Applied Strength of Materials 6th edition Mott Solutions Manual

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Chapter 2 Design Properties of Materials

Only those problems requiring numerical data are shown.

2-14 $s_u = 90$ ksi (621 MPa); $s_y = 60$ ksi (414 MPa); 25% Elongation [Appendix A-10]

Because % Elongation >5%, it is ductile.

2-15 1020 HR: 36% Elongation – **Greater ductility** [Appendix A-10]

1040 HR: 25% Elongation

2-16 SAE 1141 OQT 700: High sulfur alloy steel with 0.41% carbon, quenched in oil, tempered at 700°F. [Appendix A-10]

2-17 Yes, AISI 1141 steel has: $s_y = 172$ ksi @ OQT 700, $s_y = 129$ ksi @ OQT 900

By interpolation, $s_y \approx 150$ ksi @ OQT 800. [Appendix A-10]

2-18 $E = 30 \times 10^6$ psi (207 GPa) For all carbon and alloy steels. [Appendix A-10]

2-19 $Wt = \text{Density} \times \text{Volume} = (0.283\ \text{lb/in}^3)(1.0)(4.0)(14.5)\text{in}^3 = \mathbf{16.4\ lb}$

[Appendix A-10] Value of lb_m = Value of lb force (Wt)

2-20 $\text{Volume} = \text{Area} \times \text{Length} = \frac{\pi}{4}(50)^2 \times 250 = 4.909 \times 10^5\ \text{mm}^3$

Steel Bar: $\text{Mass} = \frac{7680\ \text{kg}}{\text{m}^3} \times \frac{4.909\times10^5\ \text{mm}^3}{1} \times \frac{1\ \text{m}^3}{(10^3\ \text{mm})^3} = 3.77\ \text{kg}$ [Appendix A-10]

$Wt = m \cdot g = 3.77\ \text{kg} \cdot 9.81\ \text{m/s}^2 = 36.98\ \text{kg} \cdot \text{m/s}^2 = \mathbf{36.98\ N}$

2-21 Magnesium would stretch more because it has a lower E.

$E_{Mag} = 45$ GPa; $E_{Ti} = 114$ GPa; Ti is stiffer. [Appendix A-11]

2-23 Alloy of aluminum with silicon and magnesium. Heat treated to T6 temper.

2-24

	s_u	s_y	E	Density
6061-0	18 ksi	8 ksi	10×10^6 psi	$0.10\ \text{lb/in}^3$
6061-T4	35 ksi	21 ksi	10×10^6 psi	$0.10\ \text{lb/in}^3$
6061-T6	45 ksi	40 ksi	10×10^6 psi	$0.10\ \text{lb/in}^3$

[Appendix A-14]

2-29 $s_{ut} = 40$ ksi; $s_{uc} = 140$ ksi [Appendix A-13]

2-31 Bending $\sigma_d = 1450$ psi; Tension $\sigma_d = 850$ psi; Compression 1000 psi Parallel to grain, 385 psi Perpendicular to grain; Shear $\tau_d = 95$ psi [Appendix A-15]

2-32 2000 to 7000 psi [Section 2-11]

2-44 Graphite fibers.

2-45 S-glass, quartz fibers, tungsten fibers coated with silicon carbide

2-51

Material	Specific strength (in)	Ratio to SAE 1020
Graphite/Epoxy (High Strength)	4.86×10^6	25.0
Aramid/Epoxy Composite	4.00×10^6	20.6
Boron/Epoxy Composite	3.60×10^6	18.5
Graphite/Epoxy (Ultra-high mod.)	2.76×10^6	14.2
Glass/Epoxy Composite	1.87×10^6	9.63
Titanium Ti-6Al-4V	1.00×10^6	5.15
SAE 5160 OQT 700 Steel	0.929×10^6	4.78
Aluminum 7075-T6	0.822×10^6	4.23
Aluminum 6061-T6	0.459×10^6	2.36
SAE 1020 HR Steel	0.194×10^6	1.00

2-52

Material	Specific modulus (in)	Ratio to SAE 1020
Graphite/Epoxy (Ultra-high mod.)	8.28×10^8	7.81
Boron/Epoxy Composite	4.00×10^8	3.77
Graphite/Epoxy (High Strength)	3.45×10^8	3.25
Aramid/Epoxy Composite	2.20×10^8	2.07
SAE 1020 HR Steel	1.06×10^8	1.00
SAE 5160 OQT 700 Steel	1.06×10^8	1.00
Titanium Ti-6Al-4V	1.03×10^8	0.97
Aluminum 6061-T6	1.02×10^8	0.96
Aluminum 7075-T6	0.99×10^8	0.93
Glass/Epoxy Composite	0.66×10^8	0.62

2-60 $V_m = 1.0 - V_f = 1.0 - 0.60 = 0.40$

2-61 See Equation (2-10)

2-62 See Equations (2-11), (2-12), (2-13), (2-14)

2-63 Given: $V_f = 0.50$; Fibers are high strength carbon-PAN; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $s_{uc} = s_{uf} V_f + \sigma_m' V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (820\text{x } 10^3 \text{ psi})/(40\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.0205$

Stress in matrix at this strain: $\sigma_m' = E_m \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.0205) = 11\ 480 \text{ psi}$

Then: $s_{uc} = (820\text{x } 10^3 \text{ psi})(0.50) + (11\ 480 \text{ psi})(0.50) = \underline{415\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f V_f + E_m V_m = (40\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 20.3\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f V_f + \gamma_m V_m = (0.065)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.056 \text{ lb/in}^3}$

2-64 Given: $V_f = 0.50$; Fibers are high modulus carbon; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $= s_{uf} V_f + \sigma_m' V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (325\text{x } 10^3 \text{ psi})/(100\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.00325$

Stress in matrix at this strain: $\sigma_m' = E_m \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.00325) = 1820 \text{ psi}$

Then: $s_{uc} = (325\text{x } 10^3 \text{ psi})(0.50) + (1820 \text{ psi})(0.50) = \underline{163\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f V_f + E_m V_m = (100\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 50.3\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f V_f + \gamma_m V_m = (0.078)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.0625 \text{ lb/in}^3}$

2-65 Given: $V_f = 0.50$; Fibers are aramid; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $s_{uc} = s_{uf} V_f + \sigma_m' V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (500\text{x } 10^3 \text{ psi})/(19\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.0263$

Stress in matrix at this strain: $\sigma_m' = E_m \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.0263) = 14\ 740 \text{ psi}$

Then: $s_{uc} = (500\text{x } 10^3 \text{ psi})(0.50) + (14\ 740 \text{ psi})(0.50) = \underline{257\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f V_f + E_m V_m = (19\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 9.78\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f V_f + \gamma_m V_m = (0.052)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.0495 \text{ lb/in}^3}$

Solutions to Problems 2-66 to 2-77: Some data are approximated from Figure P2-66.

- The most accurate values are for ultimate strength (b.) and % elongation (f.).
- The elastic limit (d.) is estimated between the proportional limit (c.) and yield strength (a.).
- The modulus of elasticity (e.) is computed from [Δ stress / Δ strain], the slope of the straight-line part of each curve.
- Listed materials are found in Appendixes A-10 – A-14, matching s_u, s_y, E, and % elongation.

2-66
a. s_y = 73 ksi; Offset method
b. s_u = 83 ksi
c. s_p = 60 ksi
d. s_{el} = 67 ksi
e. E = 10.0×10^6 psi
f. 11% elongation
g. Ductile
h. Aluminum
i. 7075-T6

2-67
a. s_y = 173 ksi; Yield point
b. s_u = 187 ksi
c. s_p = 162 ksi
d. s_{el} = 168 ksi
e. E = 29.0×10^6 psi
f. 15% elongation
g. Ductile
h. Steel
i. SAE 4140 OQT 900

2-68
a. s_y = 62 ksi; Offset method
b. s_u = 75 ksi
c. s_p = 50 ksi
d. s_{el} = 56 ksi
e. E = 16.7×10^6 psi
f. 15% elongation
g. Ductile
h. Copper alloy
i. C54400 Bronze-Hard

2-69
a. s_y = 49 ksi; Yield point
b. s_u = 65 ksi
c. s_p = 46 ksi
d. s_{el} = 48 ksi
e. E = 26.5×10^6 psi
f. 36% elongation
g. Ductile
h. Steel
i. SAE 1020 CD

2-70
a. No yield strength-Brittle
b. s_u = 55 ksi
c. s_p = 50 ksi
d. s_{el} = 53 ksi
e. E = 20.0×10^6 psi
f. 0.5% elongation
g. Brittle
h. Cast iron
i. ASTM A48 Grade 60

