Mechanical Design of Machine Components SI Version 2nd edition Ugural Solutions Manual

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CHAPTER 2 MATERIALS

SOLUTION (**2.1**)

$$A_0 = \tfrac{\pi}{4}(12.5)^2 = 122.7 \text{ mm}^2, \quad A_f = \tfrac{\pi}{4}(12.5 - 0.006)^2 = 122.6 \text{ mm}^2$$

We have $\varepsilon_a = \frac{0.3}{200} = 1500\ \mu, \quad \varepsilon_t = \frac{0.006}{12.5} = 480\ \mu$

Thus

$$S_p = \frac{P}{A_0} = \frac{18(10^3)}{122.7} = 146.8 \text{ MPa}$$

$$E = \frac{S_p}{\varepsilon_a} = \frac{146.7(10^6)}{1500(10^{-6})} = 97.8 \text{ GPa}, \qquad \nu = \frac{\varepsilon_t}{\varepsilon_a} = 0.32 \qquad \blacktriangleleft$$

Also

$$\%\ elongation = \tfrac{0.3}{200}(100) = 0.15$$

$$\%\ reduction\ \ in\ area = \tfrac{122.7 - 122.6}{122.7}(100) = 0.082 \qquad \blacktriangleleft$$

SOLUTION (**2.2**)

Normal stress is

$$\sigma = \frac{P}{A} = \frac{2200}{\frac{\pi}{4}(3.125)^2} = 286.8 \text{ MPa}$$

This is below the yield strength of 350 MPa (Table B.1).
We have

$$\varepsilon = \frac{\delta}{L} = \frac{7.5}{5600} = 0.001339 = 1339\ \mu$$

Hence

$$E = \frac{\sigma}{\varepsilon} = \frac{286.8(10^6)}{1339(10^{-6})} = 214.2 \text{ GPa} \qquad \blacktriangleleft$$

SOLUTION (**2.3**)

The cross-sectional area: $A = w_o t_o = 12.7(6.1) = 77.47 \text{ mm}^2$

(**a**) Axial strain and axial stress are

$$\varepsilon_a = \frac{0.0841}{63.5} = 0.001324 = 1324\ \mu$$

$$\sigma_a = \frac{P}{A} = \frac{21{,}500}{77.47(10^{-6})} = 277.5 \text{ MPa}$$

Because $\sigma_a < S_y$ (See Table B.1), Hooke's Law is valid.

(**b**) Modulus of elasticity,

$$E = \frac{\sigma_a}{\varepsilon_a} = \frac{277.5(10^6)}{1324(10^{-6})} = 209.6 \text{ GPa}$$

(**c**) Decrease in the width and thickness

$$\Delta w = \nu w_o = 0.3(12.7) = 3.81 \text{ mm} \qquad \blacktriangleleft$$

$$\Delta t = \nu t_o = 0.3(6.1) = 1.83 \text{ mm}$$

SOLUTION (**2.4**)

Assume Hooke's Law applies. We have

$$\varepsilon_t = -\frac{1.5}{5} = -300 \ \mu$$

$$\varepsilon_a = -\frac{\varepsilon_t}{\nu} = -\frac{-300}{0.34} = 822 \ \mu$$

Thus,

$$\sigma = E\varepsilon_a = (105 \times 10^9)(822 \times 10^{-9}) = 92.61 \text{ MPa}$$

Since $\sigma < S_y$, our assumption is valid.

So

$$P = \sigma A = (92.61)(\pi/4)(5)^2 = 1.818 \text{ kN} \quad ◄$$

SOLUTION (**2.5**)

We obtain

$$L_{AC} = L_{BD} = \sqrt{15^2 + 15^2} = 21.21 \text{ mm}$$

$$\varepsilon_x = \frac{\Delta L_{AC}}{L_{AC}} = \frac{21.17 - 21.21}{21.21} = -1886 \ \mu$$

$$\varepsilon_y = \frac{\Delta L_{BD}}{L_{BD}} = \frac{21.22 - 21.21}{21.21} = 471 \ \mu$$

(**a**) $E = \frac{\sigma_x}{\varepsilon_x} = \frac{100(10^6)}{-1886(10^{-6})} = 53 \text{ GPa}$ ◄

(**b**) $\nu = \frac{\varepsilon_y}{\varepsilon_x} = \left|\frac{471}{1886}\right| = 0.25$ ◄

(**c**) $G = \frac{53}{2(1+0.25)} = 21.2 \text{ GPa}$ ◄

SOLUTION (**2.6**)

Use generalized Hooke's law:

$$\varepsilon_x + \varepsilon_y + \varepsilon_z = \frac{1-2\nu}{E}(\sigma_x + \sigma_y + \sigma_z) \quad (1)$$

For a constant triaxial state of stress:

$$\varepsilon_x = \varepsilon_y = \varepsilon_z = \varepsilon, \quad \sigma_x = \sigma_y = \sigma_z = \sigma$$

Then, Eq. (1) becomes $\varepsilon = \frac{1-2\nu}{E}\sigma$. Since σ and ε must have identical signs:

$1 - 2\nu \geq 0$ or $\nu = \frac{1}{2}$ ◄

SOLUTION (**2.7**)

We have $\sigma_x = \frac{450(10^3)}{50(75)} = 120 \text{ MPa}$

(CONT.)

2.7 (CONT.)

