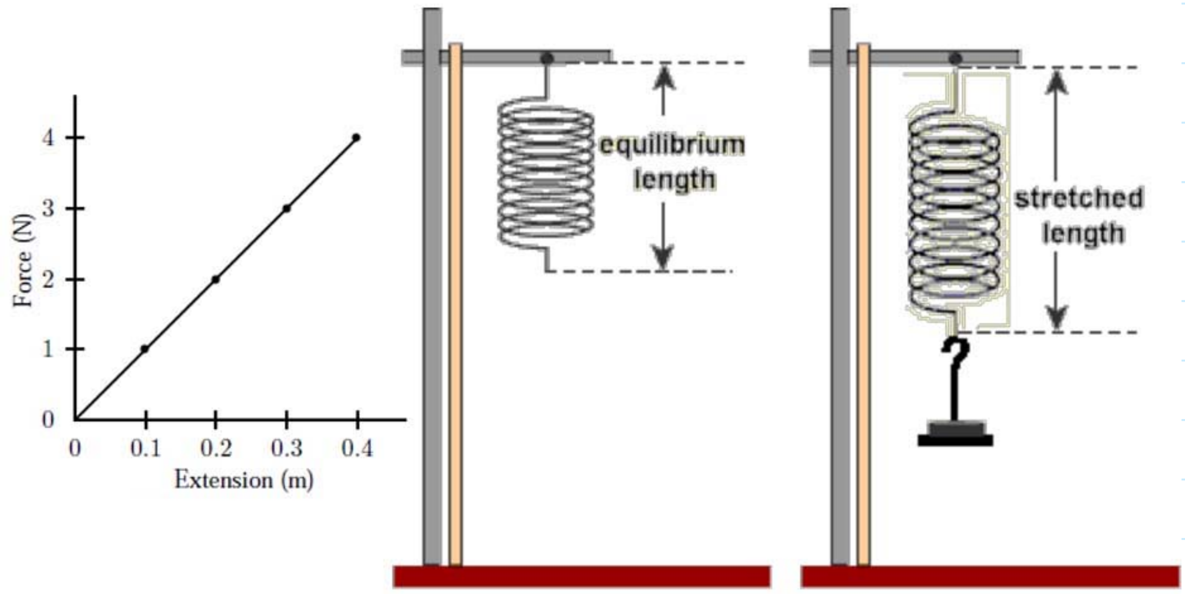
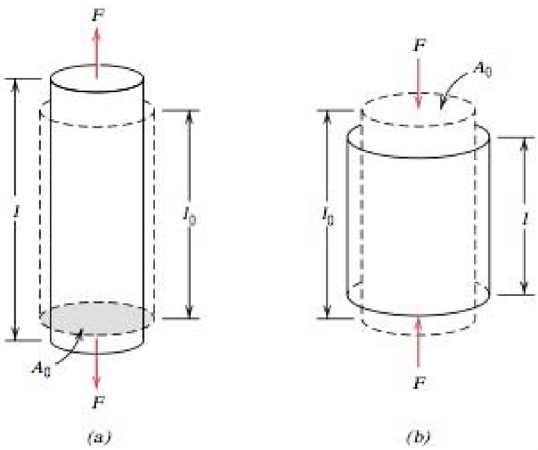
Unit 4 - Mechanical properties of solids

