Mechanical Properties of Materials

- Engineering stress-strain
- True stress-strain
- Notch effects
- Bending tests
- Impact energy and fracture toughness
- Hardness
- Fatigue
- High temperature properties
- Residual stress

Material Testing

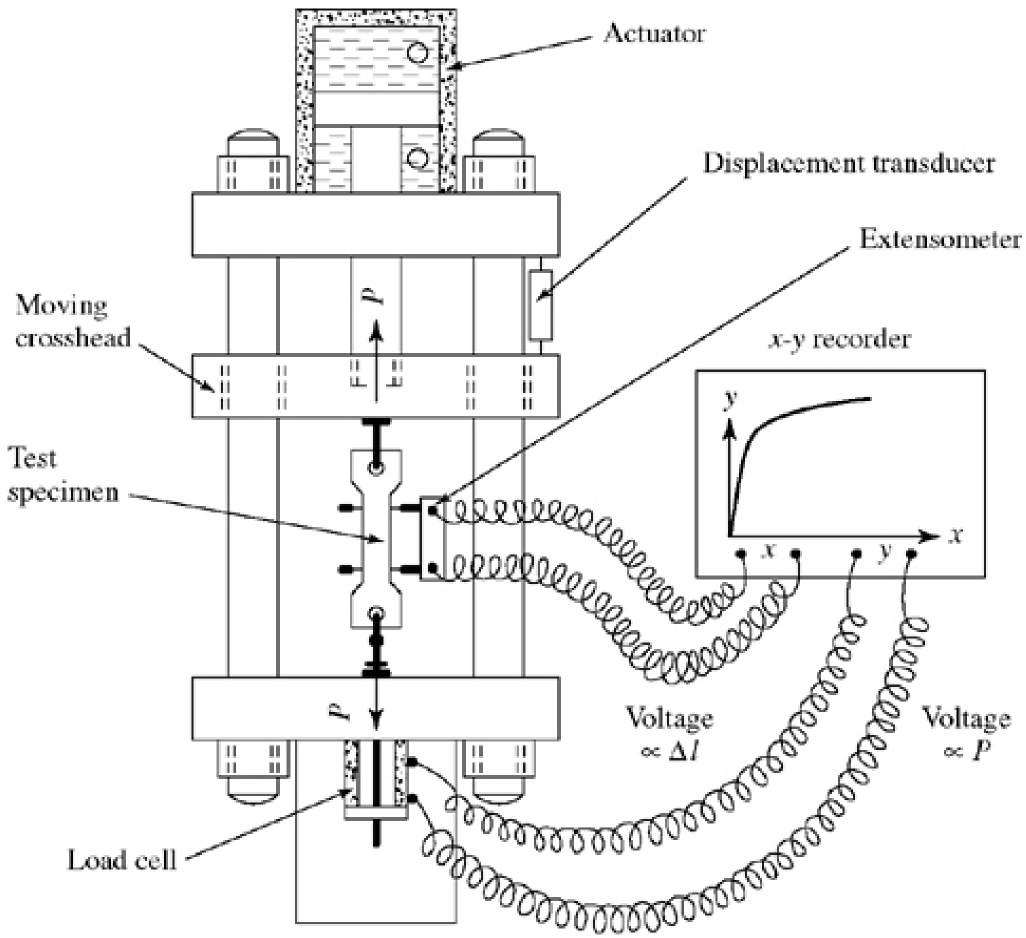
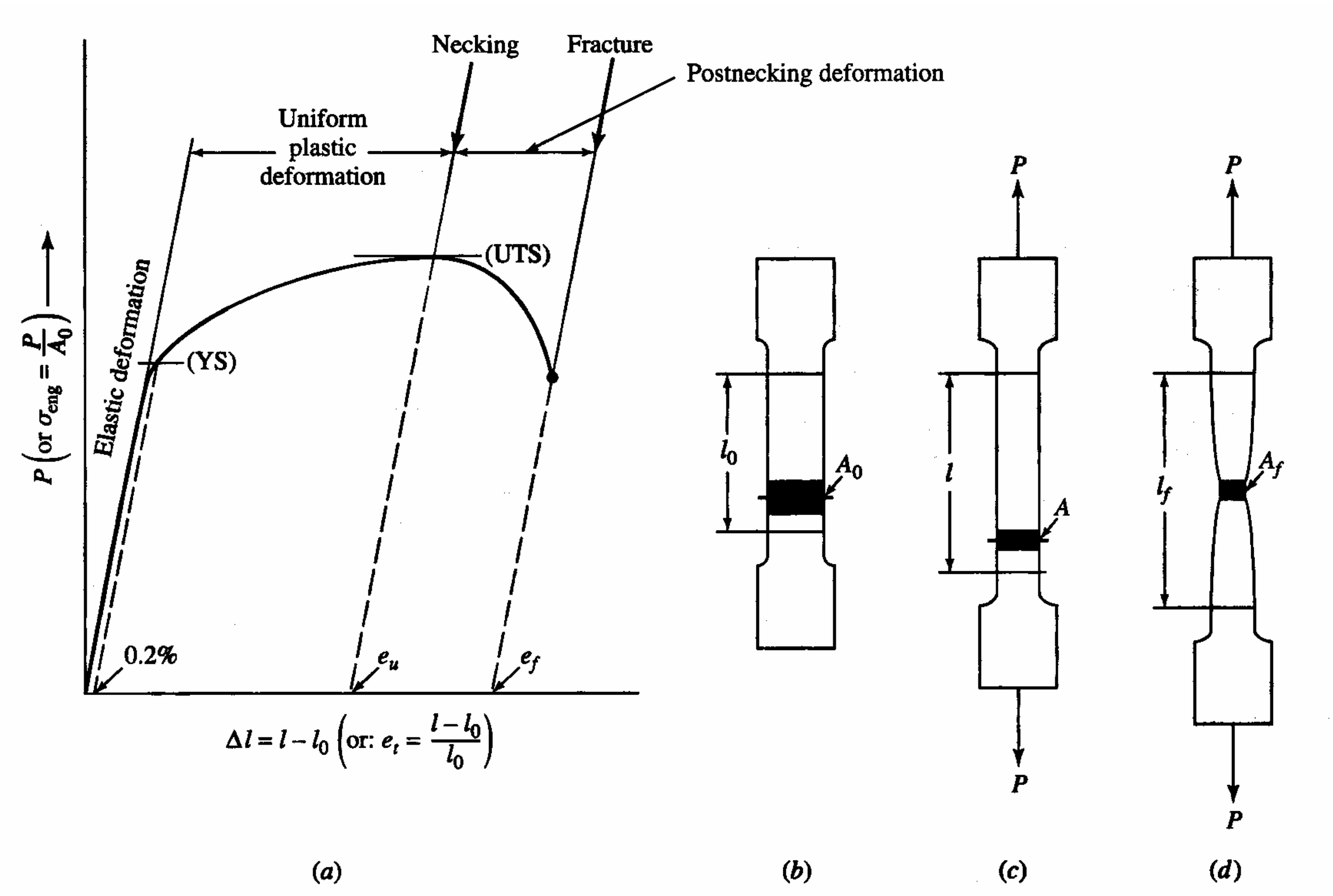
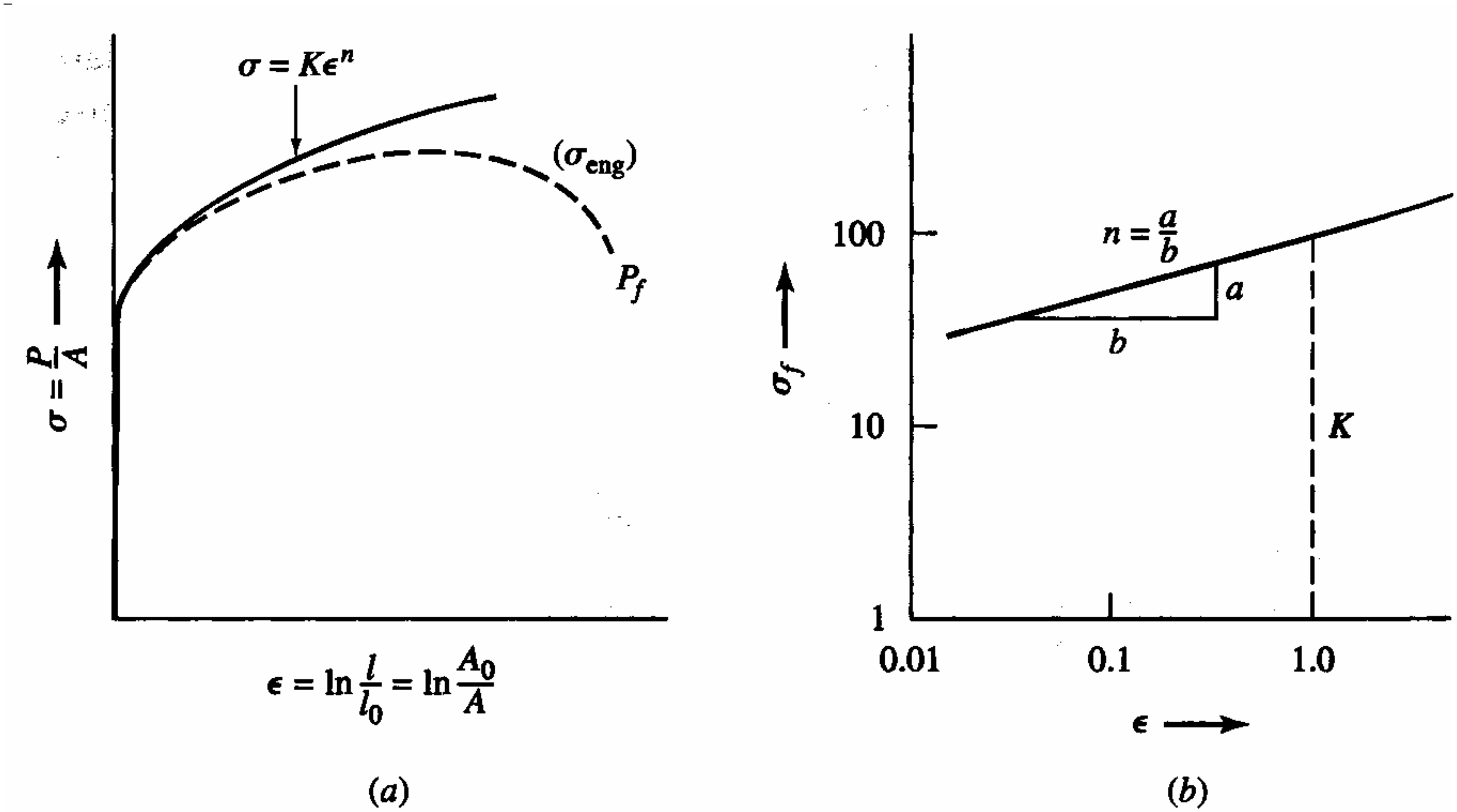