(a) $\varepsilon_x = \frac{0.5}{250} = 2000\ \mu, \quad \varepsilon_y = -\frac{0.025}{50} = -500\ \mu$

$\nu = \left|\frac{500}{2000}\right| = 0.25$ ◀

(b) $E = \frac{\sigma_x}{\varepsilon_x} = \frac{120(10^6)}{2000(10^{-6})} = 60\ \text{GPa}$ ◀

(c) $\varepsilon_z = -\frac{\nu\sigma_x}{E} = -0.25\frac{120(10^6)}{60(10^9)} = -500\ \mu$

$\Delta a = -500(10^{-6})75 = -37.5(10^{-3})\ \text{mm}; \qquad a' = 75 - 0.0375 = 74.9625\ \text{mm}$ ◀

(d) $G = \frac{60(10^9)}{2(1+0.25)} = 24\ \text{GPa}$ ◀

SOLUTION (**2.8**)

We have

$$\varepsilon_y = \varepsilon_z = 0 \qquad \sigma_x = \frac{25\,(10^3)}{20\times 10\,(10^{-6})} = 125 \quad \text{MPa}$$

Thus

$$\varepsilon_y = 0 = \tfrac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)] \qquad (1)$$

$$\varepsilon_z = 0 = \tfrac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)] \qquad (2)$$

$$\varepsilon_x = \tfrac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)] \qquad (3)$$

Equations (1) and (2) become

$$\sigma_y - \nu\sigma_z = \nu\sigma_x \qquad (1')$$

$$\sigma_z - \nu\sigma_y = \nu\sigma_x \qquad (2')$$

Adding : $\nu(\sigma_y + \sigma_z) = 2\nu^2\sigma_x/(1-\nu)$. Then, Eq. (3):

$$\varepsilon_x = \frac{1-\nu-2\nu^2}{1-\nu}\frac{\sigma_x}{E}$$ ◀

Substituting the data:

$$\varepsilon_x = \frac{1-0.3-0.18}{0.7}\frac{125\,(10^6)}{70\,(10^9)} = 1327 \quad \mu$$ ◀

SOLUTION (**2.9**)

<u>Hooke's Law.</u> We have $\sigma_y = 0$ and

$$\varepsilon_x = \frac{\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$= \frac{10^6}{72\times10^9}[(80) - 0 - 0.3(140)] = 0.000528 = 528\ \mu$$

$$\varepsilon_y = -\frac{\nu\sigma_x}{E} + \frac{\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$= \frac{10^6}{72\times10^9}[-0.3(80) + 0 - 0.3(140)] = -917\ \mu$$

$$\varepsilon_z = -\frac{\nu\sigma_x}{E} - \frac{\nu\sigma_y}{E} + \frac{\sigma_z}{E}$$

$$= \frac{10^6}{72\times10^9}[-0.3(80) - 0 + 140] = 1611\ \mu$$

(CONT.)

2.9 (CONT.)

(**a**) Change in length $\Delta L_{AB} = \varepsilon_x a$,

$$\Delta L_{AB} = (528 \times 10^{-6})(320) = 0.169 \text{ mm}$$ ◄

(**b**) Change in thickness

$$\Delta t = \varepsilon_y t = (-917 \times 10^{-6})(15) = -0.014 \text{ mm}$$ ◄

(**c**) Change in volume,

$$e = \varepsilon_x + \varepsilon_y + \varepsilon_z = 528 - 917 + 1611 = 1.222$$

$$\Delta V = eV_o = 1.222(320 \times 320 \times 15) = 1.877 \text{ mm}^3$$ ◄

SOLUTION (**2.10**)

By assumptions, rubber in triaxial stress:

$$\sigma_x = \sigma_z = -p, \quad \sigma_y = -\frac{F}{\pi d^2/4} = -\frac{4F}{\pi d^2}$$

Stains are $\varepsilon_x = \varepsilon_z = 0$. Hooke's law gives

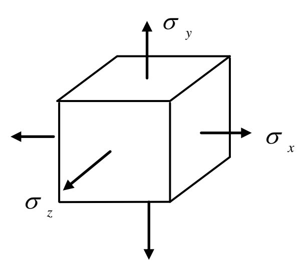
$$\varepsilon_x = 0 = \tfrac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)]$$

or

$$0 = p - \nu \frac{4F}{\pi d^2 (1-\nu)}$$

Solving,

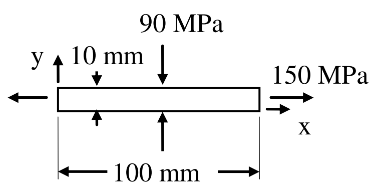
$$p = \frac{4\nu F}{\pi d^2 (1-\nu)}$$ Q.E.D. ◄



Substitute the data:

$$p = \frac{4(0.5)(10\times 10^3)}{\pi(62.5)^2(1-0.5)} = 3.26 \text{ MPa} \quad \text{(C)}$$ ◄

SOLUTION (**2.11**)



Hooke's law gives

$$\varepsilon_x = \tfrac{1}{E}(\sigma_x - \nu\sigma_y) = \frac{10^6}{100(10^9)}(150 + \tfrac{90}{3}) = 1800 \quad \mu$$

$$\varepsilon_y = \tfrac{1}{E}(\sigma_y - \nu\sigma_x) = \frac{10^6}{100(10^9)}(-90 - \tfrac{150}{3}) = -1400 \quad \mu$$

$$\varepsilon_z = -\tfrac{\nu}{E}(\sigma_x + \sigma_y) = -\frac{(1/3)10^6}{100(10^9)}(150 - 90) = -200 \quad \mu$$

Thus

$$\Delta L = 1800 \ \mu(100) = 180 \ \mu\text{m}$$

$$\Delta a = -1400 \ \mu(50) = -70 \ \mu\text{m}$$

$$\Delta b = -200 \ \mu(10) = -2 \ \mu\text{m}$$

and

$$L' = 100.018 \text{ mm}, \quad a' = 49.993 \text{ mm}, \quad b' = 9.9998 \text{ mm}$$ ◄

SOLUTION (**2.12**)

We have

$$\sigma_x = \sigma_y = \sigma_z = -p$$

Gen. Hooke's law:

$$\varepsilon_x = \varepsilon_y = \varepsilon_z = -\tfrac{p}{E}(1-2\nu) = -\frac{120\,(10^6)}{100\,(10^9)}\,\frac{1}{3} = -400\ \mu$$

Thus

$$\Delta L = -400\ \mu(100\ ) = -40\ \ \mu\text{m}$$

$$\Delta a = -400\ \mu(50\ ) = -20\ \ \mu\text{m}$$

$$\Delta b = -400\ \mu(10\ ) = -4\ \ \mu\text{m}$$

and

$$L' = 99.96\ \text{mm}, \quad a' = 49.98\ \text{mm}, \quad b' = 9.996\ \text{mm}$$ ◄