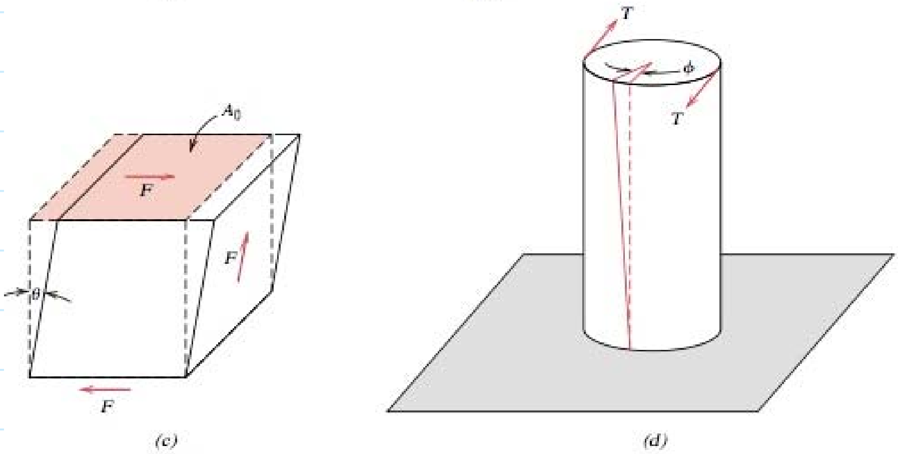
Hooke's law



Stress

$$\sigma = \frac{F}{A}$$



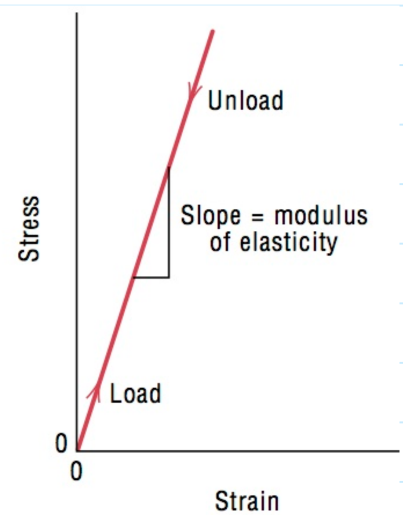


Strain

$$\varepsilon = \frac{\Delta \ell}{\ell} \qquad (3.2)$$

Stress-strain relationship.

$$Y = \frac{\sigma}{\varepsilon} = \frac{F}{A}\frac{\ell}{\Delta \ell} \qquad (3.3)$$



Group exercise

$\Delta \ell$

A piece of copper originally 305 mm (12 in.) long is pulled in tension with a stress of 276 MPa (40,000 psi). If the deformation is entirely elastic, what will

A piece of copper originally 305 mm (12 in.) long is pulled in tension with a stress of 276 MPa (40,000 psi). If the deformation is entirely elastic, what will be the resultant elongation?

σ

Poisson ratio

$$\frac{\Delta l_2}{l_2} = \frac{\Delta l_3}{l_3} = -\nu \frac{\Delta l_1}{l_2}$$

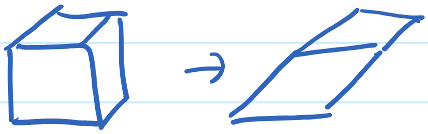
Greek nu

not 1

P.67.- two things

Modulus of rigidity

$$G = \frac{\tau}{\alpha}$$



Bulk modulus

$$K = -\Delta P \frac{V}{\Delta V}$$

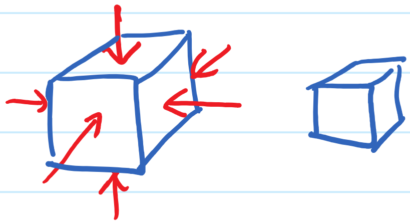


Table 7.1 Room-Temperature Elastic and Shear Moduli, and Poisson's Ratio for Various Materials

Material	Modulus of Elasticity		Shear Modulus		Poisson's Ratio
	GPa	10^6 psi	GPa	10^6 psi	
Metal Alloys					
Tungsten	407	59	160	23.2	0.28
Steel	207	30	83	12.0	0.30
Nickel	207	30	76	11.0	0.31
Titanium	107	15.5	45	6.5	0.34
Copper	110	16	46	6.7	0.34
Brass	97	14	37	5.4	0.34
Aluminum	69	10	25	3.6	0.33
Magnesium	45	6.5	17	2.5	0.35
Ceramic Materials					
Aluminum oxide (Al_2O_3)	393	57	—	—	0.22
Silicon carbide (SiC)	345	50	—	—	0.17
Silicon nitride (Si_3N_4)	304	44	—	—	0.30
Spinel ($MgAl_2O_4$)	260	38	—	—	—
Magnesium oxide (MgO)	225	33	—	—	0.18
Zirconia[a]	205	30	—	—	0.31
Mullite ($3Al_2O_3$-$2SiO_2$)	145	21	—	—	0.24
Glass–ceramic (Pyroceram)	120	17	—	—	0.25
Fused silica (SiO_2)	73	11	—	—	0.17
Soda–lime glass	69	10	—	—	0.23
Polymers[b]					
Phenol-formaldehyde	2.76–4.83	0.40–0.70	—	—	—
Polyvinyl chloride (PVC)	2.41–4.14	0.35–0.60	—	—	0.38
Polyester (PET)	2.76–4.14	0.40–0.60	—	—	—
Polystyrene (PS)	2.28–3.28	0.33–0.48	—	—	0.33
Polymethyl methacrylate (PMMA)	2.24–3.24	0.33–0.47	—	—	—
Polycarbonate (PC)	2.38	0.35	—	—	0.36
Nylon 6,6	1.58–3.80	0.23–0.55	—	—	0.39
Polypropylene (PP)	1.14–1.55	0.17–0.23	—	—	—
Polyethylene—high density (HDPE)	1.08	0.16	—	—	—
Polytetrafluoroethylene (PTFE)	0.40–0.55	0.058–0.080	—	—	0.46
Polyethylene—low density (LDPE)	0.17–0.28	0.025–0.041	—	—	—