2-71
a. s_y = 53 ksi; Offset Method
b. s_u = 59 ksi
c. s_p = 31 ksi
d. s_{el} = 42 ksi
e. E = 12.0×10^6 psi
f. 5.0% elongation
g. Borderline Ductile/Brittle
h. Zinc
i. Cast ZA-12

2-72
a. s_y = 35 ksi; Yield point
b. s_u = 57 ksi
c. s_p = 30 ksi
d. s_{el} = 27 ksi
e. E = 26.0×10^6 psi
f. 21% elongation
g. Ductile
h. Structural Steel
i. ASTM A36

2-73
a. s_y = 19 ksi; Offset Method
b. s_u = 40 ksi
c. s_p = 14 ksi
d. s_{el} = 17 ksi
e. E = 6.0×10^6 psi
f. 5.0% elongation
g. Borderline Ductile/Brittle
h. Magnesium
i. ASTM AZ 63A-T6

2-74
a. $s_y = 155$ ksi; Offset Method
b. $s_u = 170$ ksi
c. $s_p = 142$ ksi
d. $s_{el} = 149$ ksi
e. $E = 16.5 \times 10^6$ psi
f. 8% elongation
g. Ductile
h. Titanium
i. 6Al-4V

2-75
a. $s_y = 40$ ksi; Offset Method
b. $s_u = 45$ ksi
c. $s_p = 30$ ksi
d. $s_{el} = 35$ ksi
e. $E = 10.0 \times 10^6$ psi
f. 17% elongation
g. Ductile
h. Aluminum
i. 6061-T6

2-76
a. $s_y = 80$ ksi; Offset Method
b. $s_u = 90$ ksi
c. $s_p = 62$ ksi
d. $s_{el} = 71$ ksi
e. $E = 26.0 \times 10^6$ psi
f. 15% elongation
g. Ductile
h. Stainless Steel
i. SAE 430 – Full hard

2-77
a. $s_y = 80$ ksi; Offset Method
b. $s_u = 95$ ksi
c. $s_p = 55$ ksi
d. $s_{el} = 68$ ksi
e. $E = 26.0 \times 10^6$ psi
f. 2.0% elongation
g. Brittle – Does not yield
h. Malleable Iron
i. ASTM A220 Grade 80002

Figure 2–1 **(See color insert.)** Understanding the properties of a material is critical to achieving safe and effective designs. Test equipment, such as that shown here, is available to determine the performance of a wide variety of materials with regard to strength and deformation.

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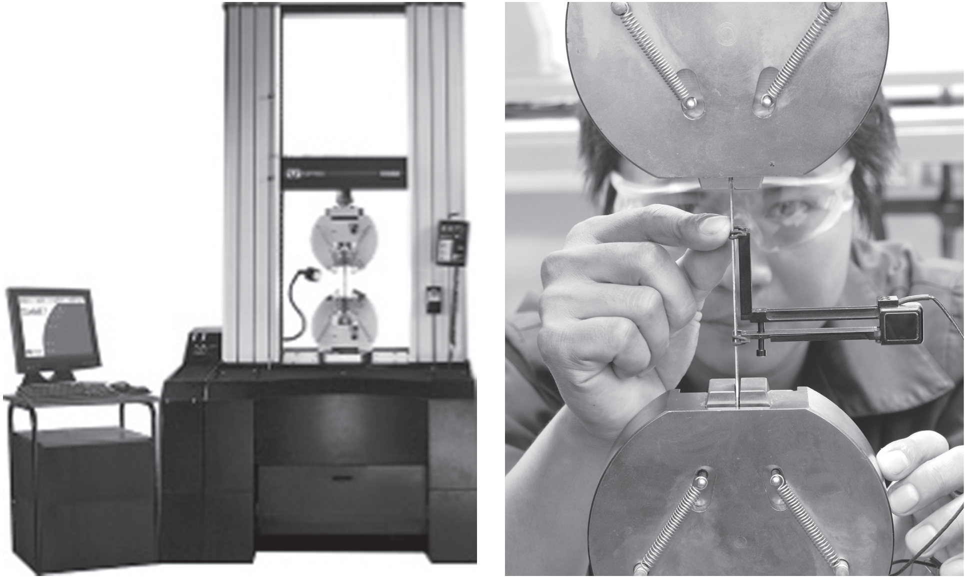
Courtesy of CRC Press/Taylor & Francis Group



(a) *(b)*

Figure 2–2 ***(a)*** Universal testing machine for obtaining stress–strain data for materials. (Courtesy of Instron Corporation, Norwood, MA.) ***(b)*** A technician is installing a tensile test specimen in a holder that is installed in the instrument shown in part (a). The device attached to the specimen, called an *extensometer,* is used to continuously monitor elongation as the tensile load is increased during the test.

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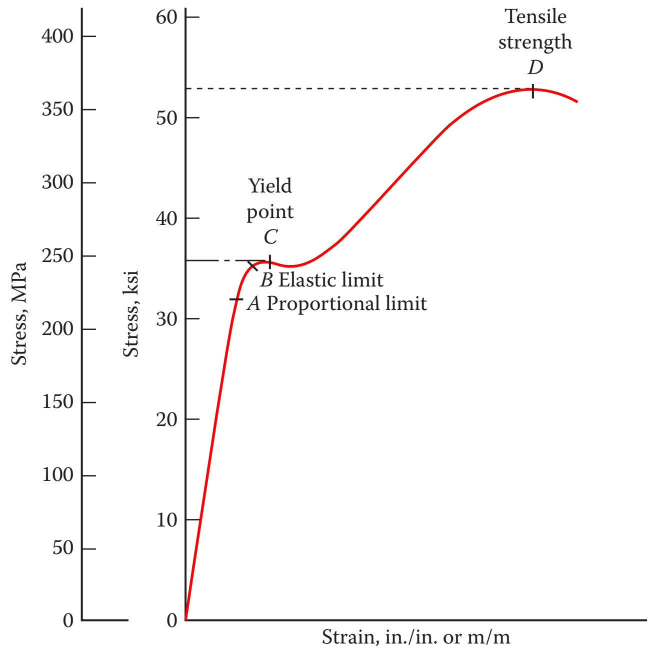

Figure 2–3 Typical stress–strain curve for steel.

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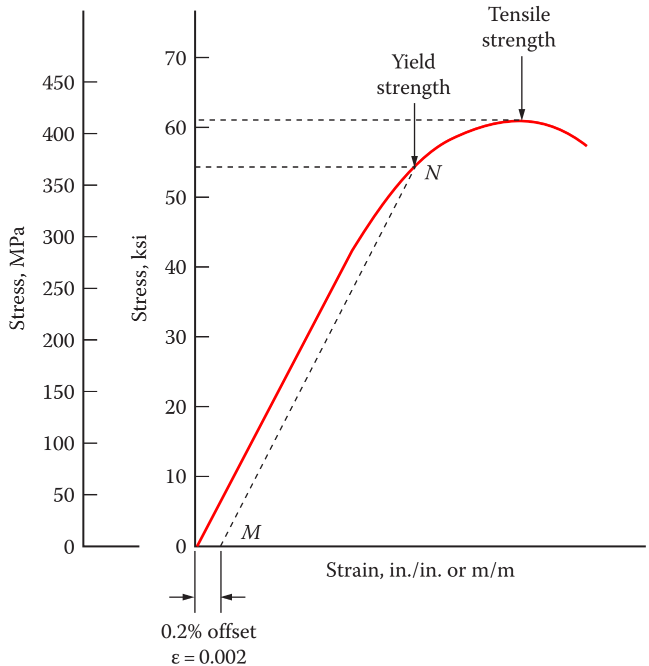

Figure 2–4 Typical stress–strain curve for aluminum.

