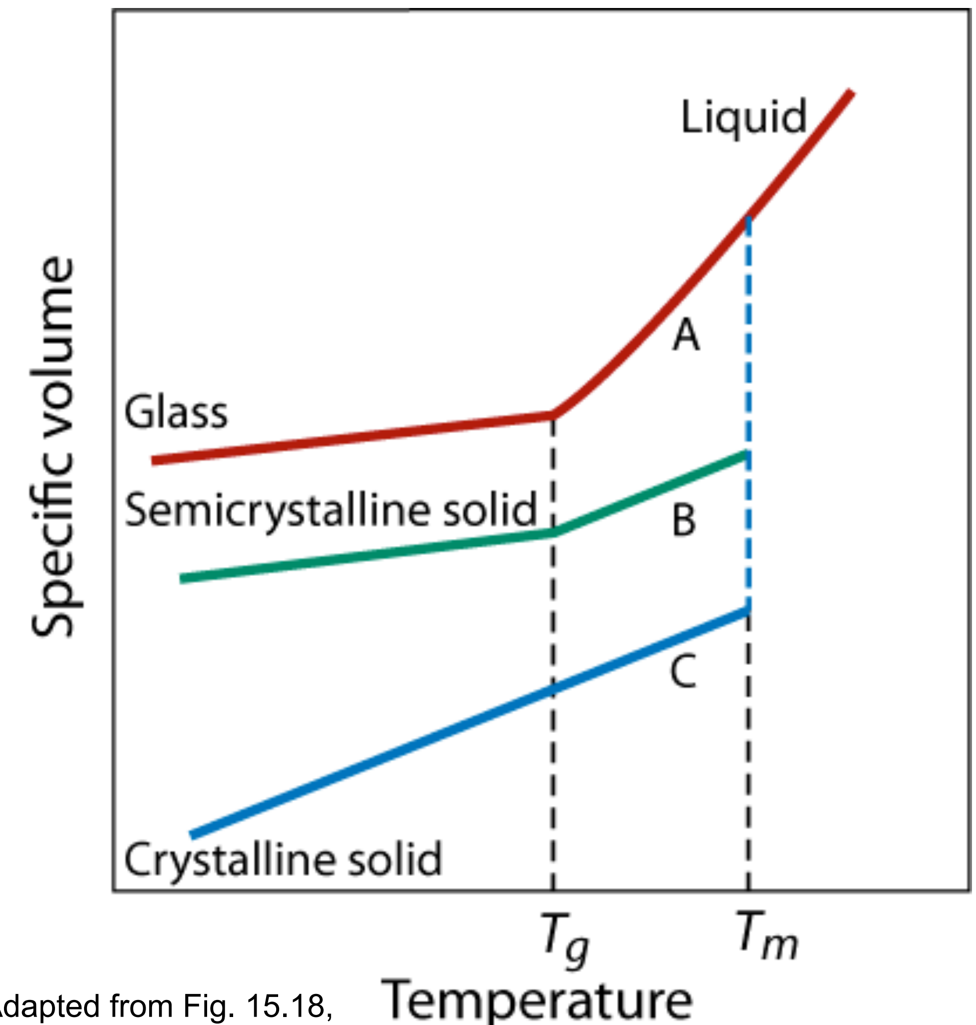


amorphous
region

Adapted from Fig. 14.11, *Callister 6e.*
(Fig. 14.11 is from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, John Wiley and Sons, Inc., 1965.)

T_m and T_g

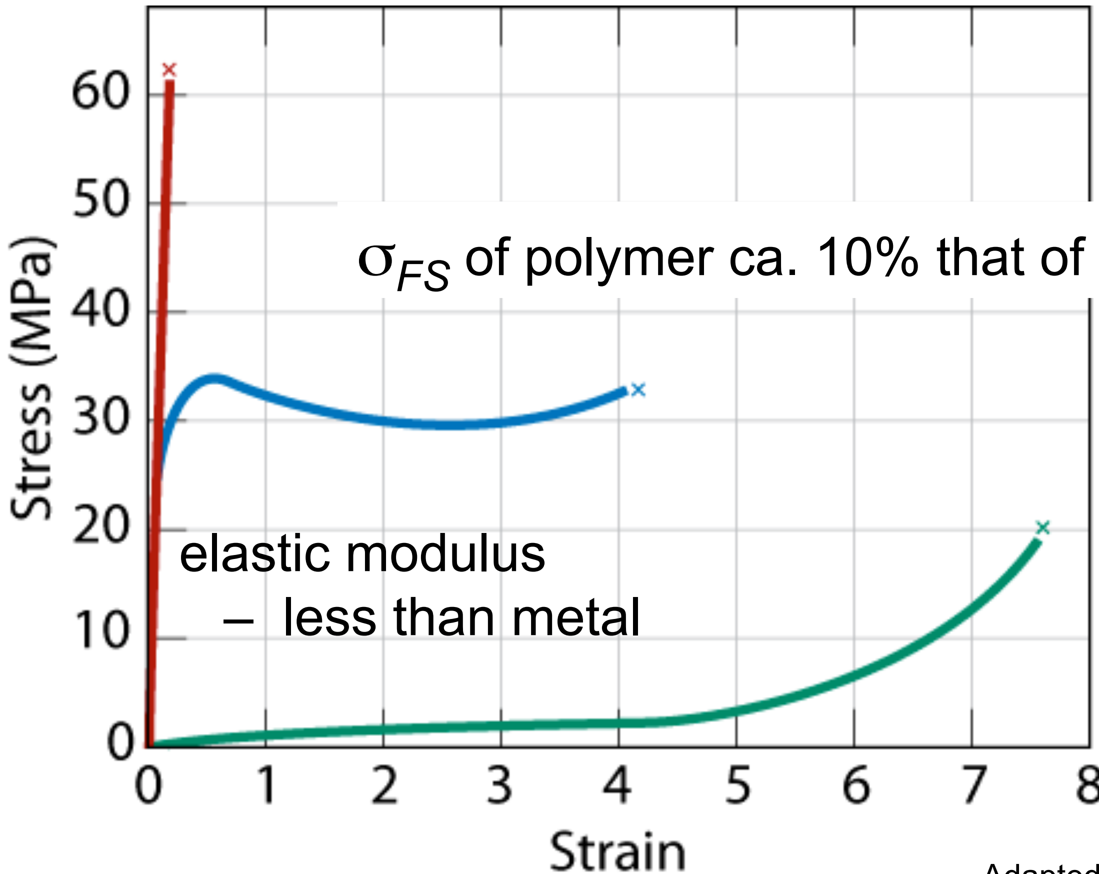
What factors affect T_m and T_g?



