3.22 For a number of points during a tension test on Man-Ten steel, engineering stress and strain data are given in Table P3.22. Also given are minimum diameters measured in the necked region in the latter portions of the test. The initial diameter was 6.32 mm.

(a) Evaluate the following engineering stress–strain properties: elastic modulus, yield strength, ultimate tensile strength, and percent reduction in area.

(b) Determine true stresses and strains to the fracture point, and plot the true stress–strain curve, showing both raw and corrected values of true stress. Also evaluate the true fracture stress and strain.

(c) Calculate true plastic strains for the data beyond yielding to fracture. Then fit Eq. 3.27 to these values and the corresponding corrected stresses, determining H and n.

Table P3.22

Engr. Stress σ, MPa	Engr. Strain ε	Diameter d, mm
0	0	6.32
125	0.0006	—
257	0.0012	—
359	0.0017	—
317	0.0035	—
333	0.0070	—
357	0.0100	—
397	0.0170	—
458	0.0300	—
507	0.0500	—
541	0.0790	5.99
576	—	5.72
558	—	5.33
531	—	5.08
476	—	4.45
379	—	3.50

(Final point is fracture.)

3.23 Assume that a material is quite ductile, so that elastic strains are small compared with plastic strains over most of the stress–strain curve. Plastic and total strains can then be taken as equivalent, $\tilde{\varepsilon}_p \approx \tilde{\varepsilon}$, and Eq. 3.26: $\tilde{\sigma} = H\tilde{\varepsilon}_p^n$ becomes $\tilde{\sigma} = H\tilde{\varepsilon}^n$.

(a) Show that the strain hardening exponent n is then expected to be equal to the true strain $\tilde{\varepsilon}_u$ at the engineering ultimate strength point—that is, $n \approx \tilde{\varepsilon}_u$. (Suggestion: Start by making substitutions into $\tilde{\sigma} = H\tilde{\varepsilon}^n$ from Sections 3.6.1 (Definitions of True Stress and Strain) and 3.6.2 (Constant Volume Assumption), to obtain an equation $\sigma = f(\tilde{\varepsilon}, H, n)$ that gives engineering stress.)

(b) How closely is this expectation realized for the tension test on AISI 1020 steel of Ex. 3.1, 3.2, and 3.3? (See Table E3.1 and Fig. 3.23.)

(c) From your derivation for (a), write an equation for estimating the ultimate tensile strength σ_u

from H and n. How well does this estimate work for the AISI 1020 steel of Ex. 3.1, 3.2, and 3.3?

Table E3.1 Data and Analysis for a Tension Test on AISI 1020 Hot-Rolled Steel

(a) Test Data			(b) Calculated Values				
Force P, kN	Engr. Strain ε	Diam. d, mm	Engr. Stress σ, MPa	True Strain $\tilde{\varepsilon}$	Raw True Stress $\tilde{\sigma}$, MPa	Corrected True Stress $\tilde{\sigma}_M$, MPa	True Plastic Strain $\tilde{\varepsilon}_p$
0	0	9.11	0	0	0	0	0
6.67	0.00050	—	102.3	0.00050	102.3	102.3	0
13.34	0.00102	—	204.7	0.00102	204.7	204.7	0
19.13	0.00146	—	293.5	0.00146	293.5	293.5	0
17.79	0.00230	—	272.9	0.00230	272.9	272.9	0
17.21	0.00310	—	264.0	0.00310	264.0	264.0	0.00178
17.53	0.00500	—	268.9	0.00499	268.9	268.9	0.00365
17.44	0.00700	—	267.6	0.00698	269.4	269.4	0.00564
17.21	0.01000	—	264.0	0.00995	266.7	266.7	0.00862
20.77	0.0490	8.89[4]	318.6	0.0478	334.3	334.3	0.0462
24.25	0.1250	—	372.0	0.1178	418.5	418.5	0.1157
25.71	0.2180	8.26[4]	394.4	0.1972	480.4	480.4	0.1948
25.75[1]	0.2340	—	395.0	0.2103	487.5	487.5	0.2078
25.04	0.3060	7.62	384.2	0.3572	549.1	542.9	0.3545
23.49	0.3300	6.99	360.4	0.5298	612.1	585.5	0.5269
21.35	0.3480	6.35	327.5	0.7218	674.2	614.6	0.7188
18.90	0.3600	5.72	290.0	0.9308	735.5	636.2	0.9276
17.39[2]	0.3660	5.28[3]	266.8	1.0909	794.2	663.1	1.0876

Notes: [1]Ultimate. [2]Fracture. [3]Measured from broken specimen. [4]Not used in calculations.