figure 4.1

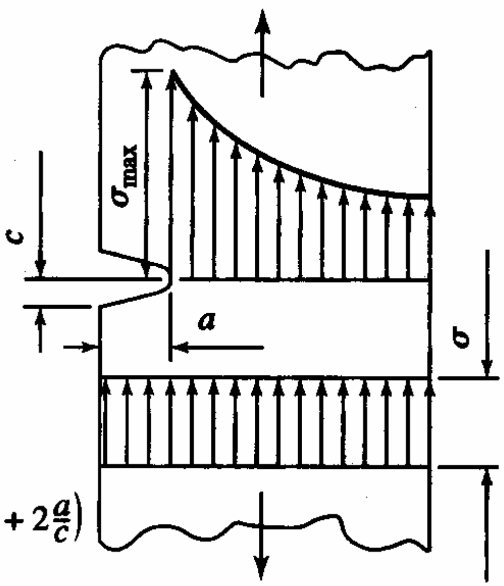
Engineering Stress-Strain



True Stress-Strain



Notch Effects



$$K = \frac{\sigma_{max}}{\sigma} = \left(1 + 2\frac{a}{c}\right)$$

Figure 4–8 A notch on the surface of a body results in a sharp increase of stresses: It causes stress concentration.

- K is the stress concentration factor.
- The presence of cracks on the surface or inside the body may severely reduce the tensile stress that a material can withstand with fracture.
- Fracture stress depends on the crack radius and crack depth.
- Fracture stress is also a function of material constant, which need to be determined in repeated tests.