For isotropic materials

$$G = \frac{Y}{2(1+\nu)} \qquad (3.7)$$

$$K = \frac{Y}{\cdots} \qquad (3.8)$$

$$K = \frac{Y}{3(1-2\nu)} \qquad (3.8)$$

Poisson Ratio

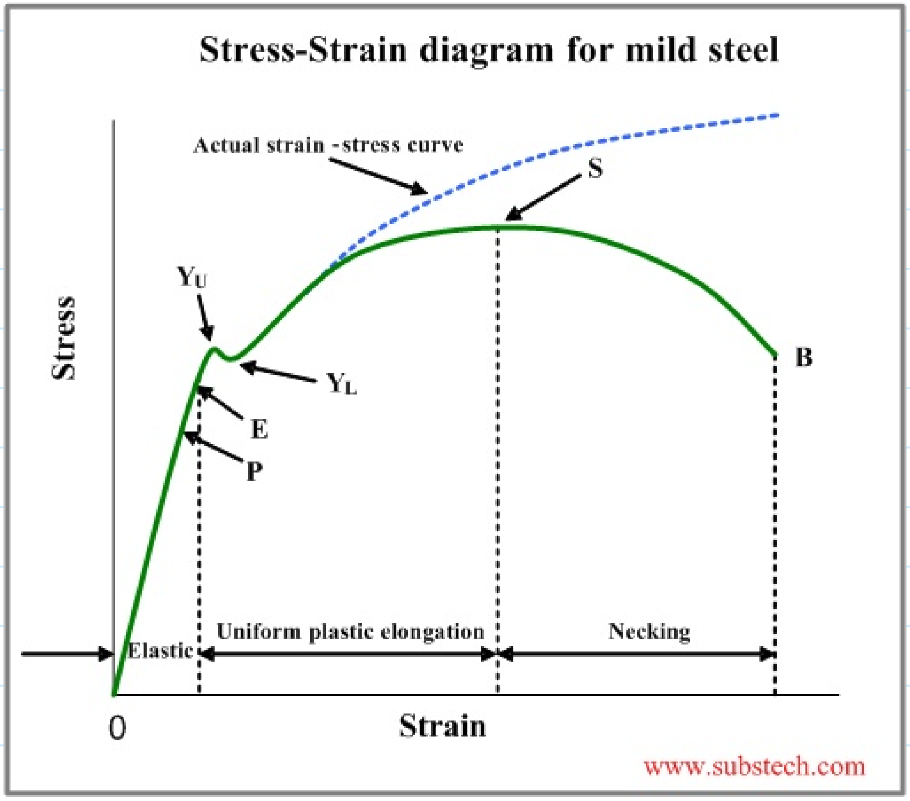
Poisson's ratio

From <https://en.wikipedia.org/wiki/Poisson's_ratio>

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z} \qquad \left(\varepsilon_z = \frac{\Delta l_z}{l_z}\right)$$

Group exercise

A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10 mm (0.4 in.). Determine the magnitude of the load required to produce a 2.5×10^{-3} mm (10^{-4} in.) change in diameter if the deformation is entirely elastic.



Different Materials.