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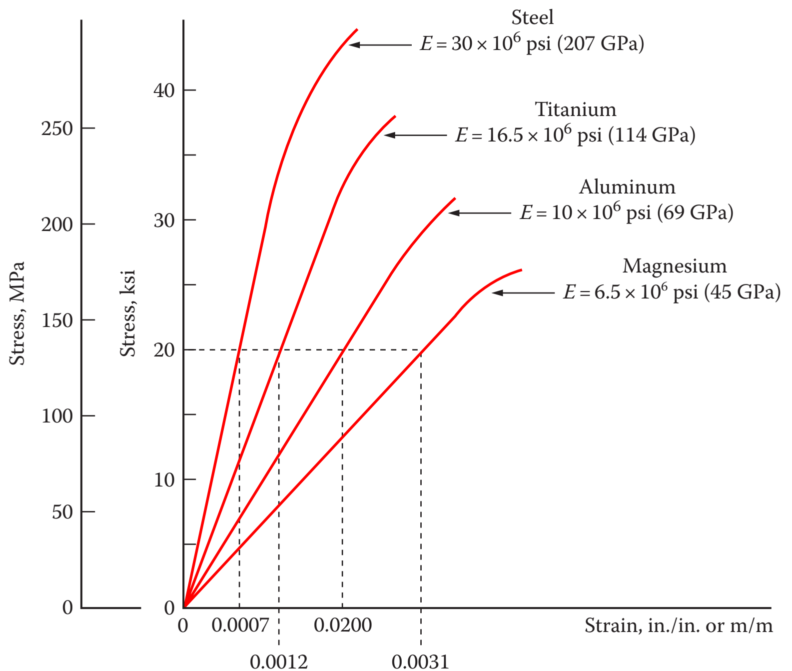

Figure 2–5 Modulus of elasticity for different metals.

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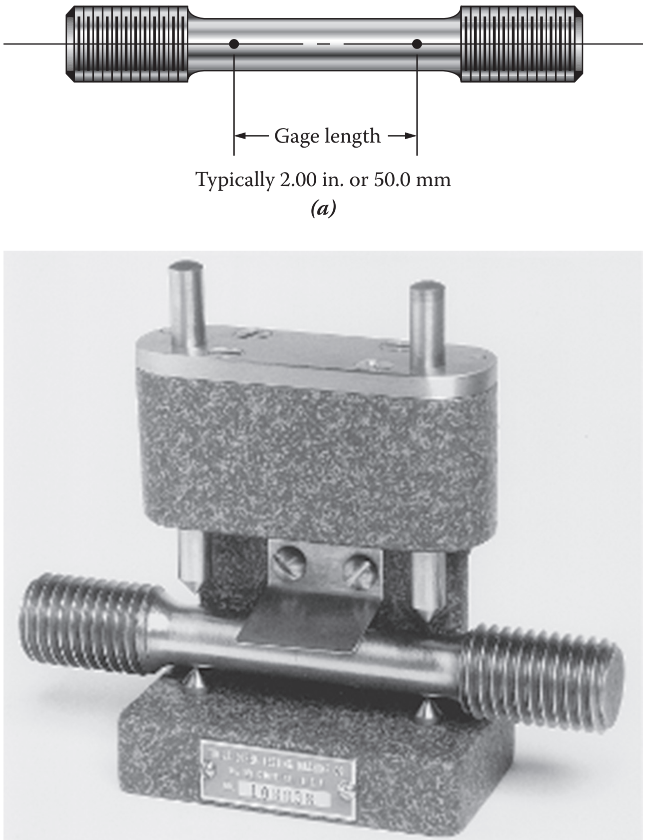

(a)

(b)

Figure 2–6 Gage length for tensile test specimen: ***(a)*** gage length marked on a test specimen and ***(b)*** test specimen in a fixture used to mark gage length. (Courtesy of Tinius Olsen Testing Machine Co., Inc., Willow Grove, PA.)

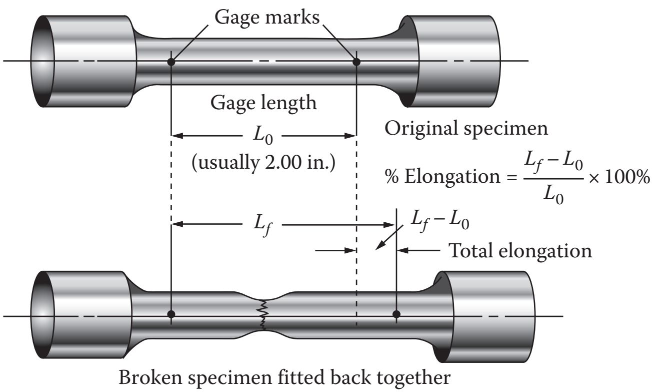

Figure 2–7 Measurement of percent elongation.

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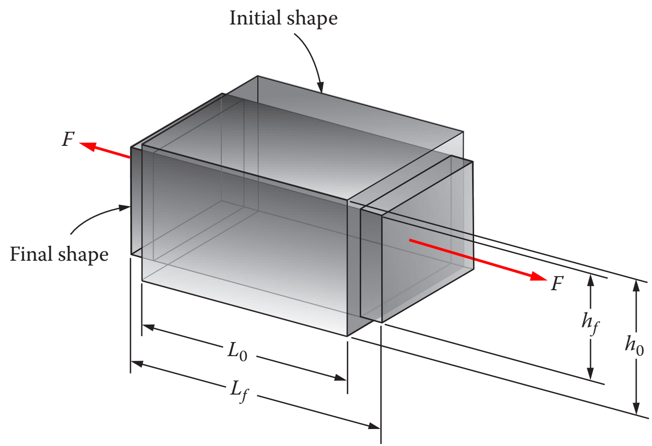

$$\text{Axial strain} = \frac{L_f - L_0}{L_0} = \varepsilon_a$$

$$\text{Lateral strain} = \frac{h_f - h_0}{h_0} = \varepsilon_L$$

$$\text{Poisson's ratio} = \frac{-\varepsilon_L}{\varepsilon_a} = \nu$$

Figure 2–8 Illustration of Poisson's ratio for an element in tension.

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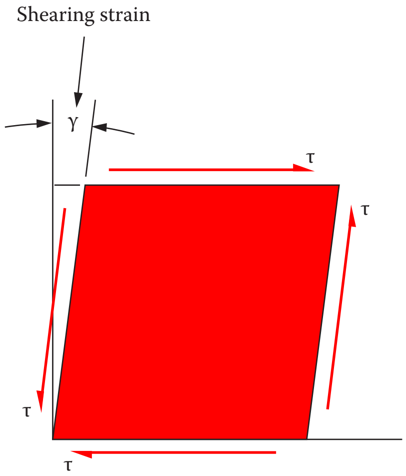

Figure 2–9 Shearing strain shown on a stress element.

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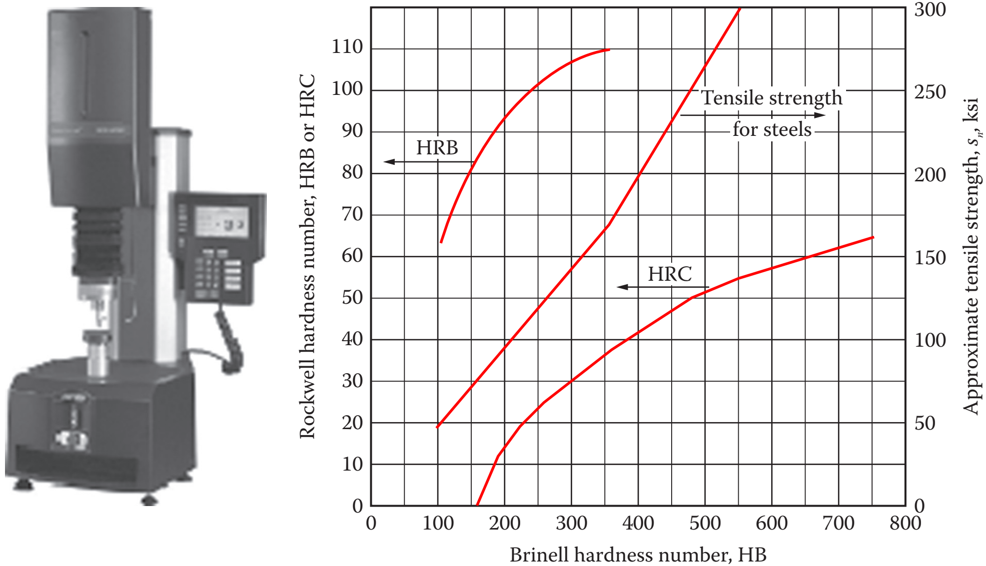

(a) *(b)*

Figure 2–10 Hardness tester and conversions: ***(a)*** Rockwell hardness tester and ***(b)*** hardness conversions and relations to tensile strength for steels. (Courtesy of Instron Corporation, Norwood, MA.)