SOLUTION (**2.13**)

We have

$\sigma_x = \sigma_y = \sigma_z = -p$. The volume is

$$V_o = \tfrac{4}{3}\pi r^3 = \tfrac{4\pi}{3}(125)^3 = 8.181(10^6)\ \text{mm}^3$$

(a) $\varepsilon_x = -\tfrac{1}{E}[\sigma - \nu(\sigma + \sigma)] = -\tfrac{\sigma}{E}(1-2\nu)$

$$= \frac{168(10^6)}{70(10^9)}(1-0.5) = -1200\ \mu$$

Change in diameter,

$$\Delta d = \varepsilon_x d = -1200(10^{-6})250 = -0.3\ \text{mm}$$

Decrease in circumference:

$$\pi(\Delta d) = -0.3\pi = -0.9425\ \text{mm}$$ ◄

(b) $\Delta V = eV_o = (1-2\nu)\varepsilon_x V_o$

$$= (0.5)(-1200\times 10^{-6})(8.181\times 10^6) = -4909\ \text{mm}^3$$ ◄

SOLUTION (**2.14**)

From Fig.2.3b and Eq.2.20:

$$U_t = \frac{S_y + S_u}{2}\varepsilon_f \approx \frac{250+440}{2}(0.27) \approx 93\ \text{MPa}$$ ◄

We have $L_f = 50 + 50(0.27) = 63.5\ \text{mm}$

Using Eq.(2.1): $\%\ elongation = \frac{63.5-50}{50}(100) = 27\ \%$ ◄

SOLUTION (**2.15**)

Table B.1: $S_y = 260$ MPa , $E = 70$ GPa

We have

$$V = AL = \tfrac{\pi}{4}(0.005)^2(3) = 58.9 \times 10^{-6} \text{ m}^3$$

$$U_r = \frac{S_y^2}{2E} = \frac{(260\times10^6)^2}{2(70\times10^9)} = 482.9 \text{ kJ/m}^3$$

$$U_{app} = U_r V = 482.9\times10^3(58.9\times10^{-6}) = 28.44 \text{ J}$$

For $U_{app} = 9$ J :

$$n = \tfrac{28.44}{9} = 3.16$$ ◄

SOLUTION (**2.16**)

(**a**) <u>ASTM-A242.</u> $E = 200$ GPa and $\sigma_y = 345$ MPa

$$U_o = \frac{S_y^2}{2E} = \frac{(345\times10^6)^2}{2(200\times10^9)} = 298 \ \frac{\text{kJ}}{\text{m}^3}$$ ◄

(**b**) <u>Stainless (302).</u> $E = 190$ GPa and $S_y = 520$ MPa

$$U_o = \frac{S_y^2}{2E} = \frac{(520\times10^6)^2}{2(200\times10^9)} = 712 \ \frac{\text{kJ}}{\text{m}^3}$$ ◄

SOLUTION (**2.17**)

(**a**) <u>Aluminum 2014-T6.</u> $E = 72$ GPa and $\sigma_y = 410$ MPa

$$U_o = \frac{S_y^2}{2E} = \frac{(410\times10^6)^2}{2(72\times10^9)}$$

$$= 1167 \ \frac{kJ}{m^3}$$ ◄

(**b**) <u>Annealed yellow brass.</u> $E = 105$ GPa and $S_y = 105$ MPa

$$U_o = \frac{S_y^2}{2E} = \frac{(105\times10^6)^2}{2(105\times10^9)} = 52.5 \ \frac{\text{kJ}}{\text{m}^3}$$ ◄

SOLUTION (**2.18**)

Referring to Fig. P2.18: $E = \frac{105(10^6)}{0.0025} = 42$ GPa, $S_y = 192.5$ MPa

(**a**) $U_o = \frac{S_y^2}{2E} = \frac{(192.5\times10^6)^2}{2(42\times10^9)} = 441.5 \text{ kJ/m}^3$ ◄

(**b**) Total area under $\sigma - \varepsilon$ diagram:

$$U_t \approx 262.5(10^6)(0.176) = 46.2 \text{ MJ/m}^3$$ ◄

SOLUTION (**2.19**)

(**a**) $V = 50 \times 50 \times 1{,}500 = 3.75\,(10^{6})\ \text{mm}^{3}$

Thus $\quad nU = \frac{S_y^2}{2E}V$

or $\quad S_y = [\frac{2EnU}{V}]^{\frac{1}{2}}$

$$= [\frac{2 \times 200 \times 10^{9} \times 1.5 \times 400}{3.75\,(10^{-3})}]^{\frac{1}{2}} = 253\ \text{MPa} \quad ◄$$

(**b**) $U_r = \frac{S_y^2}{2E} = \frac{(253 \times 10^{6})^2}{2(200 \times 10^{9})} = 160\ \text{kPa} \quad ◄$

SOLUTION (**2.20**)

Table B.1: $\quad S_y = 250\ \text{MPa}, \qquad E = 200\ \text{GPa}$

We have

$$U = nU_{app} = 5(17) = 85\ \text{N}\cdot\text{m}$$

$$U_r = \frac{S_y^2}{2E} = \frac{(250\times10^{6})^2}{2(200\times10^{9})} = 156.25\ \text{kN}\cdot\text{m}/\text{m}^3$$

Therefore

$$V = \frac{U}{U_r} = \frac{85}{156.25(10^{3})} = 0.544(10^{-3})\ \text{m}^3$$

Also $\quad V = AL: \quad 0.544\,(10^{-3}) = \frac{\pi}{4}d^2(2.4)$

or

$$d = 0.017\ \text{m} = 17\ \text{mm} \quad ◄$$

SOLUTION (**2.21**)

Refer to Fig. P2.21. We have

$$E = \frac{190(10^{6})}{0.001} = 190\ \text{GPa}, \quad S_y \approx 245\ \text{MPa}$$

(**a**) $U_o = \frac{S_y^2}{2E} = \frac{(245\times10^{3})^2}{2(190\times10^{9})} = 158\ \frac{\text{kJ}}{\text{m}^3} \quad ◄$

(**b**) Total area under $\sigma - \varepsilon$ diagram:

$$U_t \approx 350\times10^{3}(0.28) = 98\ \frac{\text{MJ}}{\text{m}^3} \quad ◄$$

SOLUTION (**2.22**)

$V = (0.05)(0.05)(1.2) = 0.003\ m^3$ and $S_y \approx S_p$

(**a**) $n\cdot U = \frac{S_p^2}{2E}V, \quad S_p^{\,2} = \frac{nU(2E)}{V}$

Substituting the data given,

(CONT.)