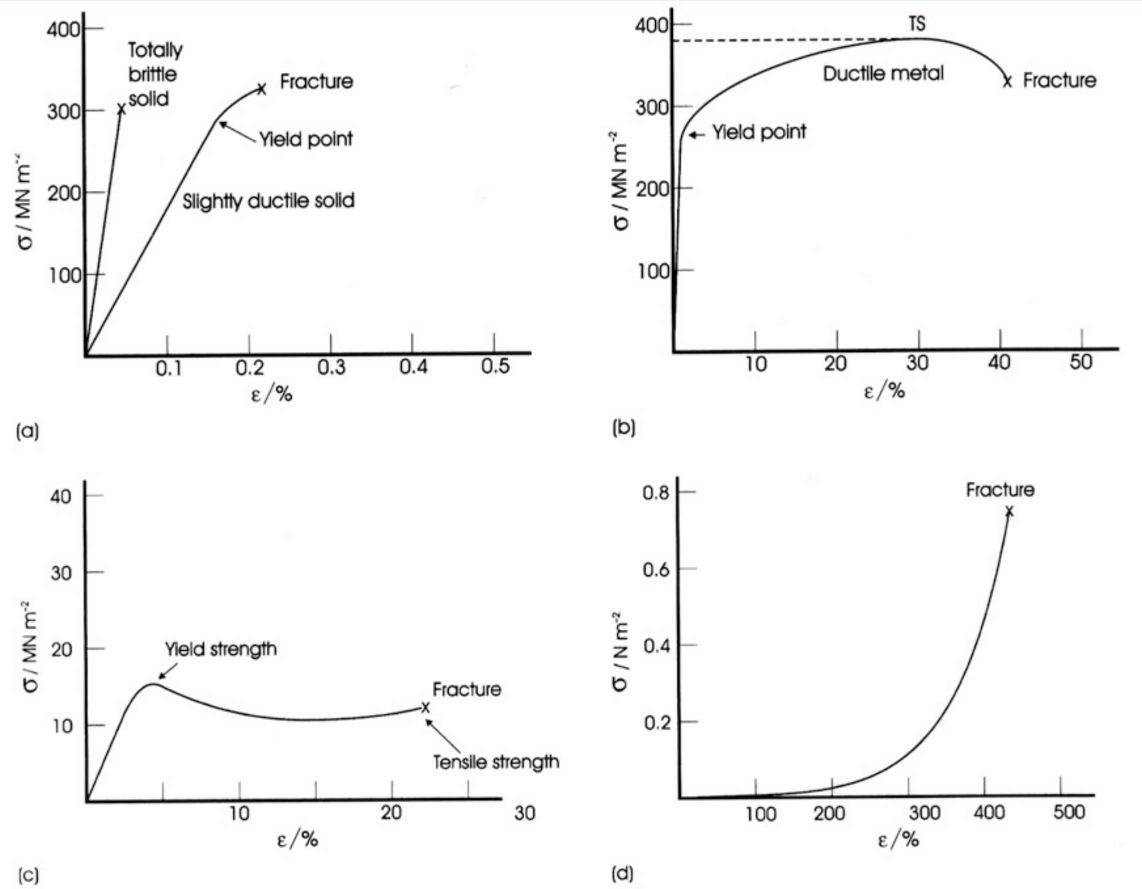
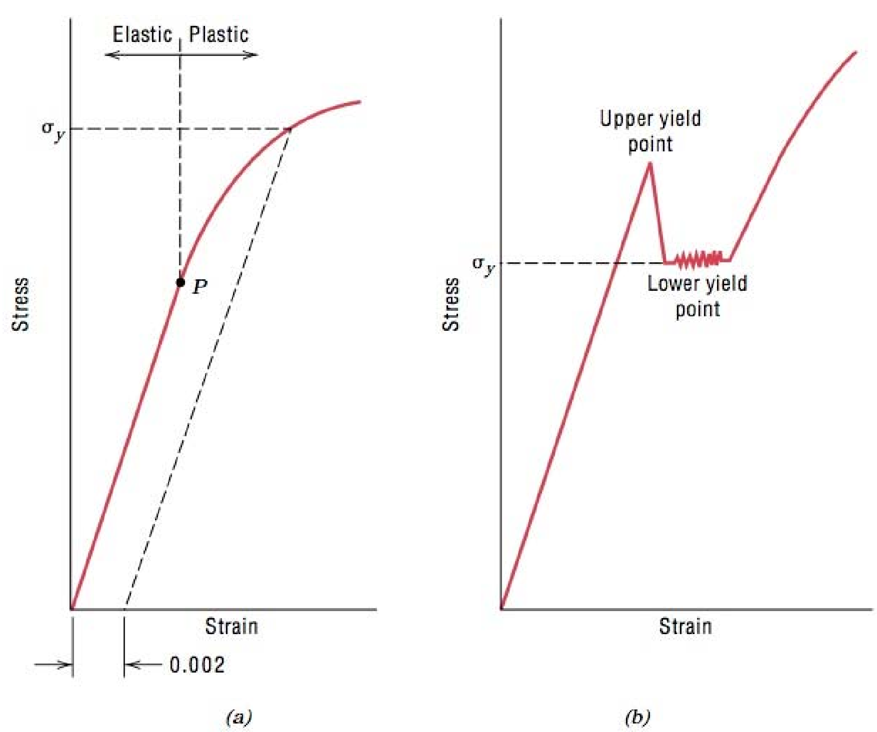