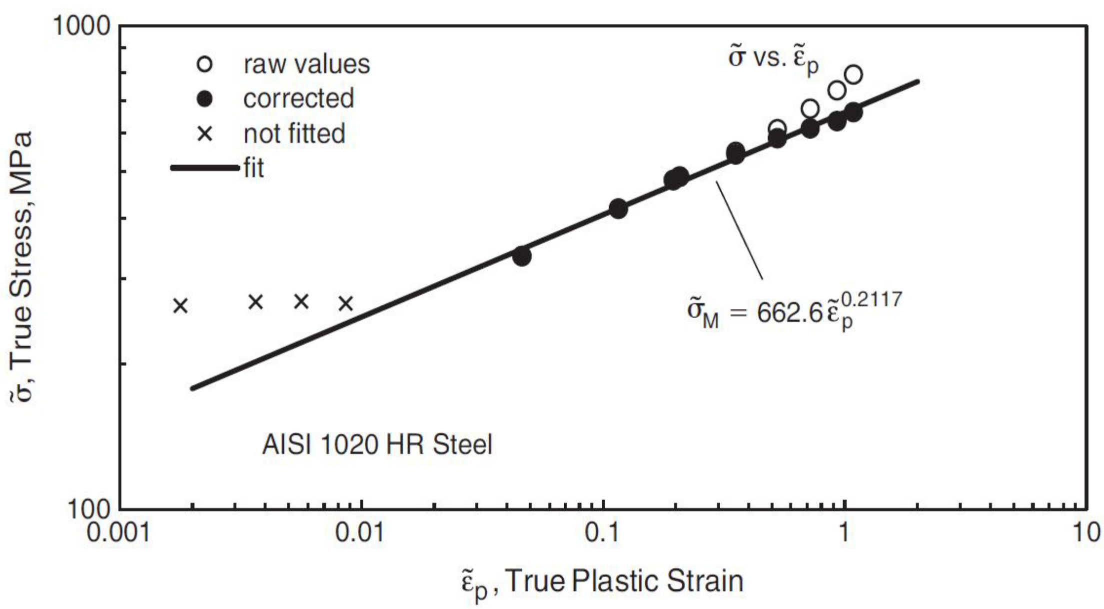

Figure 3.23 Log–log plot of true stress versus true plastic strain for AISI 1020 hot-rolled steel.

3.24 Consider the beam of circular cross section of Fig. 3.24 and Ex. 3.4. As before, the radius *r* of the cross section may vary with material, and the beam is required to have length *L* and resist a force *P*. However, in this case, the strength requirement is replaced by a requirement that the deflection not exceed a particular value v_{max}. (from the figure $v_{max} = \frac{PL^3}{3EI_z}$)

(a) Select a material from Table 3.8 such that the mass is minimized.

(b) Repeat the selection with cost being minimized.

(c) Briefly discuss your results, and suggest one or more materials that represent a reasonable choice, where both light weight and cost are important.