2.22 (CONT.)

$$S_p^{\,2} = \frac{1.8(150)(2\times 210\times 10^9)}{0.003} = 37.8\times 10^{15}$$ ◄

or

$$S_p = 194.4 \text{ MPa}$$

(b) $U_o = \frac{S_p^{\,2}}{2E} = \frac{37.8\times 10^{15}}{2(210\times 10^9)} = 90 \ \frac{\text{kJ}}{\text{m}^3}$ ◄

SOLUTION (**2.23**)

Applying Eq. (2.22), we find

$$S_u = 3.45H_B \text{ MPa} = 3.45(149) = 514 \text{ MPa}$$ ◄

Equation (2.24):

$$S_y = 3.62(149) - 207 = 332.4 \text{ MPa}$$ ◄

SOLUTION (**2.24**)

Using Eq. (2.22),

$$S_u = 3.45H_B \text{ MPa} = 3.45(179) = 618 \text{ MPa}$$ ◄

Formula (2.24):

$$S_y = 3.62(179) - 207 = 441 \text{ MPa}$$ ◄

SOLUTION (**2.25**)

Formula (2.22),

$$S_u = 3.45H_B \text{ MPa} = 3.45(156) = 538 \text{ MPa}$$ ◄

Equation (2.24):

$$S_y = 3.62(156) - 207 = 378 \text{ MPa}$$ ◄

SOLUTION (**2.26**)

Equation (2.22) gives

$$S_u = 3.45H_B \text{ MPa} = 3.45(293) = 1010.9 \text{ MPa}$$ ◄

Formula (2.24):

$$S_y = 3.62(293) - 207 = 853.7 \text{ MPa}$$ ◄

End of Chapter 2

Courtesy of CRC Press/Taylor & Francis Group

Figure 2.1
Tensile loading machine with automatic data-processing system. (Courtesy of MTS Systems Corp.)

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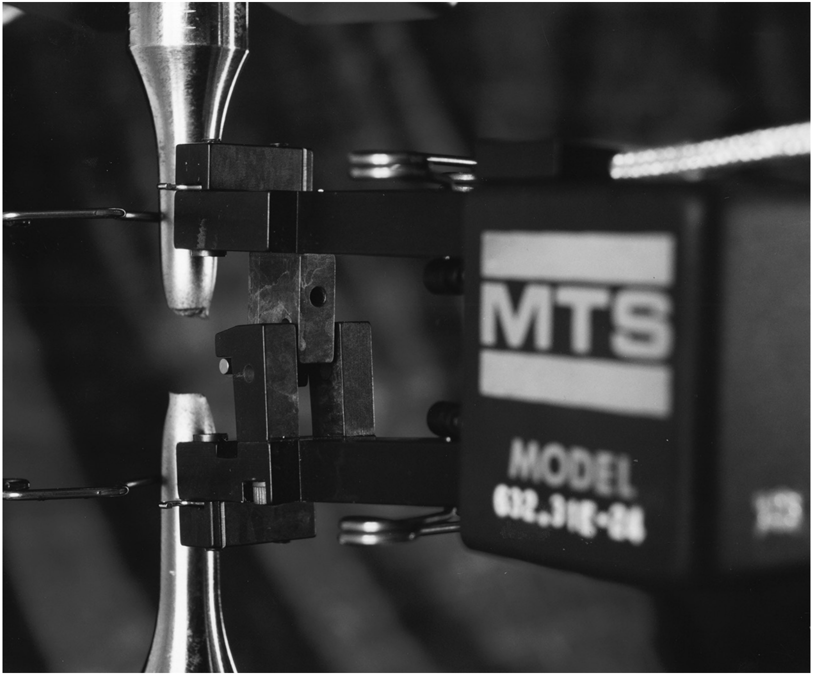

Figure 2.2
A tensile test specimen with extensometer attached; the specimen has fractured. (Courtesy of MTS Systems Corp.)

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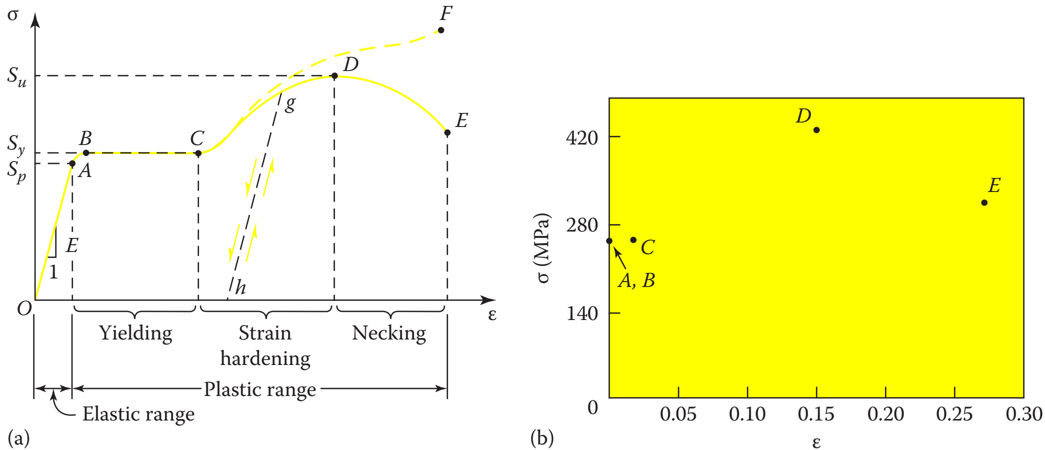

Figure 2.3
Stress–strain diagram for a typical structural steel in tension: (a) drawn not to scale and (b) drawn to scale.