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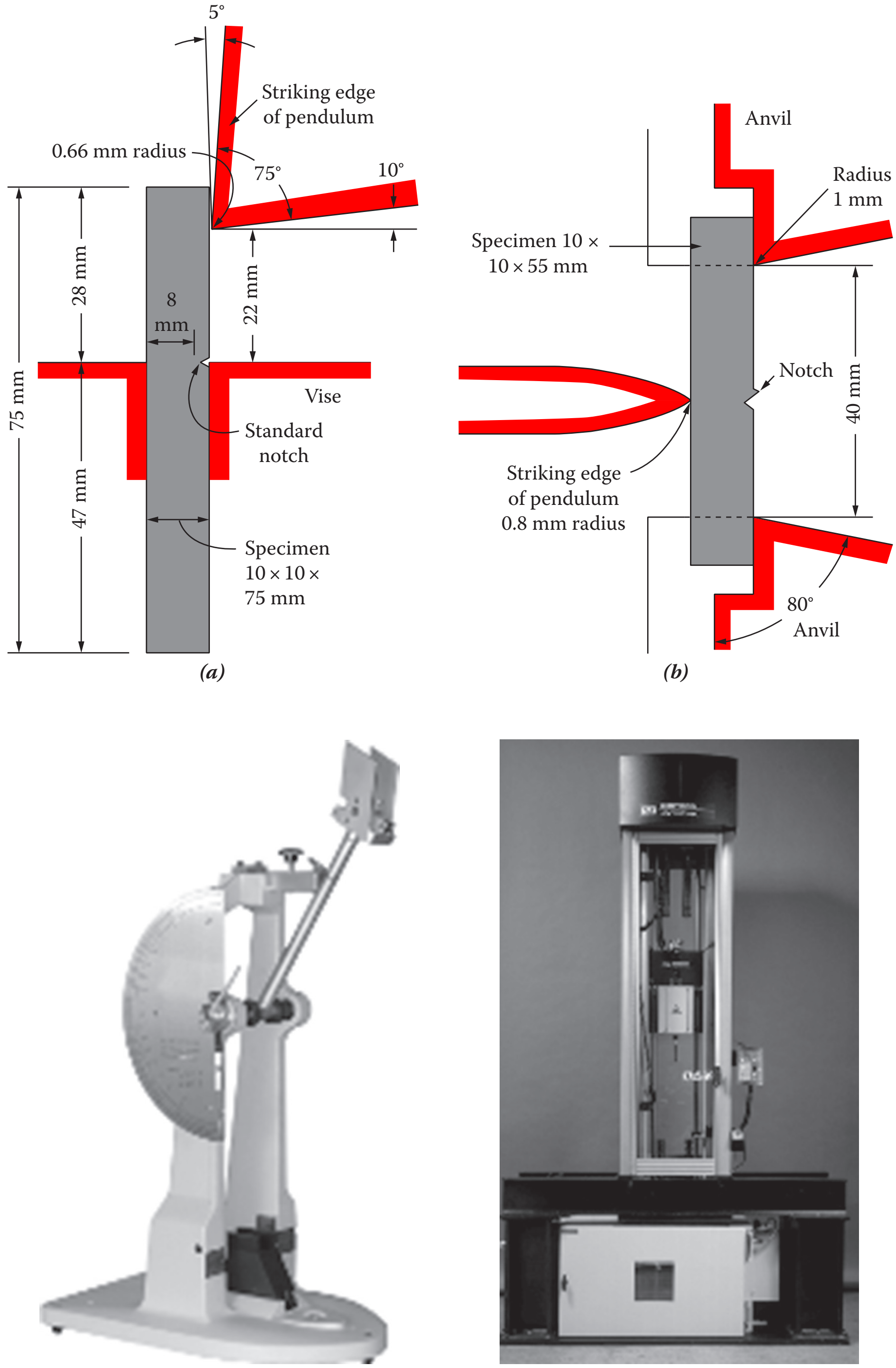

Figure 2–11 Impact testing devices and equipment: ***(a)*** Izod test specimen and striker (side view), ***(b)*** Charpy test specimen and striker (top view), ***(c)*** pendulum-type impact tester, and ***(d)*** drop-type impact tester. (Courtesy of Instron Corporation, Norwood, MA.)

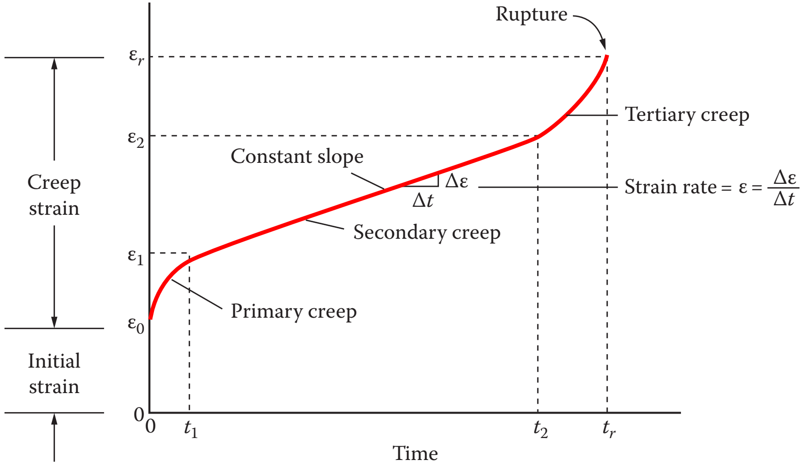

Figure 2–12 Typical creep behavior.

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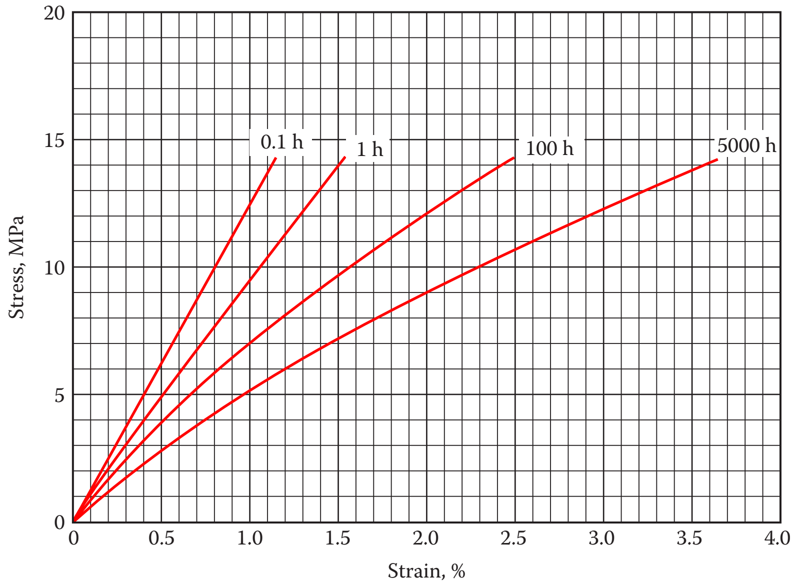

Figure 2–13 Example of stress versus strain as a function of time for nylon 66 plastic at 23°C (73°F). (Courtesy of DuPont Polymers, Wilmington, DE.)

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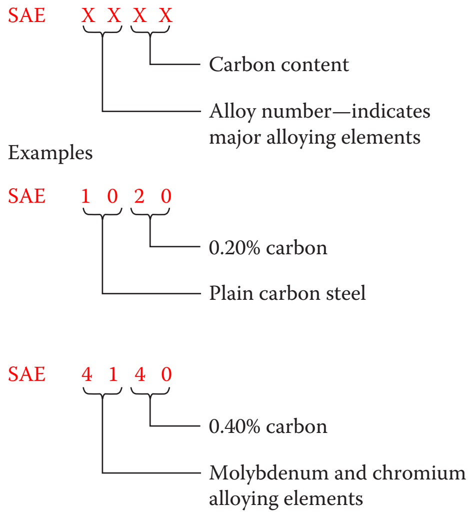

Figure 2–14 Steel designation system.

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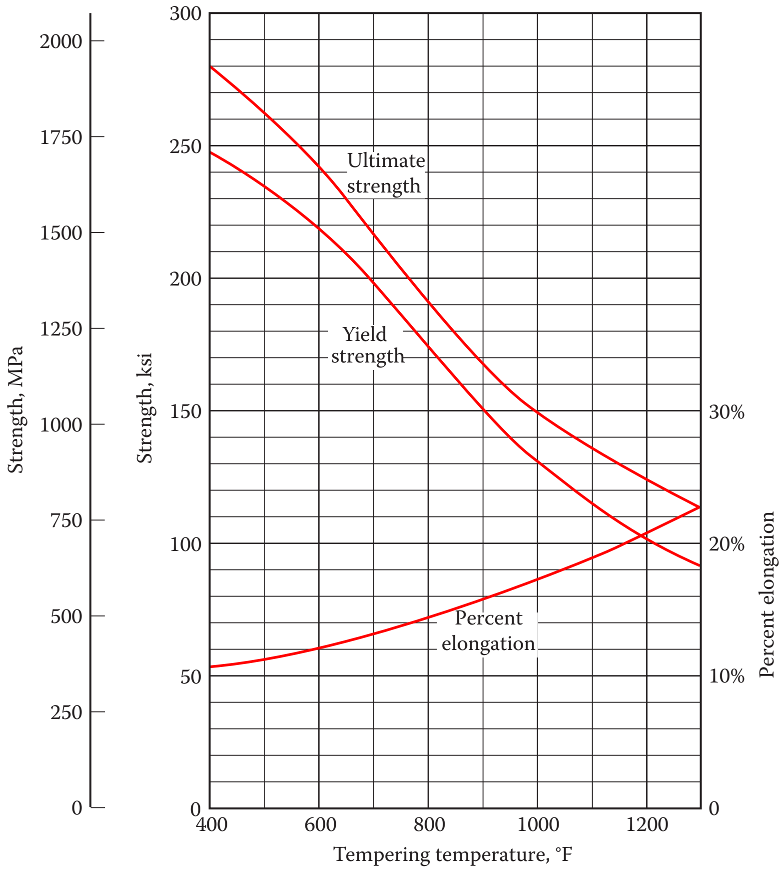

Figure 2–15 Effect of tempering temperature on the strength and ductility of an alloy steel.