Adapted from Fig. 15.18, *Callister 7e*.

Mechanical properties

i.e. stress-strain behavior of polymers



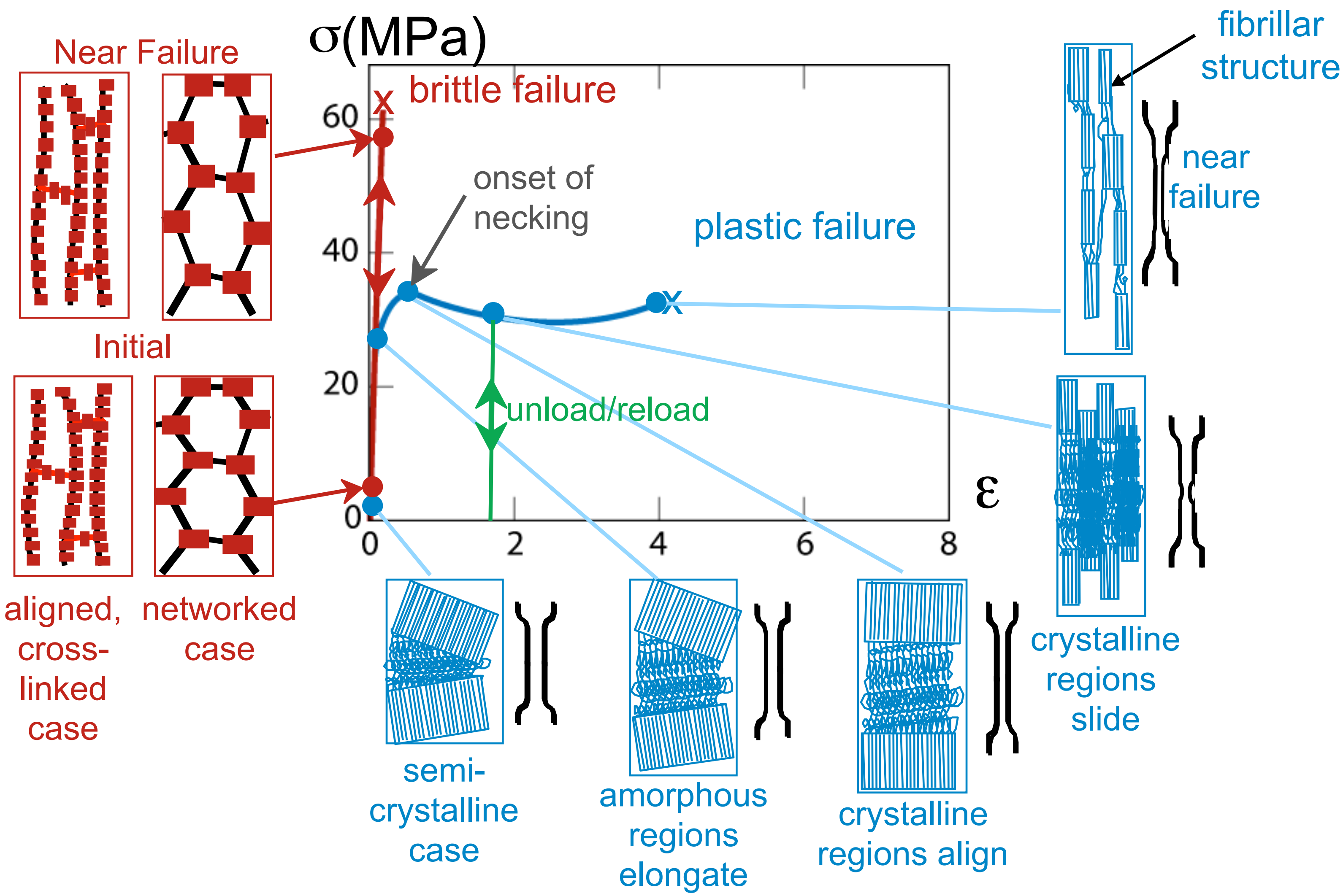
σ_{FS} of polymer ca. 10% that of metals

elastic modulus
– less than metal

Strains – deformations > 1000% possible
(for metals, maximum strain ca. 10% or less)