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Courtesy of CRC Press/Taylor & Francis Group

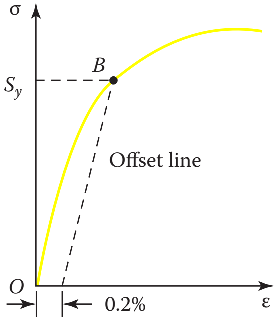

Figure 2.4
Determination of yield strength by the offset method.

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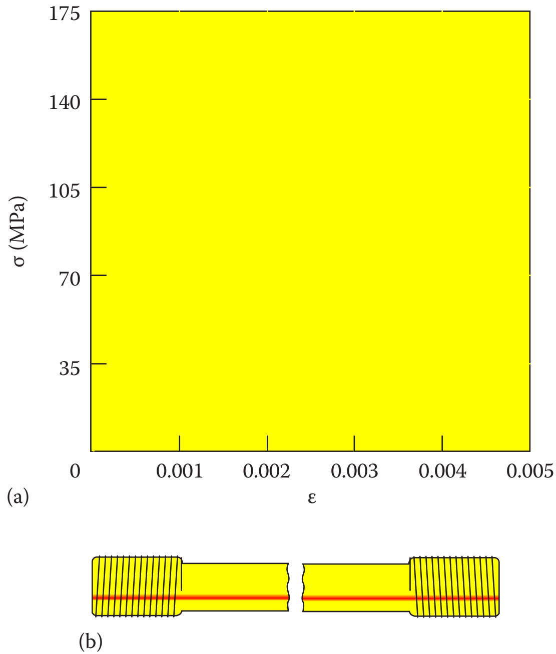

Figure 2.5
Gray cast iron in tension: (a) stress–strain diagram and (b) fractured specimen.

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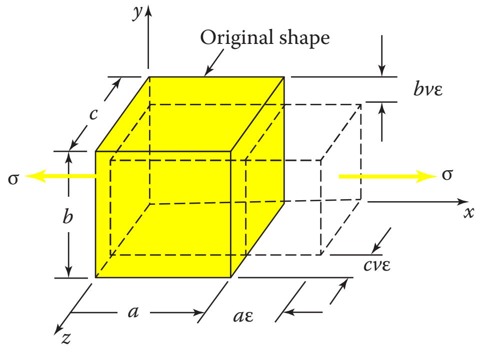

Figure 2.6
Axial elongation and lateral contraction of an element in tension (Poisson's effect).

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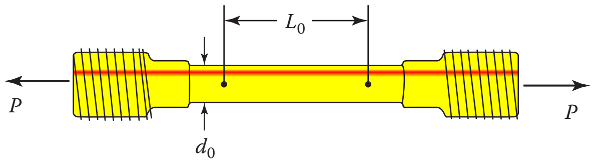

Figure 2.7
Example 2.1. A tensile specimen.

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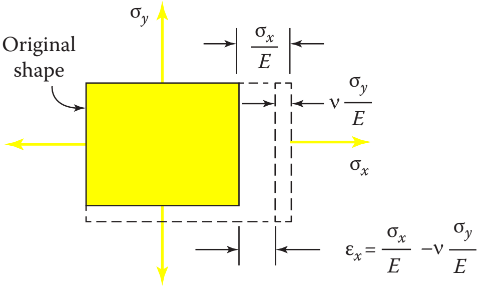

Figure 2.8
Element deformations caused by biaxial stress.

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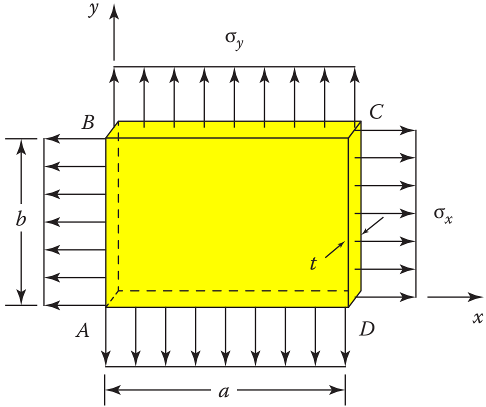

Figure 2.9
Example 2.2. Plate in biaxial stress.

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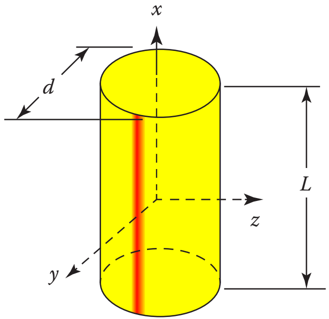

Figure 2.10
Example 2.3. A solid cylinder.

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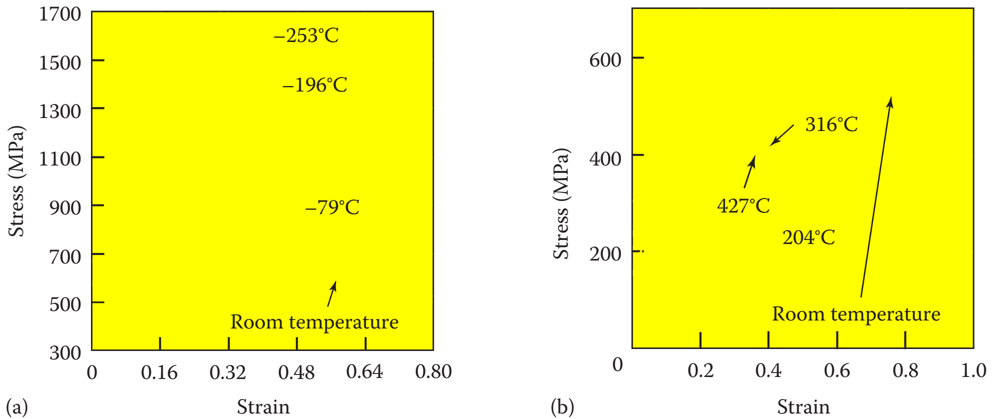

Figure 2.11
Stress–strain diagrams for AISI type 304 stainless steel in tension: (a) at low temperatures and (b) at elevated temperatures.