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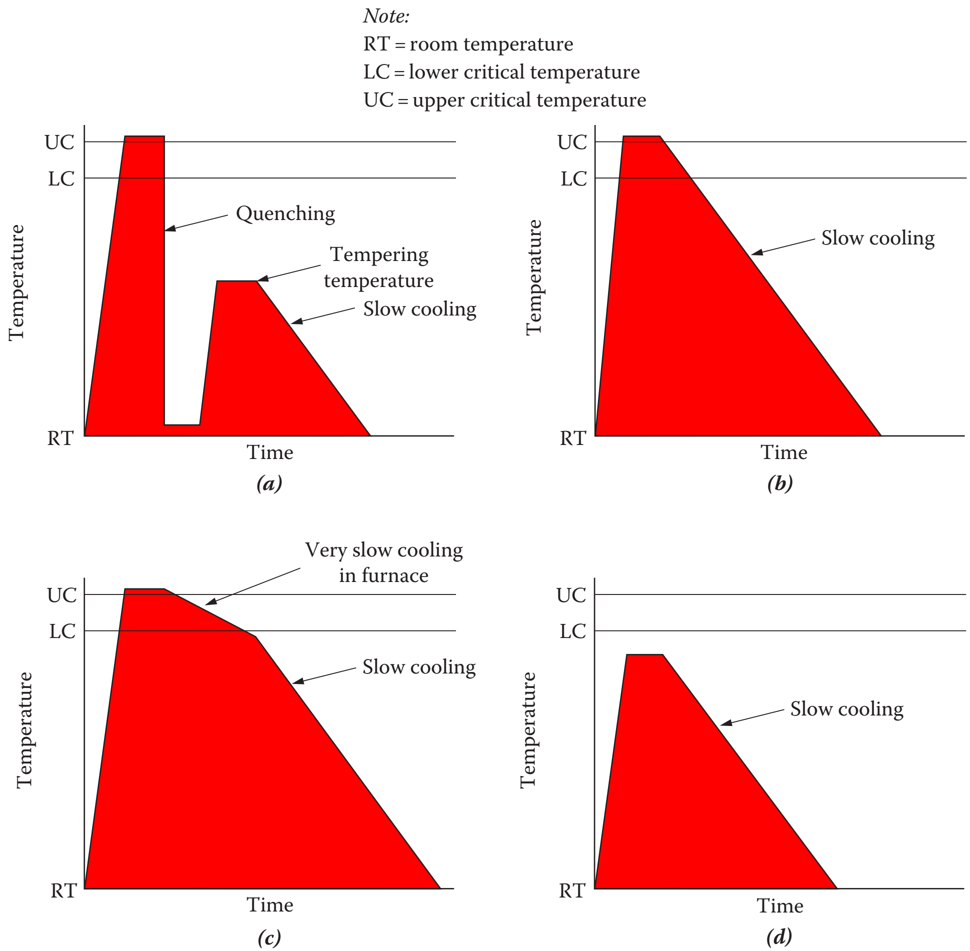

Figure 2–16 Heat treatments for steel: ***(a)*** quenching and tempering, ***(b)*** normalizing, ***(c)*** full annealing, and ***(d)*** stress-relief annealing.

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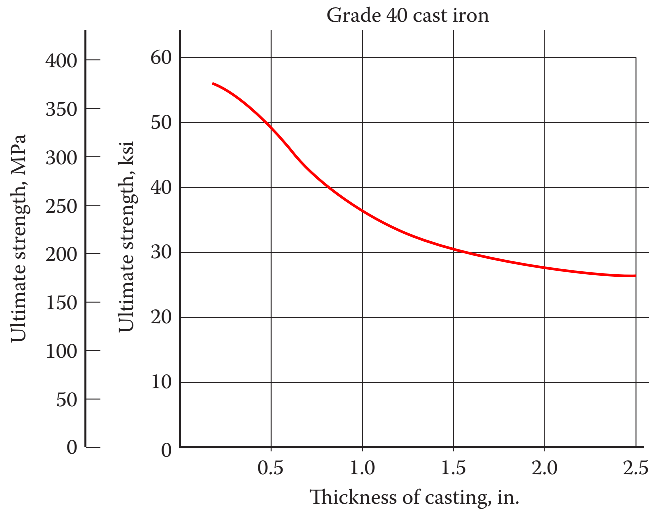

Figure 2–17 Strength versus thickness for Grade 40 gray cast iron.

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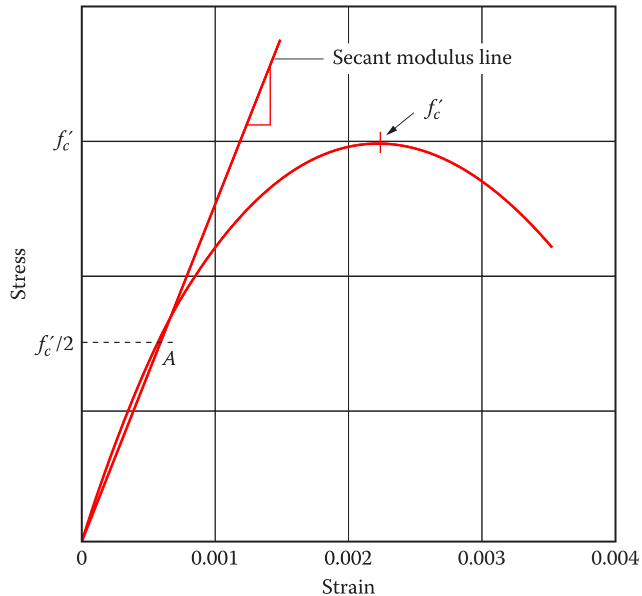

Figure 2–18 Typical stress–strain curve for concrete.

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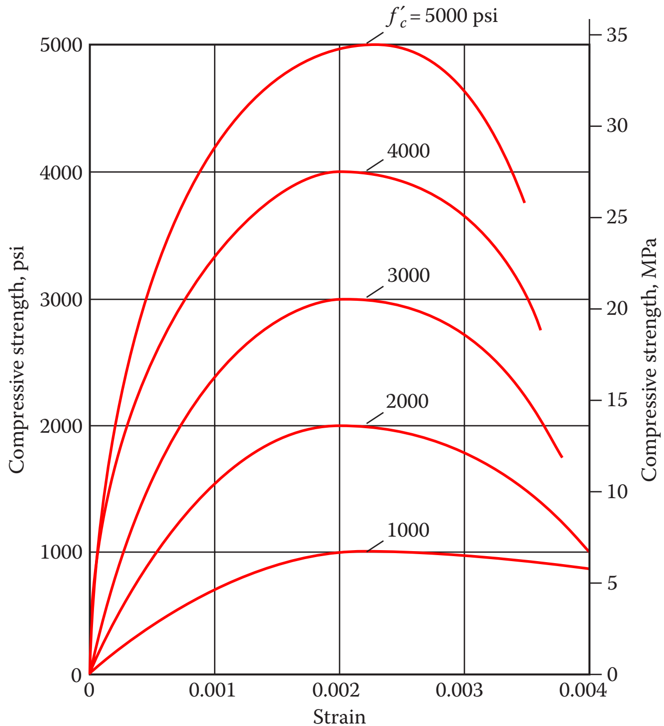

Figure 2–19 Typical stress–strain curves for a variety of concrete grades.

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Courtesy of CRC Press/Taylor & Francis Group

FIGURE 2–20 Prosthetic that employs composite materials to achieve the desired performance.