Figure 10.4 Schematic engineering stress–engineering strain (σ–ε) curves for (a) brittle and slightly ductile solids, (b) ductile metals, (c) a typical polymer, and (d) rubber, an elastomer. Note the different stress scale in part (d); point x represents fracture of the specimen; point TS is the ultimate tensile strength

FIGURE 7.10 (*a*) Typical stress–strain behavior for a metal showing elastic and plastic deformations, the proportional limit P, and the yield strength σ_y, as determined using the 0.002 strain offset method. (*b*) Representative stress–strain behavior found for some steels demonstrating the yield point phenomenon.



Group exercise

Group exercise

From the tensile stress–strain behavior for the brass specimen shown in Figure 7.12, determine the following:

(a) The modulus of elasticity.

(b) The yield strength at a strain offset of 0.002.

(c) The maximum load that can be sustained by a cylindrical specimen having an original diameter of 12.8 mm (0.505 in.).

(d) The change in length of a specimen originally 250 mm (10 in.) long that is subjected to a tensile stress of 345 MPa (50,000 psi).

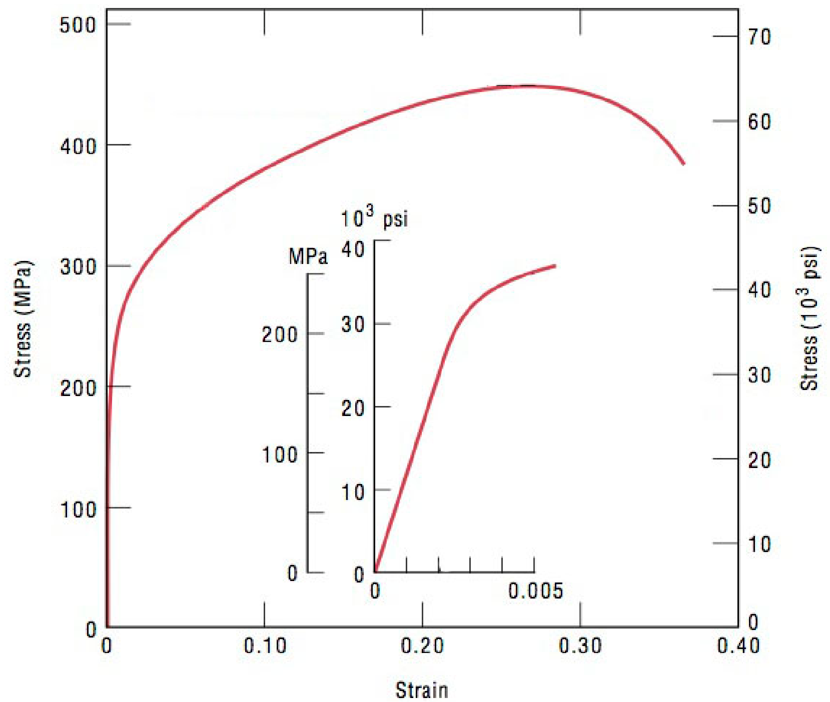


FIGURE 7.12 The stress–strain behavior for the brass specimen

Other properties.