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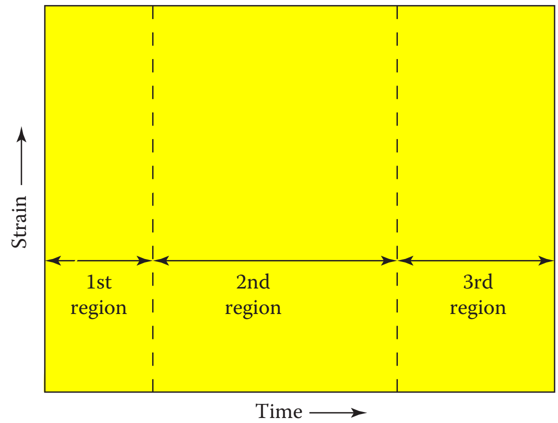

Figure 2.12
Creep curve for structural steel in tension at high temperatures.

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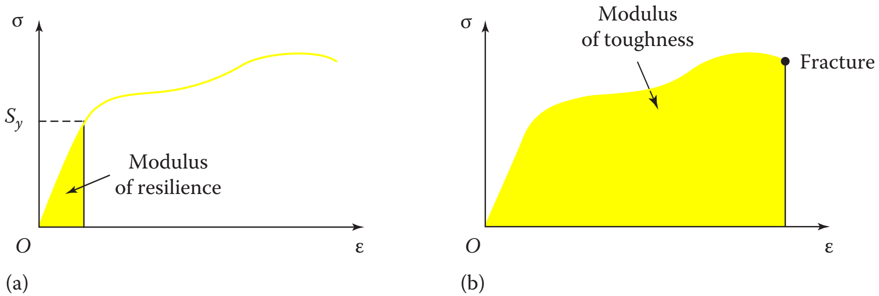

Figure 2.13
Stress–strain diagram: (a) modulus of resilience and (b) modulus of toughness.

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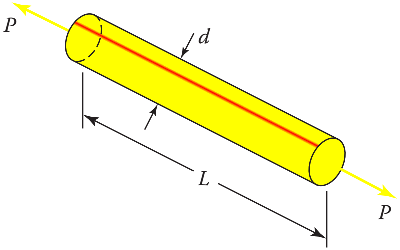

Figure 2.14
Example 2.4. Prismatic bar in tension.

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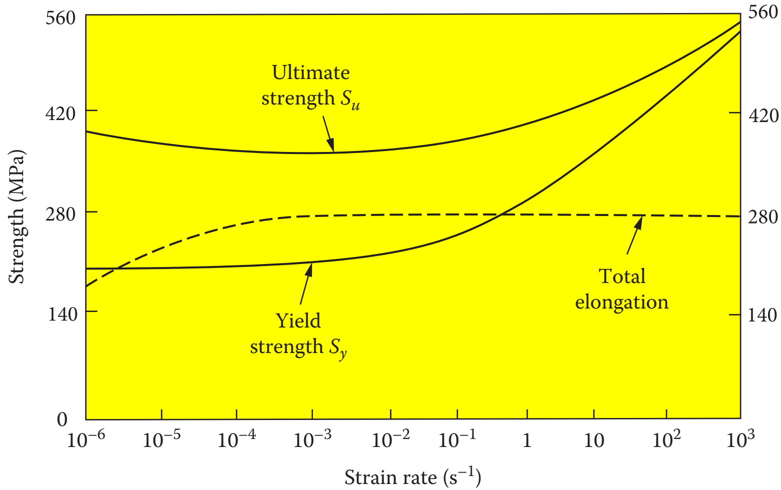

Figure 2.15
Influence of strain rate on tensile properties of a mild steel at room temperature.

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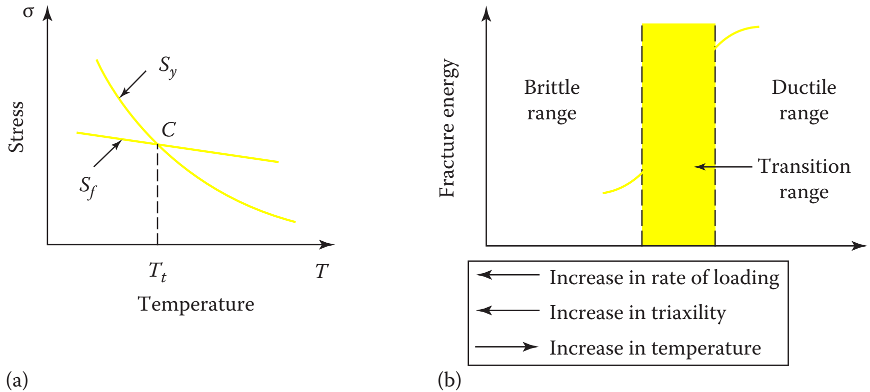

Figure 2.16
Typical transition curves for metals: (a) variation of yield strength S_y and fracture strength S_f with temperature and (b) effects of loading rate, stress around a notch, and temperature on impact toughness.

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Figure 2.17
Depiction of Titanic sinking. (Courtesy of google.com.)