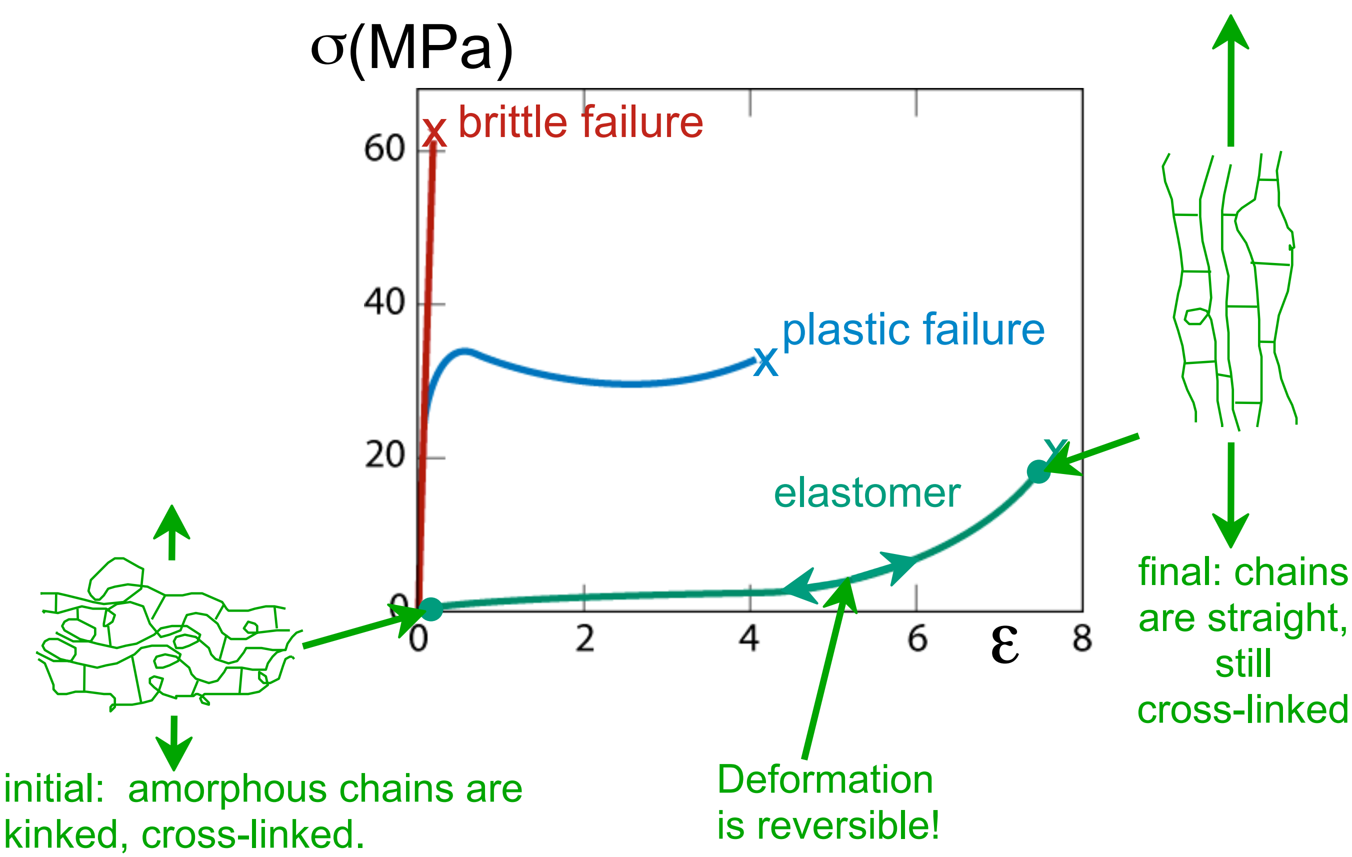
Adapted from Fig. 15.1, *Callister 7e*.

Brittle and plastic behavior



Stress-strain curves adapted from Fig. 15.1, *Callister 7e.* Inset figures along plastic response curve adapted from Figs. 15.12 & 15.13, *Callister 7e*. (Figs. 15.12 & 15.13 are from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)