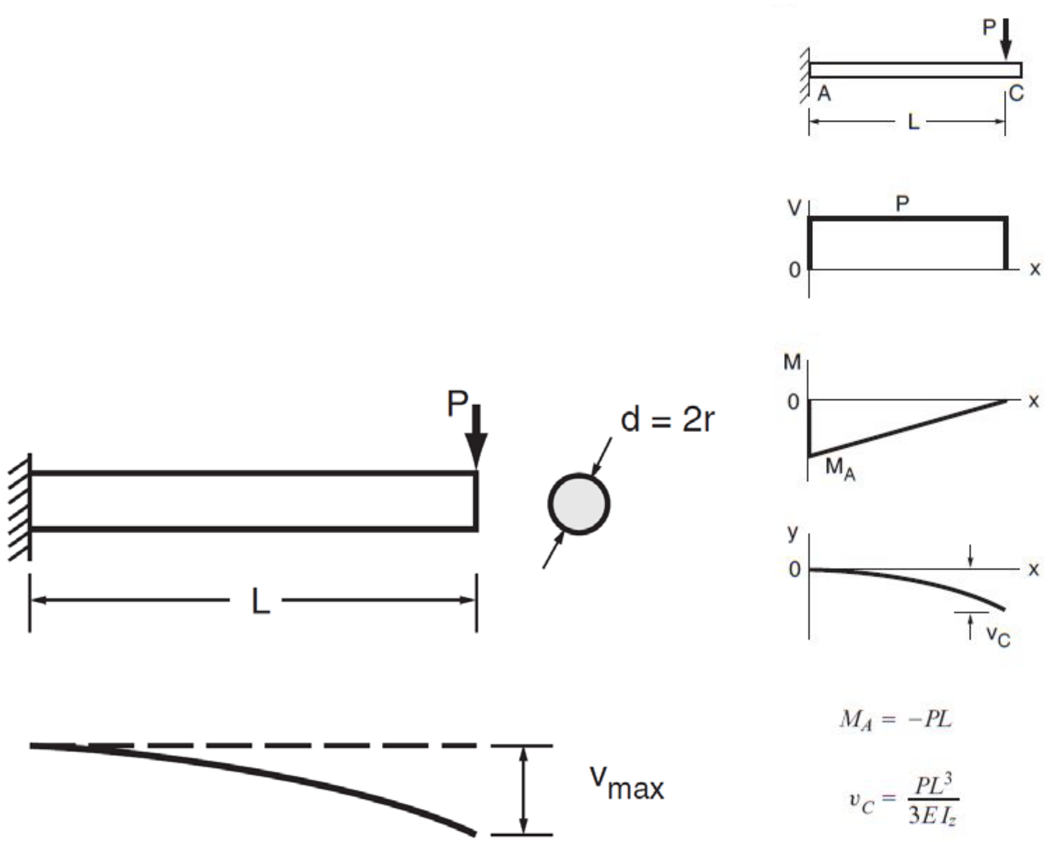

Figure 3.24 Cantilever beam.

3.25 Consider a tension member that is part of the structure of a personal aircraft. For a preliminary materials selection, assume that the member has a square cross section of side *h* that may vary with material choice. The length *L* is fixed. There are two functional requirements: (a) A force *P* must be resisted such that there is a safety factor *X* against the material exceeding its failure strength. (b) The deflection due to force *P* must not exceed a given length change ΔL. Then (c) Make a compromise choice among the materials of Table 3.8 that considers these requirements, light weight, cost, and any other considerations that you believe are important. Briefly justify your choice.

Table 3.8 Typical Materials for Selection Examples and Problems

	(a) Materials Data				(b) Calculated Values				
Material	Modulus E, GPa	Strength σ_c, MPa	Density ρ, g/cm^3	Relative Cost, C_m	$\dfrac{\rho}{\sigma_c^{2/3}}$	Mass Rank	Radius r, mm	$\dfrac{C_m \rho}{\sigma_c^{2/3}}$	Cost Rank
Mild steel (AISI 1020)	203	260	7.9	1	0.194	8	5.81	0.194	2
Low-alloy steel (AISI 4340)	207	1103	7.9	3	0.0740	6	3.59	0.222	3
Aluminum alloy (7075-T6)	71	469	2.7	6	0.0447	5	4.77	0.268	4
Titanium alloy Ti-6Al-4V	117	1185	4.5	45	0.0402	4	3.50	1.81	7
Engineering polymer Polycarbonate (PC)	2.4	62	1.2	5	0.0766	7	9.37	0.383	6
Wood (Loblolly pine)	12.3	88	0.51	1.5	0.0258	2	8.33	0.0387	1
Composite (Glass cloth in epoxy)	21	380	2.0	10	0.0381	3	5.12	0.381	5
Composite laminate (Graphite fibers in epoxy)	76	930	1.6	200	0.0168	1	3.80	3.36	8

Notes: Strengths σ_c are yield strengths in tension for metals and polymers, the bending strength for loblolly pine, and ultimate tensile strengths for the composites. Units for the calculated expressions in (b) are (g/cm^3) / MPa$^{2/3}$.
Sources: Tables 3.2, 3.3, and 15.1, and the authors synthesis of miscellaneous data.