Table 7.2 Room-Temperature Mechanical Properties (in Tension) for Various Materials

Material	*Yield Strength*		*Tensile Strength*		*Ductility, %EL [in 50 mm (2 in.)]*[a]
	MPa	*ksi*	*MPa*	*ksi*	
Metal Alloys[b]					
Molybdenum	565	82	655	95	35
Titanium	450	65	520	75	25
Steel (1020)	180	26	380	55	25
Nickel	138	20	480	70	40
Iron	130	19	262	38	45
Brass (70 Cu–30 Zn)	75	11	300	44	68
Copper	69	10	200	29	45
Aluminum	35	5	90	13	40
Ceramic Materials[c]					
Zirconia (ZrO_2)[d]	—	—	800–1500	115–215	—
Silicon nitride (Si_3N_4)	—	—	250–1000	35–145	—
Aluminum oxide (Al_2O_3)	—	—	275–700	40–100	—
Silicon carbide (SiC)	—	—	100–820	15–120	—
Glass–ceramic (Pyroceram)	—	—	247	36	—
Mullite ($3Al_2O_3$-$2SiO_2$)	—	—	185	27	—
Spinel ($MgAl_2O_4$)	—	—	110–245	16–36	—
Fused silica (SiO_2)	—	—	110	16	—
Magnesium oxide (MgO)[e]	—	—	105	15	—
Soda–lime glass	—	—	69	10	—
Polymers					
Nylon 6,6	44.8–82.8	6.5–12	75.9–94.5	11.0–13.7	15–300
Polycarbonate (PC)	62.1	9.0	62.8–72.4	9.1–10.5	110–150
Polyester (PET)	59.3	8.6	48.3–72.4	7.0–10.5	30–300
Polymethyl methacrylate (PMMA)	53.8–73.1	7.8–10.6	48.3–72.4	7.0–10.5	2.0–5.5
Polyvinyl chloride (PVC)	40.7–44.8	5.9–6.5	40.7–51.7	5.9–7.5	40–80
Phenol-formaldehyde	—	—	34.5–62.1	5.0–9.0	1.5–2.0
Polystyrene (PS)	—	—	35.9–51.7	5.2–7.5	1.2–2.5
Polypropylene (PP)	31.0–37.2	4.5–5.4	31.0–41.4	4.5–6.0	100–600
Polyethylene—high density (HDPE)	26.2–33.1	3.8–4.8	22.1–31.0	3.2–4.5	10–1200
Polytetrafluoroethylene (PTFE)	—	—	20.7–34.5	3.0–5.0	200–400
Polyethylene—low density (LDPE)	9.0–14.5	1.3–2.1	8.3–31.4	1.2–4.55	100–650

[a] For polymers, percent elongation at break.
[b] Property values are for metal alloys in an annealed state.
[c] The tensile strength of ceramic materials is taken as flexural strength (Section 7.10).
[d] Partially stabilized with 3 mol% Y_2O_3.
[e] Sintered and containing approximately 5% porosity.

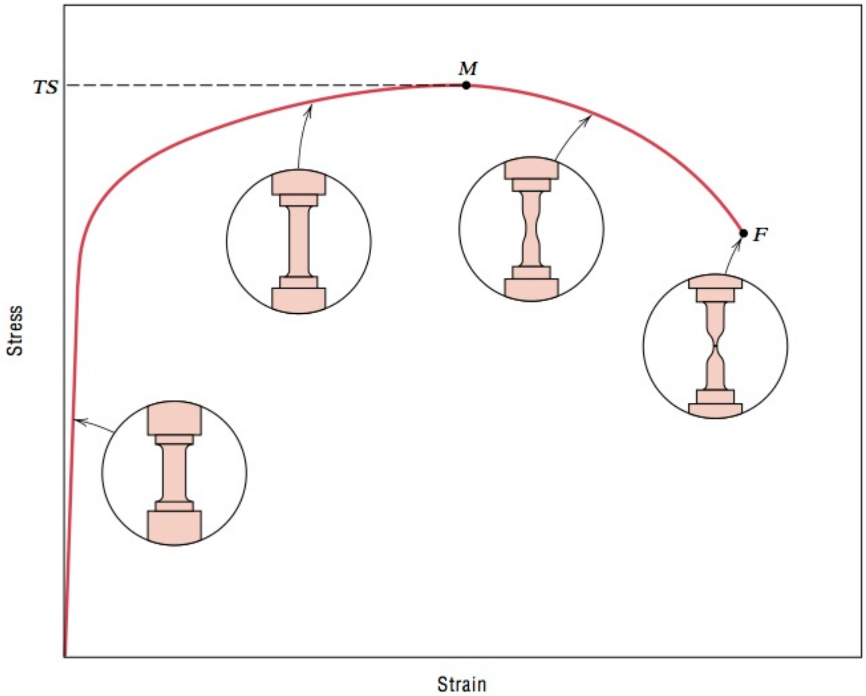
Ductility.