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Courtesy of CRC Press/Taylor & Francis Group

FIGURE 2–21 High-performance bicycle employing a composite frame and other structural components.

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Figure 2–22 Large composite wind turbine blade at the installation site.

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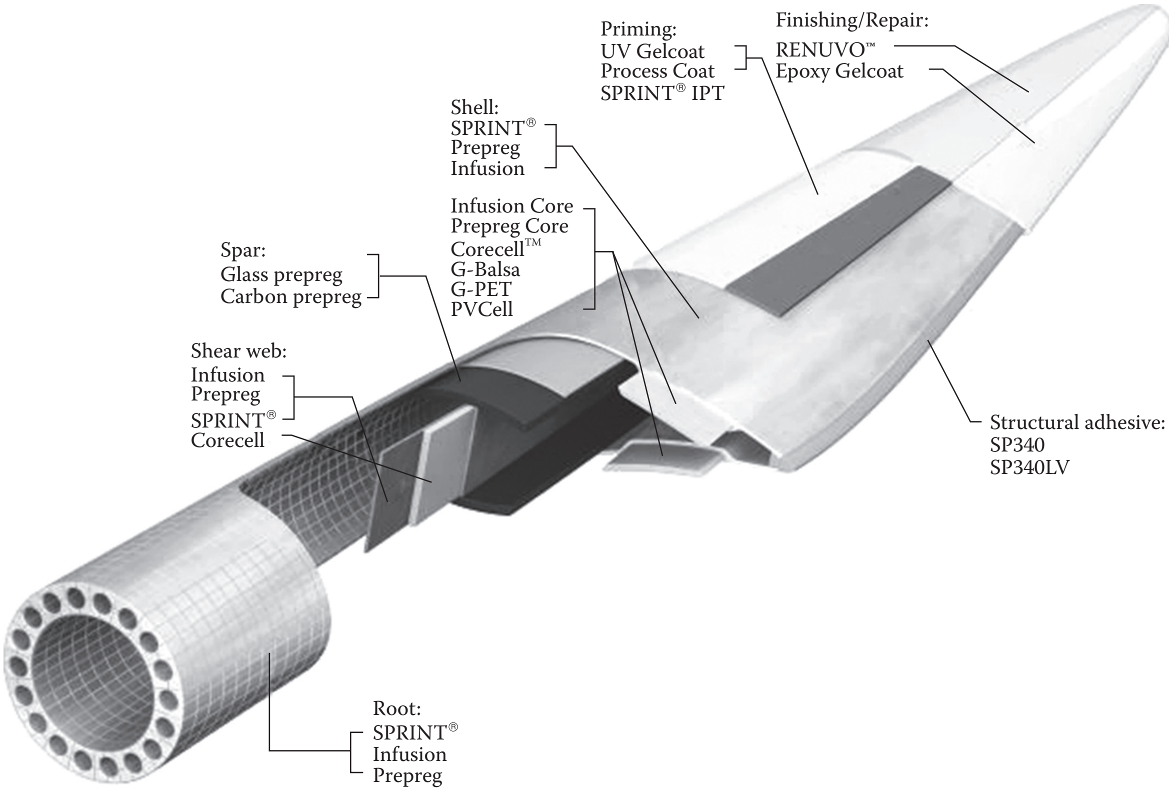

Figure 2–23 **(See color insert.)** Cut-away view of a large wind turbine blade showing the complexity and the role of composite materials in the generation of renewable energy.

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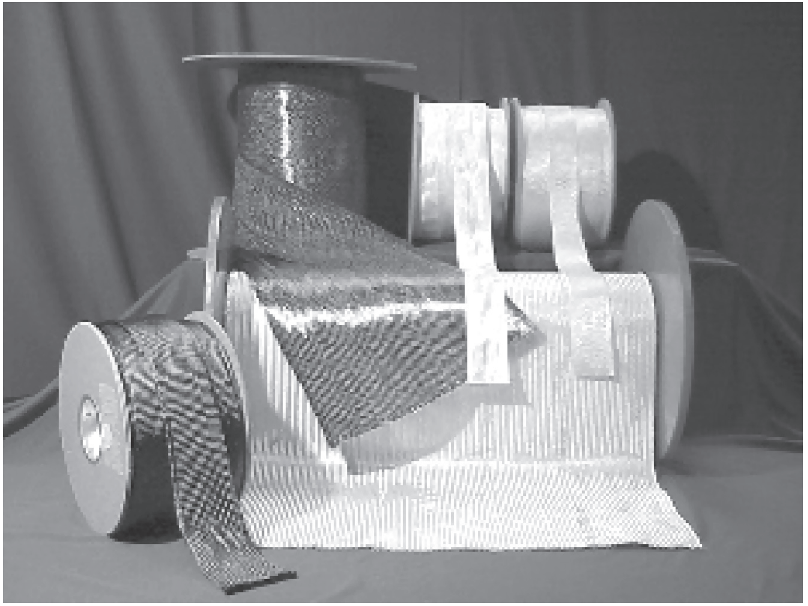

Figure 2–24 Fabrics and braided sleeves made from glass and carbon fibers used for composite materials. The products shown in Figures 2–20 through 2–23 are made with these filler materials. (Courtesy of A&P Technology, Cincinnati, OH.)

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Courtesy of CRC Press/Taylor & Francis Group

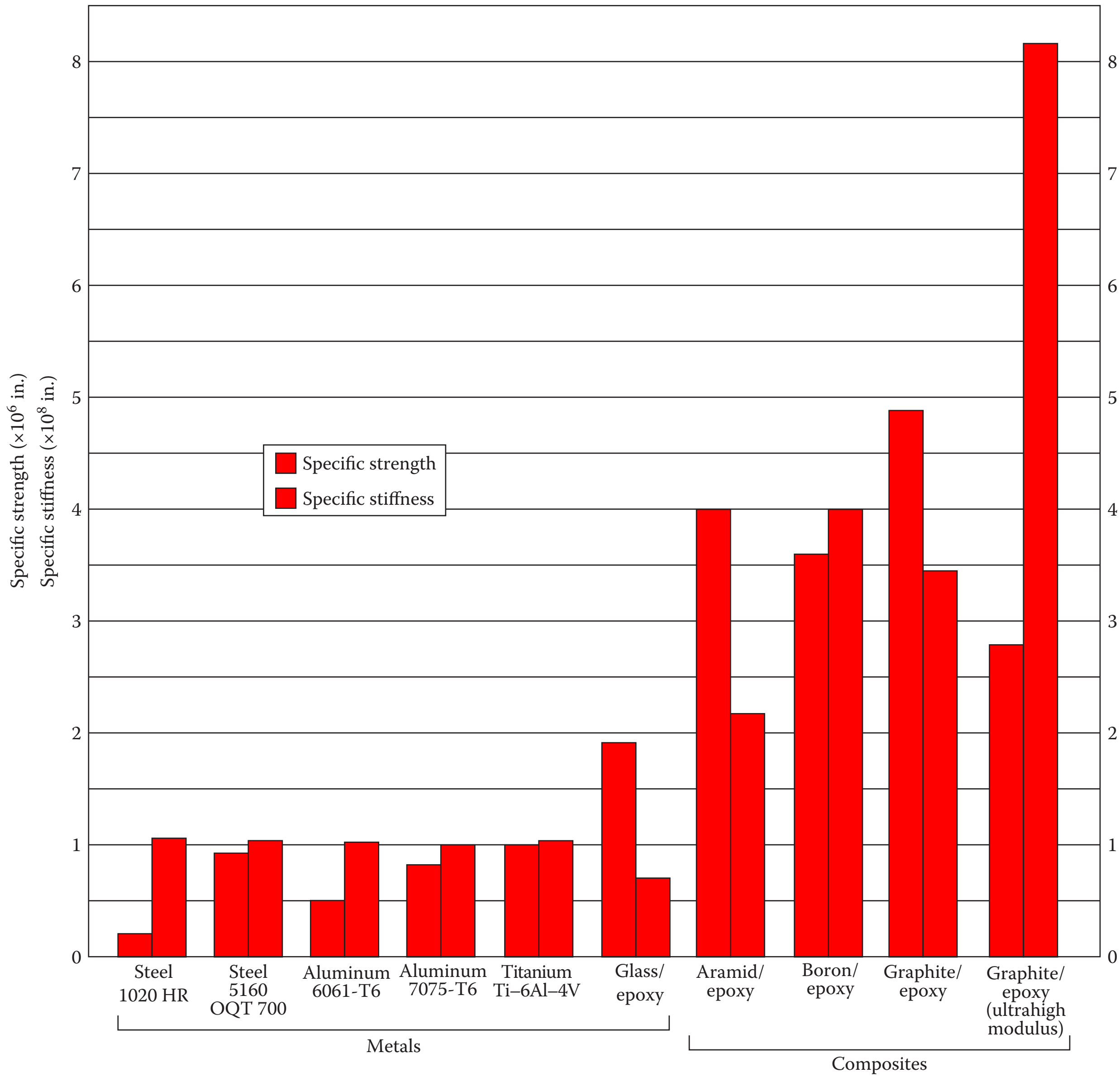

Figure 2–25 Comparison of specific strength and specific stiffness for selected materials.