Tensile response: elastomers

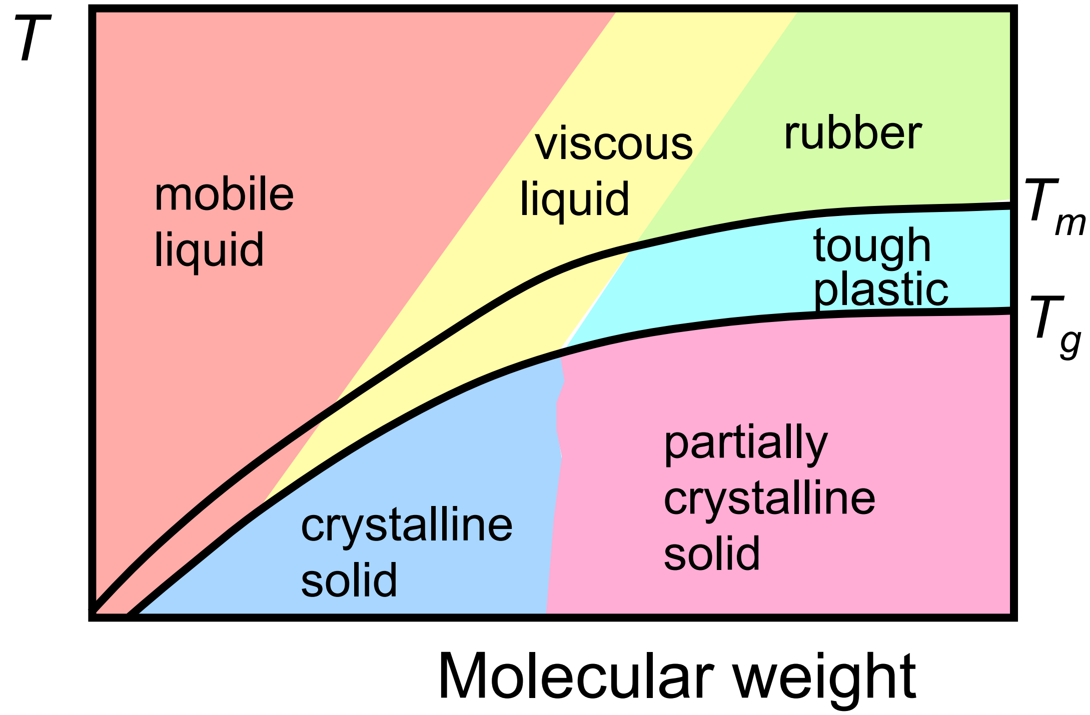


Stress-strain curves adapted from Fig. 15.1, *Callister 7e.* Inset figures along elastomer curve (green) adapted from Fig. 15.15, *Callister 7e*. (Fig. 15.15 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

- Compare to responses of other polymers:
  -- brittle response (aligned, crosslinked & networked polymer)
  -- plastic response (semi-crystalline polymers)

Thermoplastic vs. thermosets

- Thermoplastics:
  -- little crosslinking
  -- ductile
  -- soften w/heating
  -- polyethylene
  polypropylene
  polycarbonate
  polystyrene



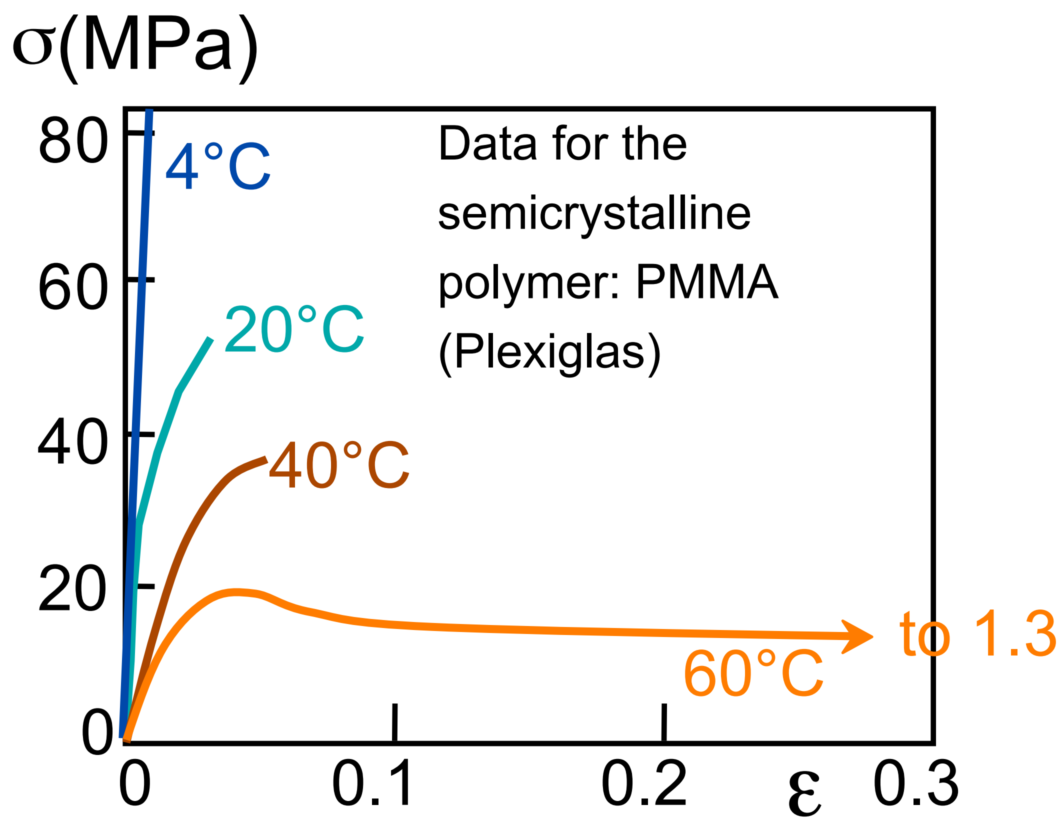
Adapted from Fig. 15.19, *Callister 7e*. (Fig. 15.19 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

- Thermosets:
  -- large crosslinking
  (10 to 50% of mers)
  -- hard and brittle
  -- do NOT soften w/heating
  -- vulcanized rubber, epoxies,
  polyester resin, phenolic resin

Strain rates and T

- Decreasing *T*...
  -- increases *E*
  -- increases *TS*
  -- decreases %*EL*

- Increasing
  strain rate...
  -- same effects
  as decreasing *T*.



Adapted from Fig. 15.3, *Callister 7e*. (Fig. 15.3 is from T.S. Carswell and J.K. Nason, 'Effect of Environmental Conditions on the Mechanical Properties of Organic Plastics", *Symposium on Plastics*, American Society for Testing and Materials, Philadelphia, PA, 1944.)

