4.3 Consider the data in Table 3.4 where strengths are given for both tension and compression for a number of glasses and ceramics. Plot the tensile strengths σ_{ut} versus the corresponding compressive strengths σ_{uc}. What general trend is seen in this comparison? Try to provide a physical explanation for this trend.

Table 3.4 Properties for Selected Glasses, Engineering Ceramics, and Natural Stones

Ceramic	Melting Temp.	Density	Elastic Modulus	Typical Strength	
	T_m °C	ρ g/cm^3	E GPa	σ_u, MPa (ksi)	
	(°F)	(lb/ft^3)	(10^3 ksi)	Tension	Compression
Soda-lime glass	730 (1350)	2.48 (155)	74 (10.7)	≈ 50 (7)	1000 (145)
Type S glass (fibers)	970 (1780)	2.49 (155)	85.5 (12.4)	4480 (650)	—
Zircon porcelain	1567 (2850)	3.60 (225)	147 (21.3)	56 (8.1)	560 (81)
Magnesia, MgO	2850 (5160)	3.60 (225)	280 (40.6)	140 (20.3)	840 (122)
Alumina, Al_2O_3 (99.5% dense)	2050 (3720)	3.89 (243)	372 (54)	262 (38)	2620 (380)
Zirconia, ZrO_2	2570 (4660)	5.80 (362)	210 (30.4)	147 (21.3)	2100 (304)
Silicon carbide, SiC (reaction bonded)	2837 (5140)	3.10 (194)	393 (57)	307 (44.5)	2500 (362)
Boron carbide, B_4C	2350 (4260)	2.51 (157)	290 (42)	155 (22.5)	2900 (420)
Silicon nitride, Si_3N_4 (hot pressed)	1900 (3450)	3.18 (199)	310 (45)	450 (65)	3450 (500)
Dolomitic limestone (Hokie stone)	—	2.79 (174)	69.0 (10.0)	19.2 (2.79)	283 (41.0)
Westerly granite	—	2.64 (165)	49.6 (7.20)	9.58 (1.39)	233 (33.8)

Notes: Data are for materials in bulk form except for type S glass. Temperatures given for the two forms of glass correspond to softening, with complete melting occurring above this.

Source: Data in [Farag 89] p. 510, [Ashby 06] p. 180, [Coors 89], [Gauthier 95] p. 104, [Karfakis 90], [Musikant 90] p. 24, and [Schwartz 92] p. 2.75.

4.6 Consider the typical hardness values for steels in Table 4.3.

(a) Plot the ultimate tensile strength σ_u as a function of the Brinell hardness values *HB*. Show the estimate of Eq. 4.4 on the same graph, and comment on the success of this relationship for estimating σ_u from *HB*.

(b) Develop an improved relationship for estimating σ_u from Brinell hardness.

(c) Plot σ_u as a function of the Vickers hardness values *HV*, and develop a relationship for estimating σ_u from *HV*.

$$\boldsymbol{\sigma_u = 3.45(HB)\mathrm{MPa}, \qquad \sigma_u = 0.50(HB)\mathrm{ksi}} \qquad (4.4)$$

Table 4.3 Approximate Equivalent Hardness Numbers and Ultimate Tensile Strengths for Carbon and Alloy Steels

Brinell	Vickers	Rockwell		Ultimate, σ_u	
HB	*HV*	*HRB*	*HRC*	MPa	ksi
627	667	—	58.7	2393	347
578	615	—	56.0	2158	313
534	569	—	53.5	1986	288
495	528	—	51.0	1813	263
461	491	—	48.5	1669	242
429	455	—	45.7	1517	220
401	425	—	43.1	1393	202
375	396	—	40.4	1267	184
341	360	—	36.6	1131	164
311	328	—	33.1	1027	149
277	292	—	28.8	924	134
241	253	100	22.8	800	116
217	228	96.4	—	724	105
197	207	92.8	—	655	95
179	188	89.0	—	600	87
159	167	83.9	—	538	78
143	150	78.6	—	490	71
131	137	74.2	—	448	65
116	122	67.6	—	400	58

Note: Force 3000 kg for *HB*. Both *HB* and *HV* are in units of kg/mm^2.
Source: Values in [Boyer 85] p. 1.61.

4.10 Equations 4.6 and 4.8 give values of fracture strength and elastic modulus from bending tests, but they apply only to the case of three-point bending. Derive analogous equations for the case of four-point bending with a rectangular cross section, as illustrated in Fig. 4.19(b).

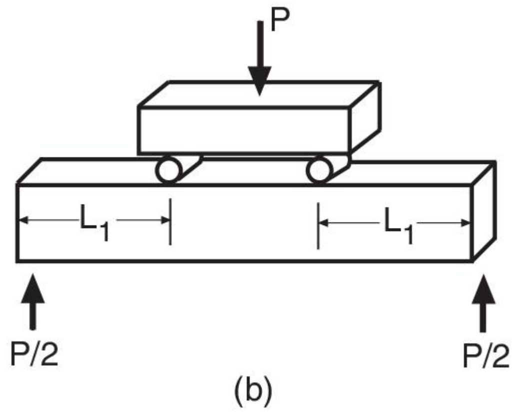
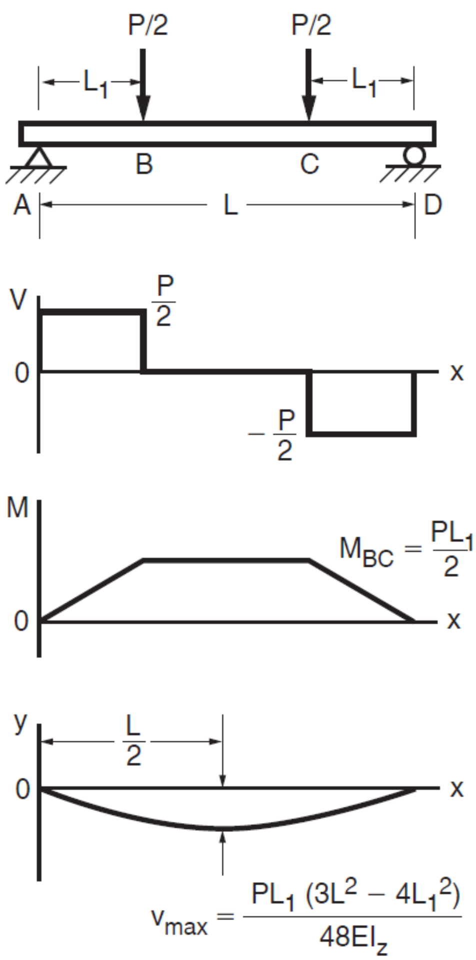


Figure 4.19(b).

$$\sigma_{fb} = \frac{3L}{8tc^2} P_f \qquad (4.6)$$

$$E = \frac{L^3}{48I} \left(\frac{dP}{dv}\right) = \frac{L^3}{32tc^3} \left(\frac{dP}{dv}\right) \qquad (4.8)$$



4.13 Torque vs. angle of twist data are given for the early part of a test on a solid round shaft of 2024-T351 Al. The shaft radius was 9.53 mm and the gage length for measurement of the twist angle was 160 mm. (a) Determine the shear modulus, G. (b) Estimate the yield strength in shear, τ_o.

Table P4.13

Torque T, N·m	Twist θ, degrees	Torque T, N·m	Twist θ, degrees
0	0	289	10
77.9	2	311	12
162.5	4	333	15
228	6	351	20
269	8	(Data truncated)	