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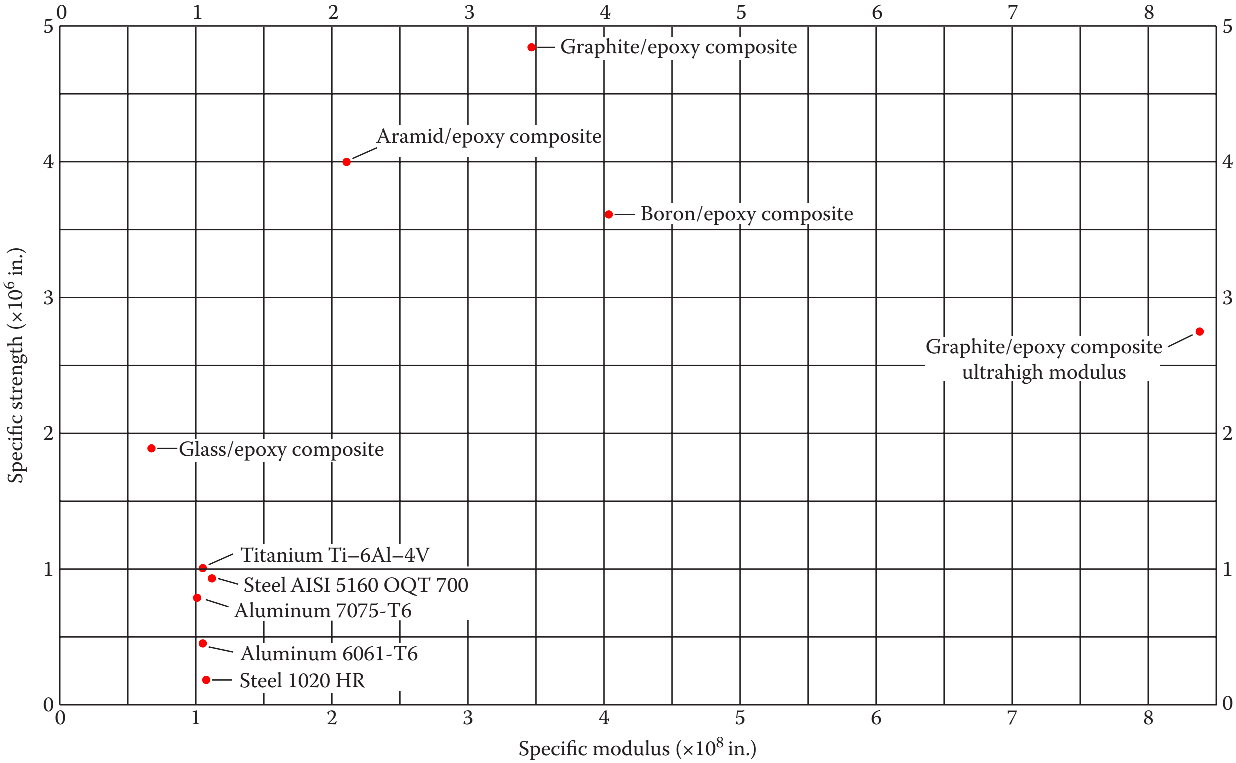

Figure 2–26 Specific strength versus specific modulus for selected metals and composites.

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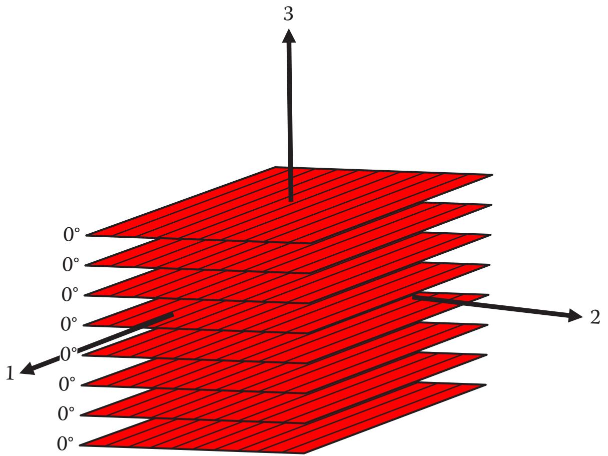

Figure 2–27 Unidirectional composite showing direction of principal axes.

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Courtesy of CRC Press/Taylor & Francis Group

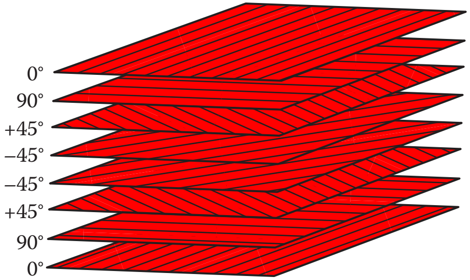

Figure 2–28 Multilayer laminated composite construction designed to produce quasi-isotropic properties.

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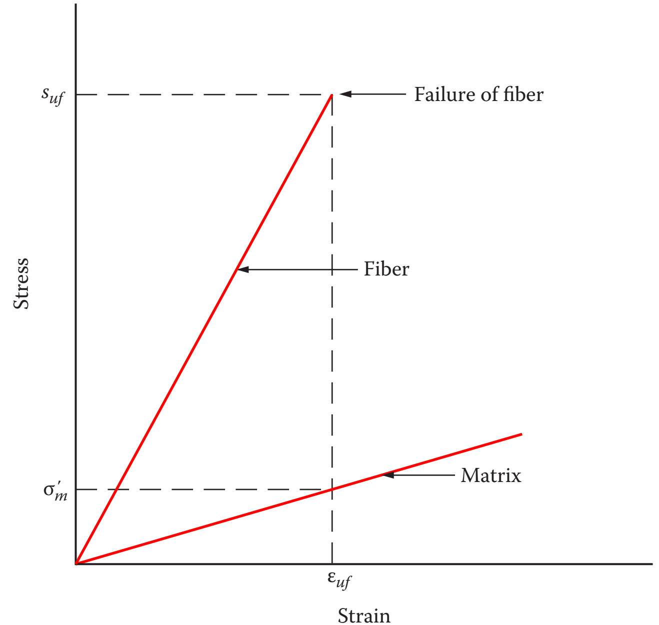

Figure 2–29 Stress versus strain for fiber and matrix materials.

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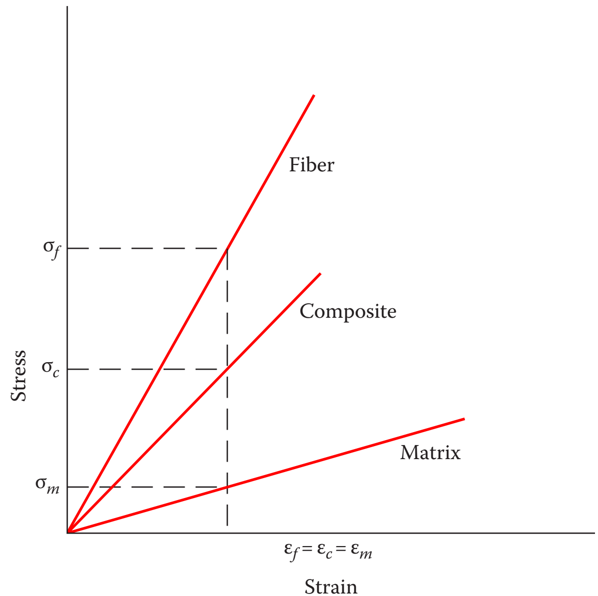

Figure 2–30 Relationship among stresses and strains for a composite and its fiber and matrix materials.