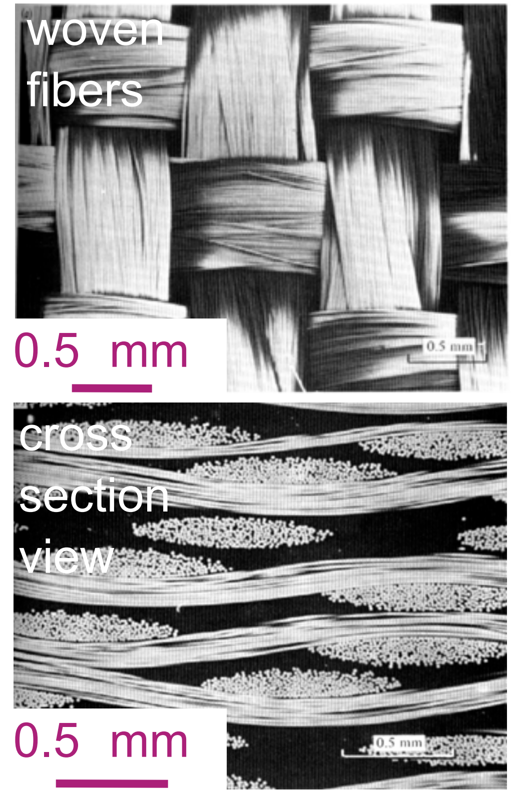
Composites

- 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

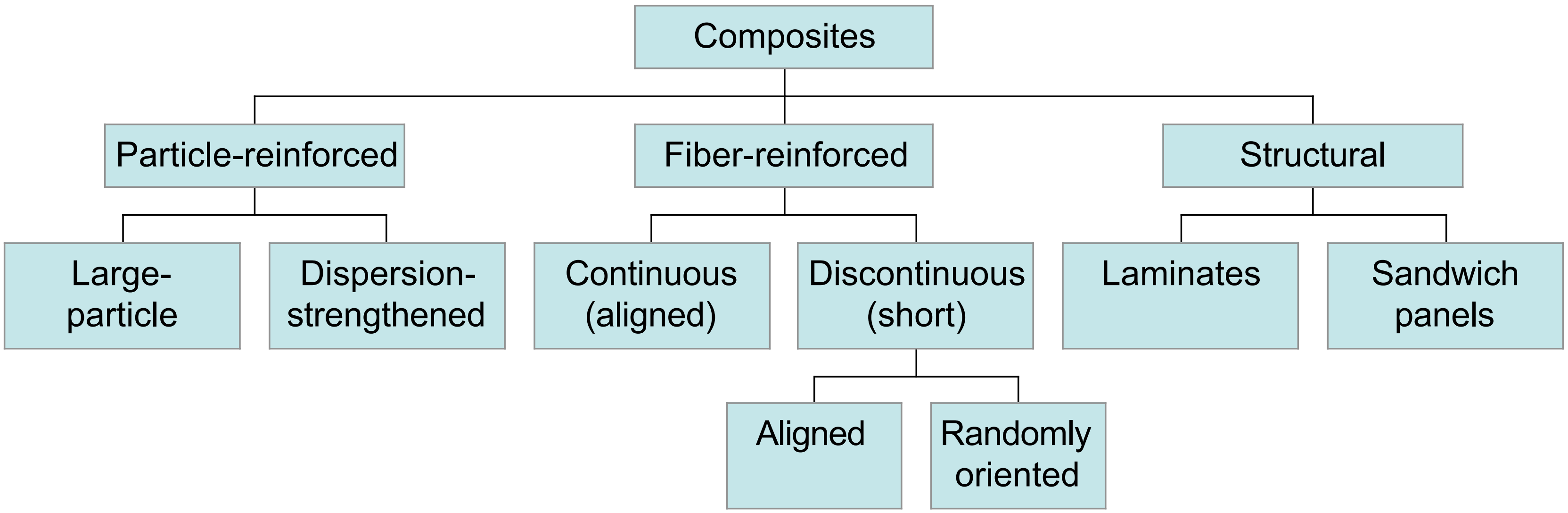
  metal ceramic polymer

- 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 classifications



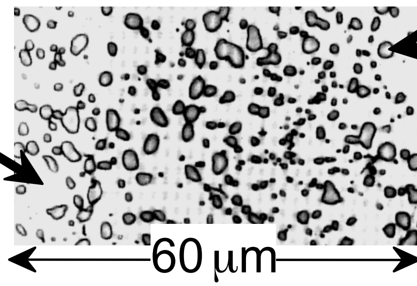
Adapted from Fig. 16.2, *Callister 7e*.

Composite classifications

Particle-reinforced | Fiber-reinforced | Structural

- Examples:
  - Spheroidite steel

matrix: ferrite (α) (ductile)

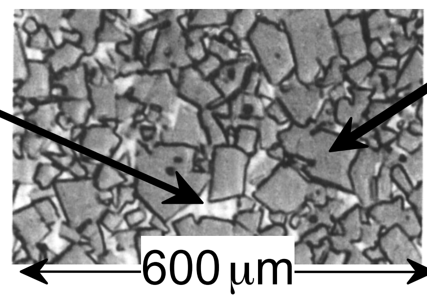


particles: cementite (Fe_3C) (brittle)

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%!