002x017.tif

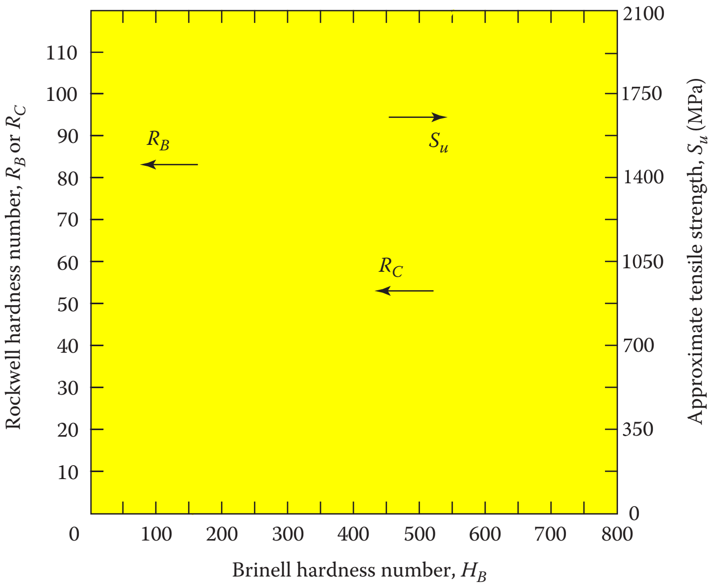

Figure 2.18
Hardness conversion to ultimate strength in tension of steel.

002x018.eps

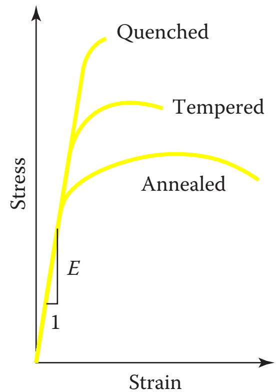

Figure 2.19
Stress–strain diagrams for annealed, quenched, and tempered steel.

002x019.eps

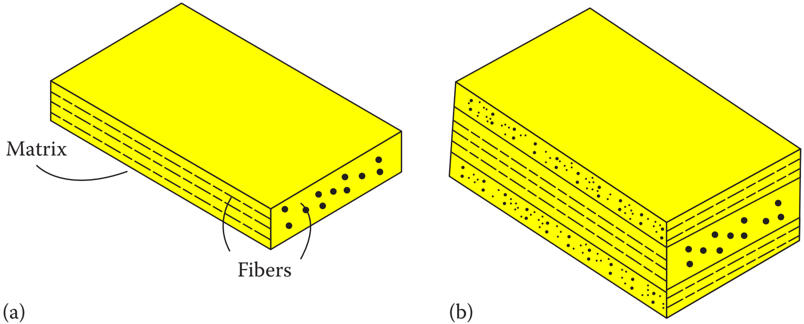

Figure 2.20
Fiber-reinforced materials: (a) single layer and (b) three-cross layer.

002x020.eps

Courtesy of CRC Press/Taylor & Francis Group

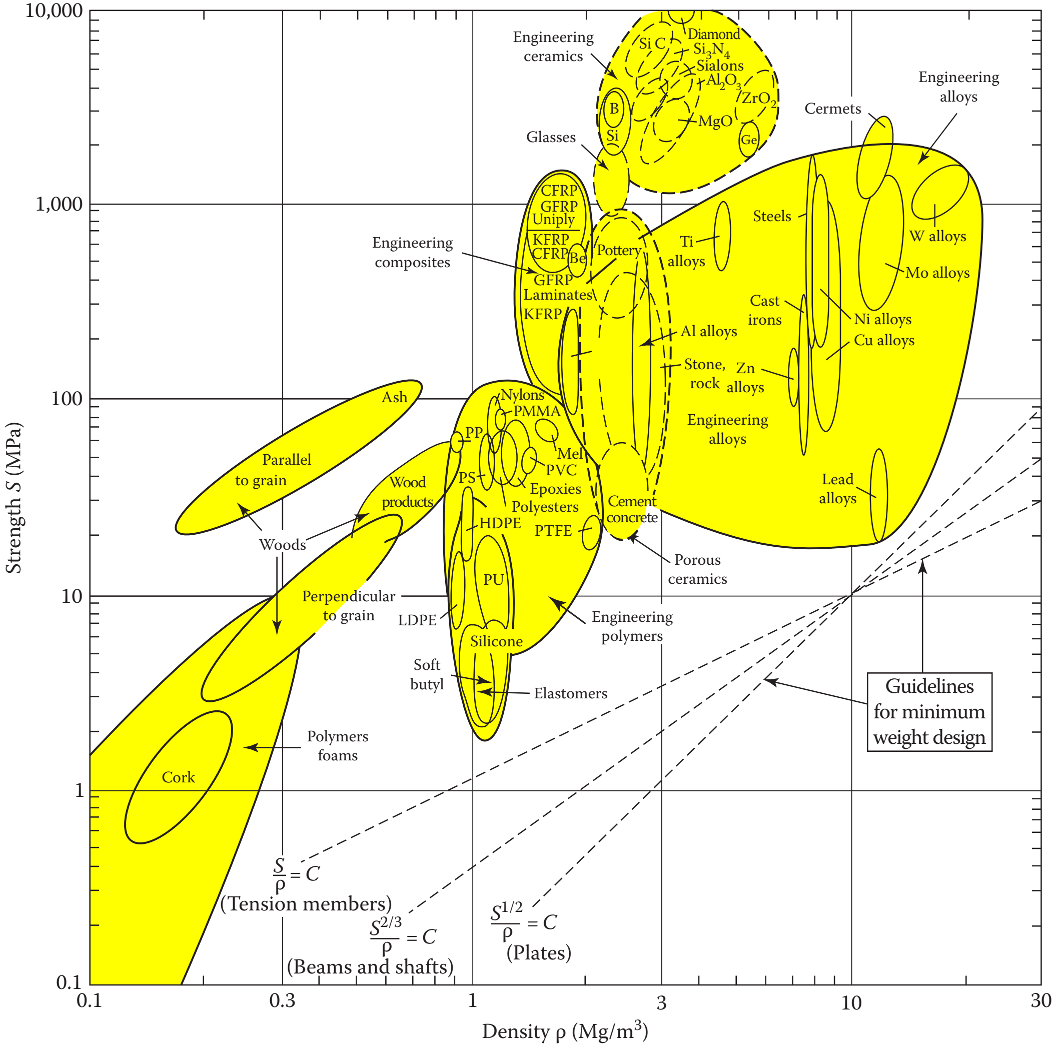

Figure 2.21
Strength versus density for engineering materials. The envelopes enclose data for a prescribed class of material. (From Ashby, M.J., *Material Selection in Mechanical Design*, 4th ed., Butterworth Heinemann, Oxford, U.K., 2011.)