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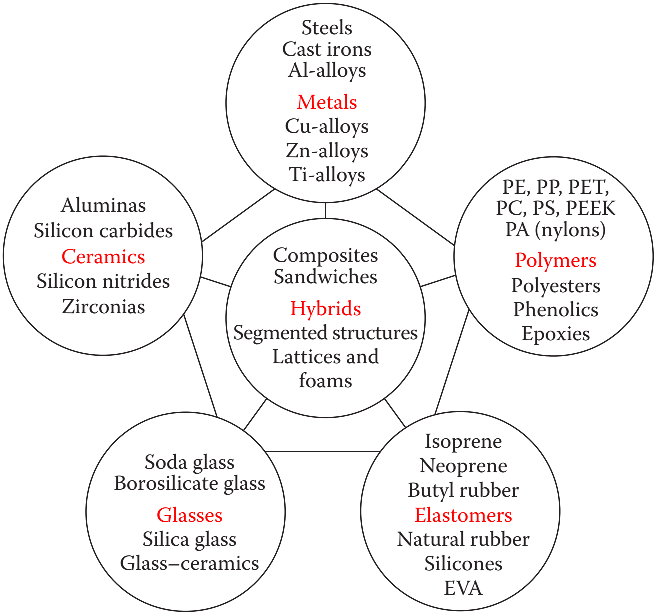
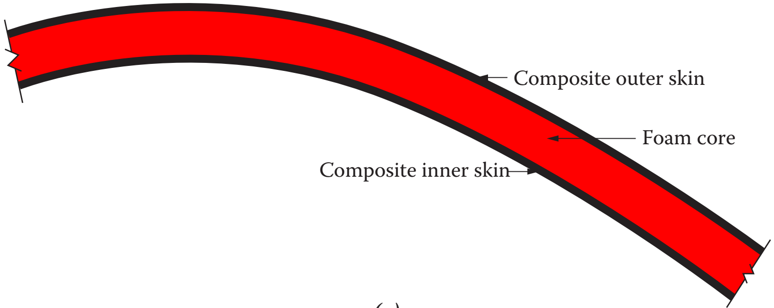
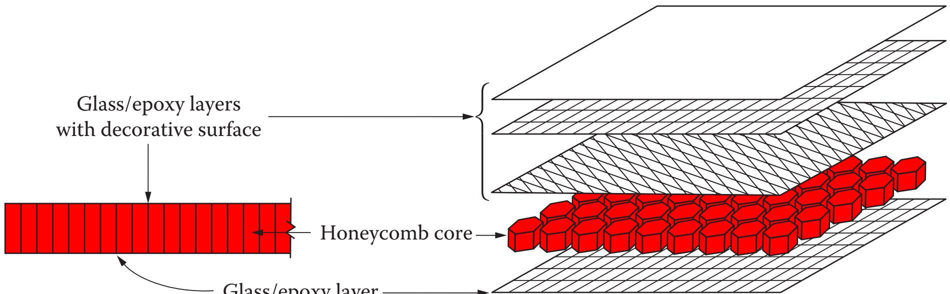


Figure 2–31 Classifications of materials. (Courtesy of Granta Design, Cambridge, U.K.)

002x031.eps



(a)



(b)

Figure 2–32 Laminated panels with lightweight cores: ***(a)*** curved panel with foam core and composite skins and ***(b)*** flat panel with honeycomb core and composite skins.

002x032.eps

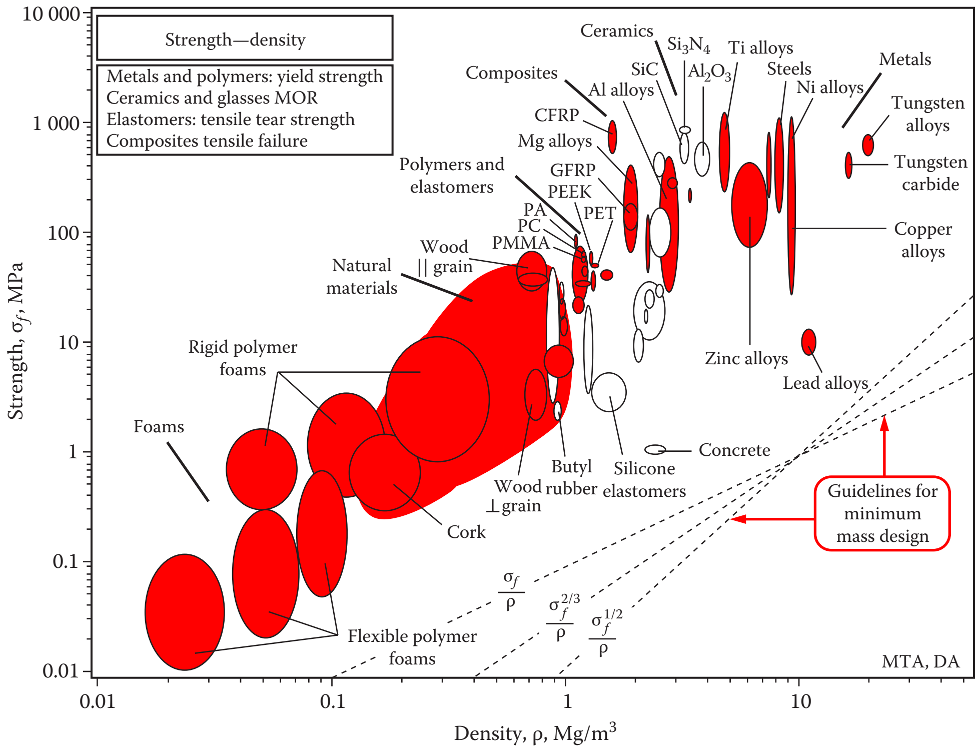


Figure 2–33 Strength versus density chart for materials selection. (Courtesy of Granta Design, Cambridge, U.K.)

002x033.eps

Courtesy of CRC Press/Taylor & Francis Group

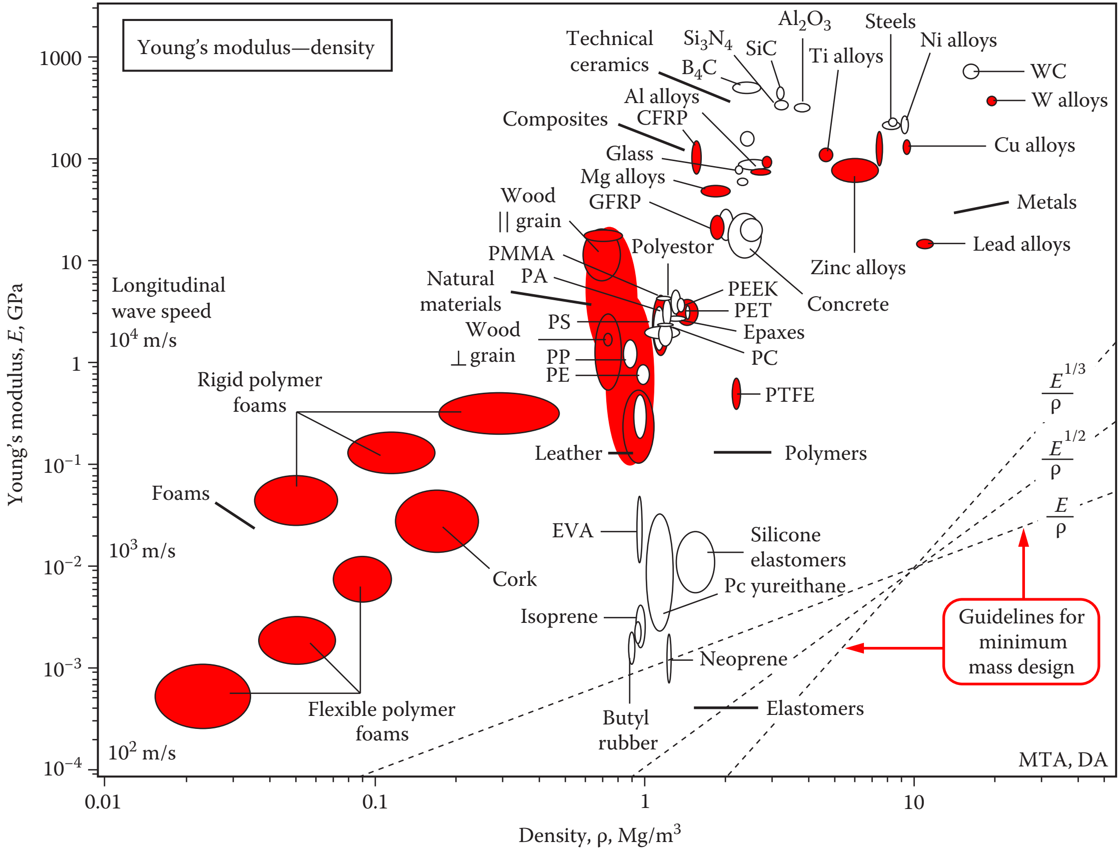


Figure 2–34 Young's modulus versus density chart for materials selection. (Courtesy of Granta Design, Cambridge, U.K.)

002x034.eps