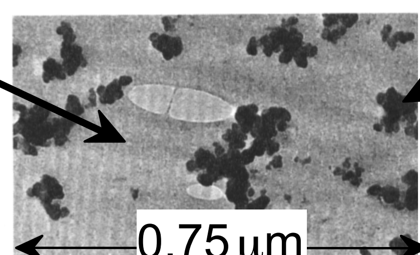


particles: WC (brittle, hard)

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)

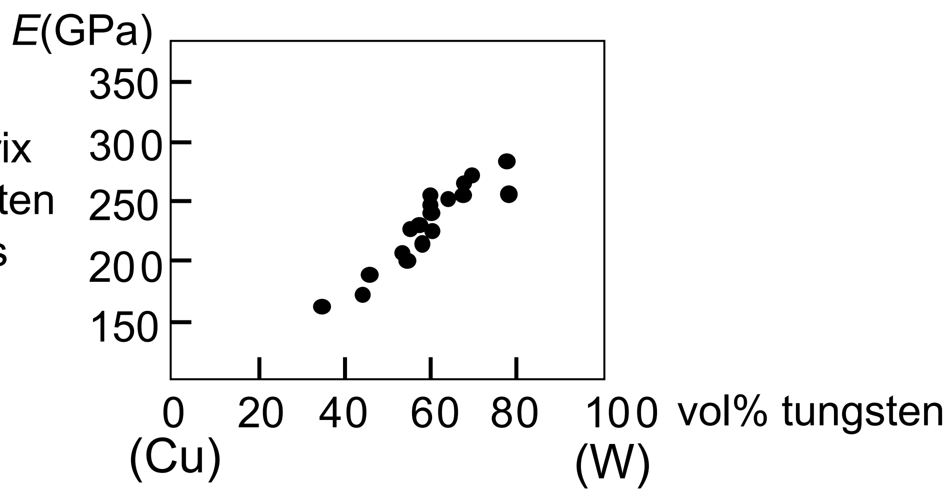
Adapted from Fig. 16.5, *Callister 7e*. (Fig. 16.5 is courtesy Goodyear Tire and Rubber Company.)

Composite classifications

Particle-reinforced | Fiber-reinforced | Structural

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

Data:
Cu matrix
w/tungsten
particles



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 classifications

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

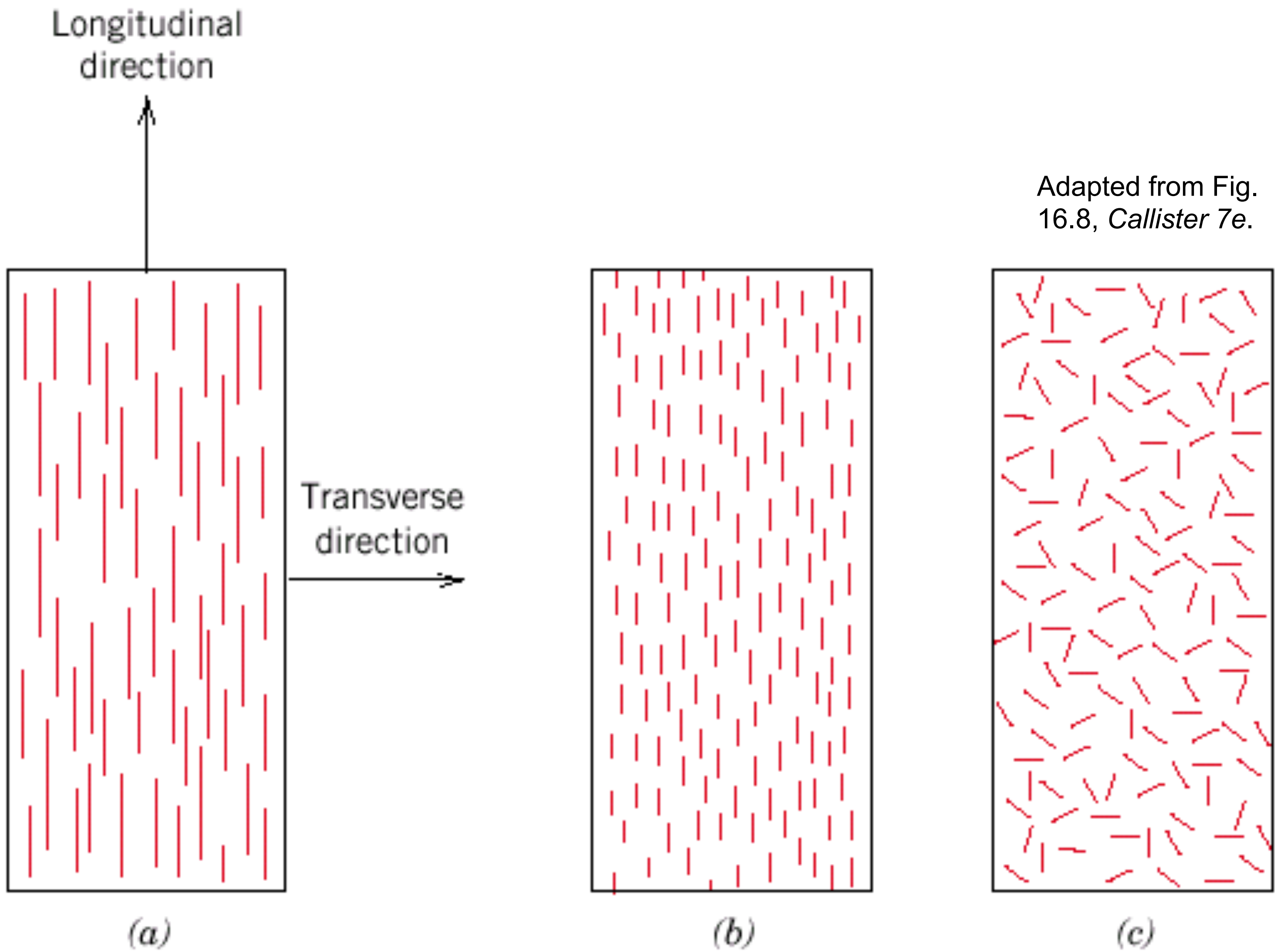
Fiber Materials

- Whiskers - Thin single crystals - large length to diameter ratio
  graphite, SiN, SiC
  high crystal perfection – extremely strong, strongest known
  very expensive