002x021.eps

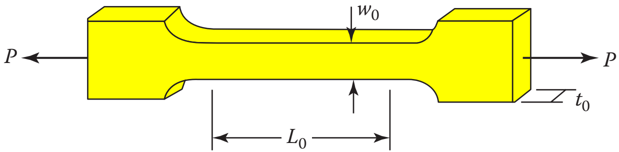

Figure P2.3

PRB002x003.eps

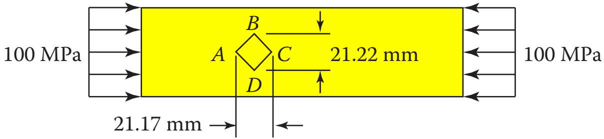

Figure P2.5

PRB002x005.eps

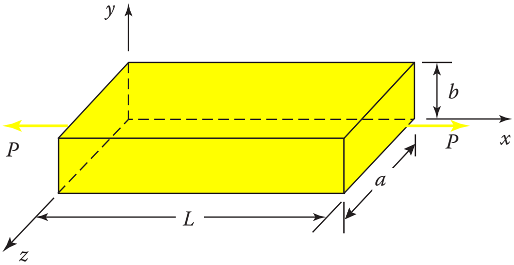

Figure P2.7

PRE0802x007.eps

Courtesy of CRC Press/Taylor & Francis Group

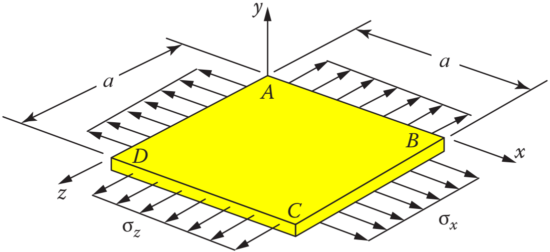

Figure P2.9

PRB002x009.eps

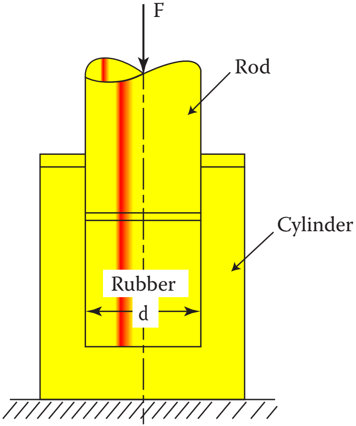

Figure P2.10

PRR002x010.eps

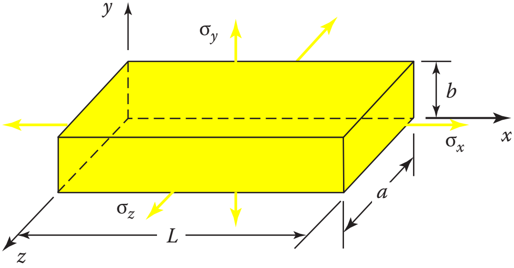

Figure P2.11

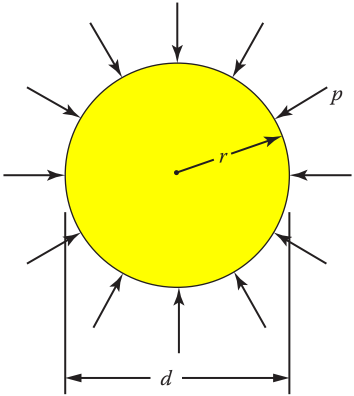

Figure P2.13

PRB002x013.eps

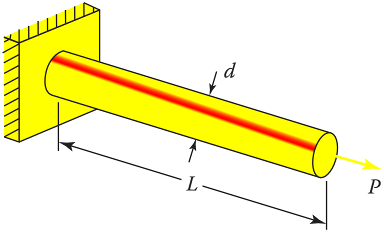

Figure P2.15

PRB002x015.eps

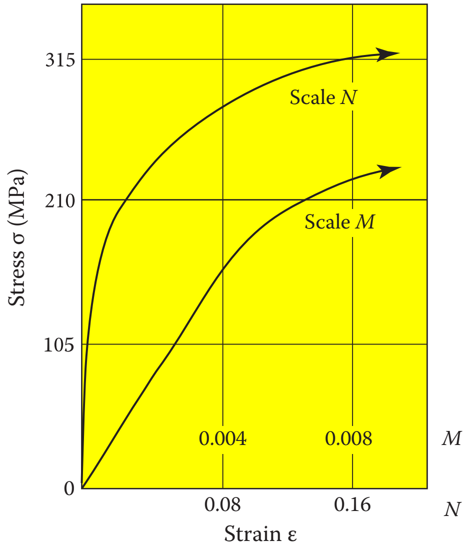

Figure P2.18

PRB002x018.eps

Courtesy of CRC Press/Taylor & Francis Group

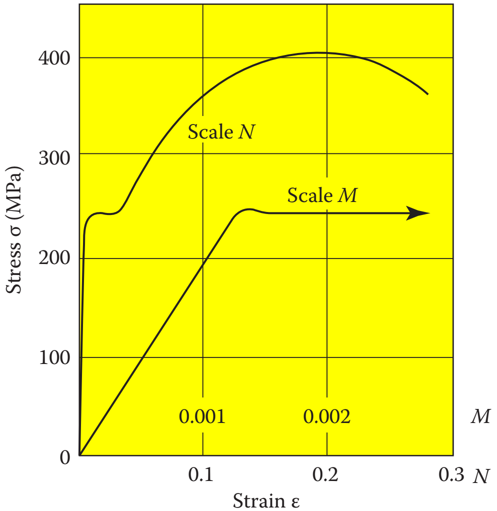

Figure P2.21

PRB002x021.eps