$$\%EL = \left(\frac{l_f - l_0}{l_0}\right) \times 100$$

$$\%RA = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$

Necking

Necking



Group exercise

A cylindrical specimen of steel having an original diameter of 12.8 mm (0.505 in.) is tensile tested to fracture and found to have an engineering fracture strength σ_f of 460 MPa (67,000 psi). If its cross-sectional diameter at fracture is 10.7 mm (0.422 in.), determine:

(a) The ductility in terms of percent reduction in area.

(b) The true stress at fracture.

Resilience

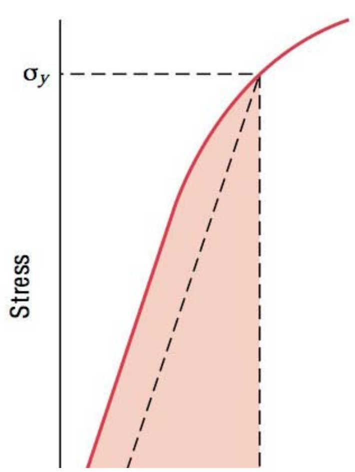


FIGURE 7.15 Schematic representation showing how modulus of resilience (corresponding to the shaded area) is determined from the tensile stress–strain behavior of a material.

$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

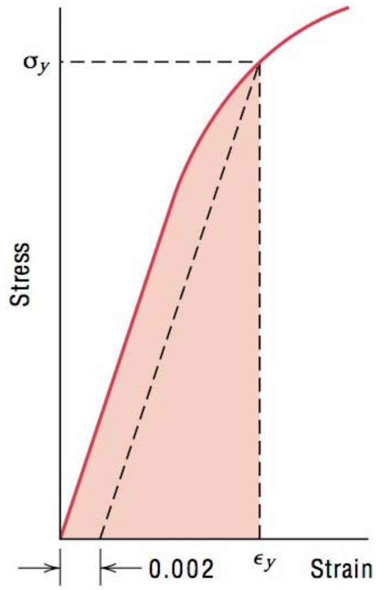


FIGURE 7.15 Schematic representation showing how modulus of resilience (corresponding to the shaded area) is determined from the tensile stress–strain behavior of a material.

$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

Group exercise

A cylindrical specimen of aluminum having a diameter of 0.505 in. (12.8 mm) and a gauge length of 2.000 in. (50.800 mm) is pulled in tension. Use the load–elongation characteristics tabulated below to complete problems a through f.

Load		*Length*	
lb_f	*N*	*in.*	*mm*
0	0	2.000	50.800
1,650	7,330	2.002	50.851
3,400	15,100	2.004	50.902
5,200	23,100	2.006	50.952
6,850	30,400	2.008	51.003
7,750	34,400	2.010	51.054
8,650	38,400	2.020	51.308
9,300	41,300	2.040	51.816
10,100	44,800	2.080	52.832
10,400	46,200	2.120	53.848
10,650	47,300	2.160	54.864
10,700	47,500	2.200	55.880
10,400	46,100	2.240	56.896
10,100	44,800	2.270	57.658
9,600	42,600	2.300	58.420
8,200	36,400	2.330	59.182
	Fracture		

(a) Plot the data as engineering stress versus engineering strain.

(b) Compute the modulus of elasticity.

(c) Determine the yield strength at a strain offset of 0.002.

(d) Determine the tensile strength of this alloy.

(e) What is the approximate ductility, in percent elongation?

(f) Compute the modulus of resilience.

Extra exercise.

Consider the brass alloy with stress–strain behavior shown in Figure 7.12. A cylindrical specimen of this material 6 mm (0.24 in.) in diameter and 50 mm (2 in.) long is pulled in tension with a force of 5000 N (1125 lb_f). If it is known that this alloy has a Poisson's ratio of 0.30, compute: **(a)** the specimen elongation, and **(b)** the reduction in specimen diameter.

Calculate the moduli of resilience for the material having the stress–strain behavior shown in Figures 7.12 .