– Fibers
  - polycrystalline or amorphous
  - generally polymers or ceramics
  - Ex: Al_2O_3 , Aramid, E-glass, Boron, UHMWPE

– Wires
  - Metal – steel, Mo, W

Fiber alignment



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

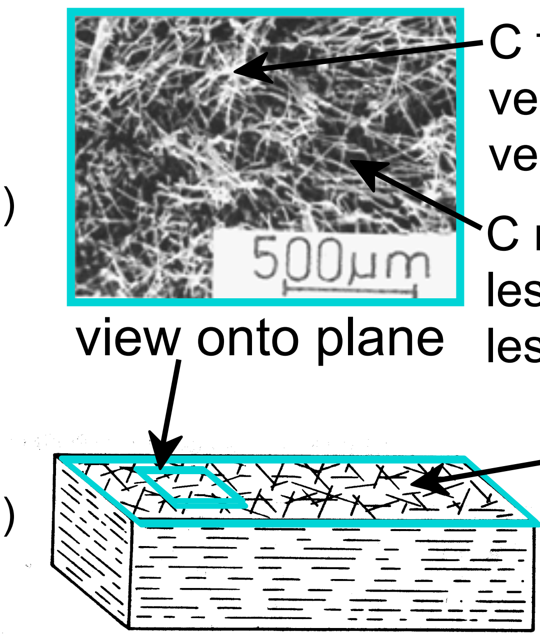
Fiber alignment

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.

(b)

(a)



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.

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

Fiber alignment

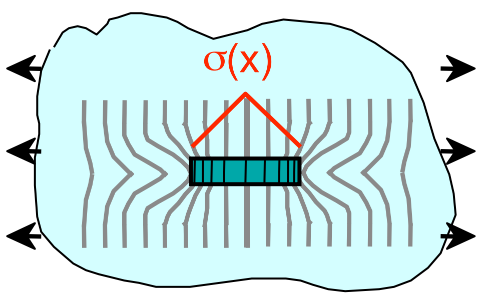
Particle-reinforced | **Fiber-reinforced** | Structural

- Critical fiber length for effective stiffening & strengthening:

- Ex: For fiberglass, fiber length > 15 mm needed

Shorter, thicker fiber:

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

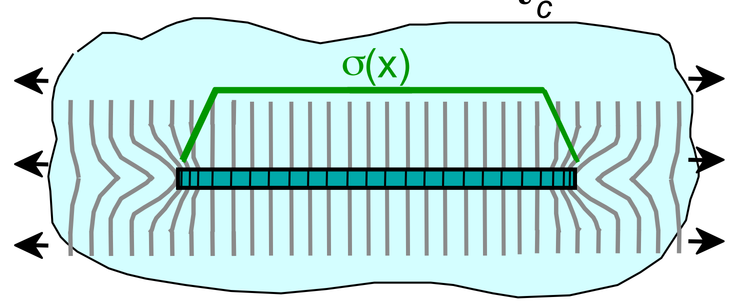


Poorer fiber efficiency

Adapted from Fig. 16.7, *Callister 7e*.

Longer, thinner fiber:

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



Better fiber efficiency

Fiber reinforcement

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

- Estimate of E_c and *TS* for discontinuous fibers:
  - -- valid when $$\text{fiber length} > 15\frac{\sigma_f d}{\tau_c}$$
  - -- Elastic modulus in fiber direction:

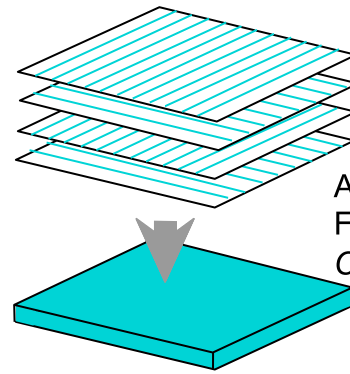
Values from Table 16.3, *Callister 7e*. (Source for Table 16.3 is H. Krenchel, *Fibre Reinforcement*, Copenhagen: Akademisk Forlag, 1964.)

  - -- *TS* in fiber direction:

Structural composites

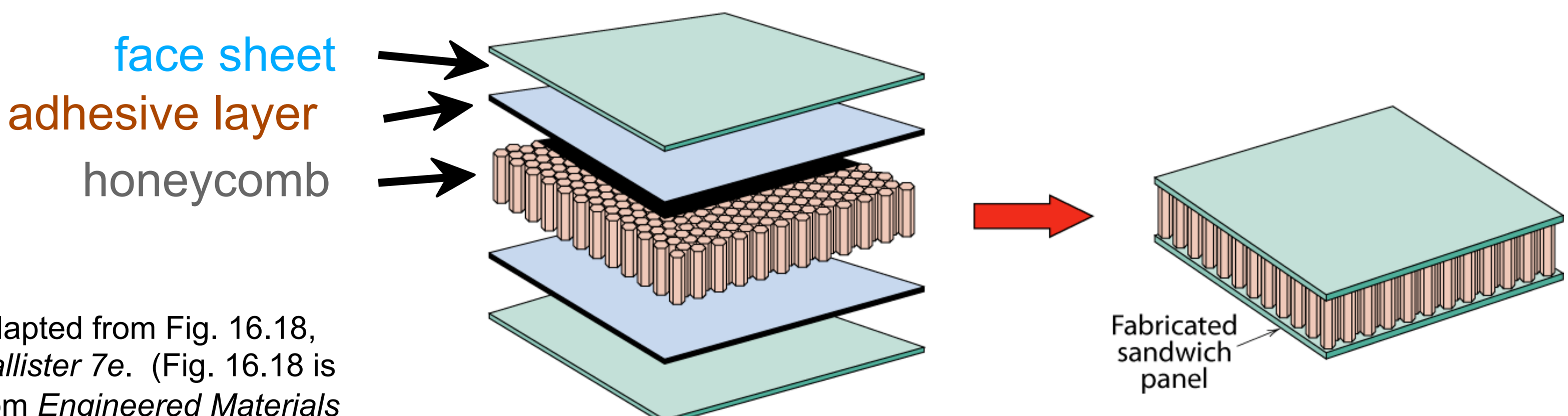
Particle-reinforced | Fiber-reinforced | **Structural**

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



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

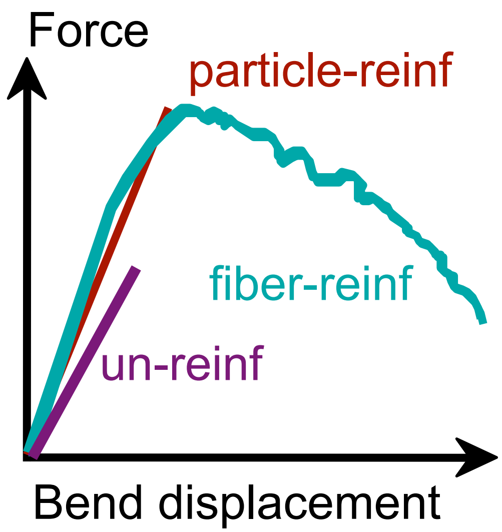
- Sandwich panels
  - -- low density, honeycomb core
  - -- benefit: small weight, large bending stiffness



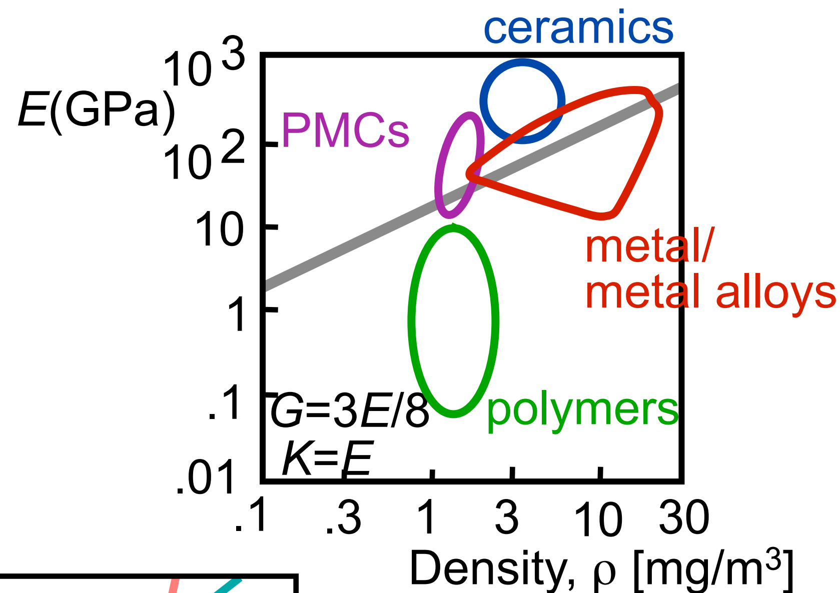
Adapted from Fig. 16.18, *Callister 7e*. (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

Composite benefits

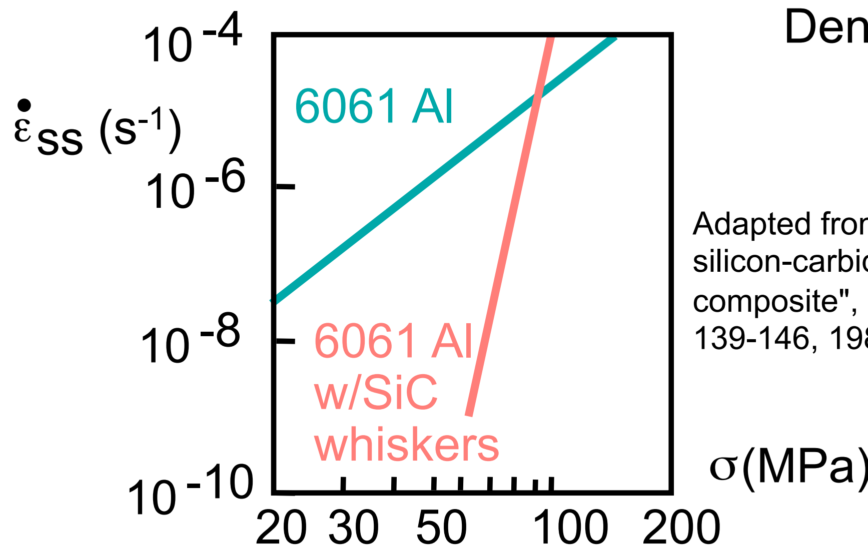
- CMCs: Increased toughness



- 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.