Bending Test

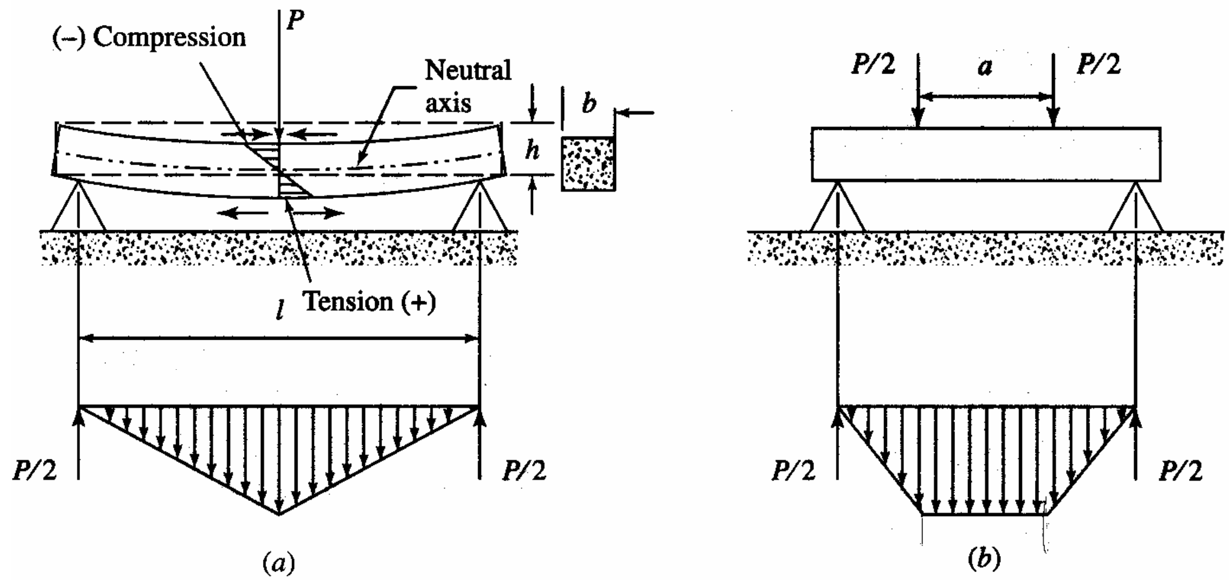


Figure 4–9 Less-ductile materials are often subjected to (a) three-point or (b) four-point bending tests. Tensile stresses peak at the center in the three-point test but are distributed uniformly between the two loading points in the four-point test.

The rupture strength (flexural strength or modulus of rapture) of brittle materials:

- In the three-point test,

$$\sigma_B = \frac{3}{2}\frac{Pl}{bh^2} \quad \text{or} \quad \sigma_B = \frac{8Pl}{\pi d^3}$$

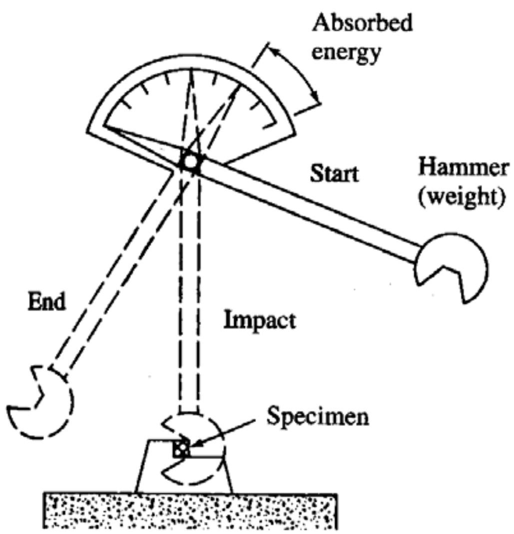
High, more scattered

- In the four-point test,

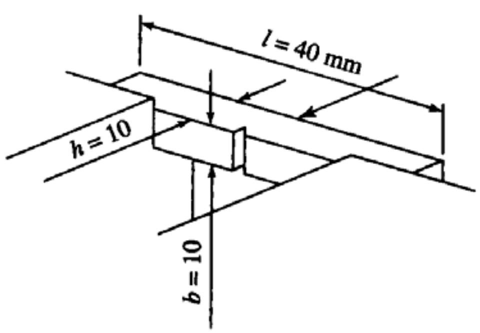
$$\sigma_B = \frac{Pl}{bh^2}$$

Low, more consistent

Impact Energy and Fracture Toughness



(a)

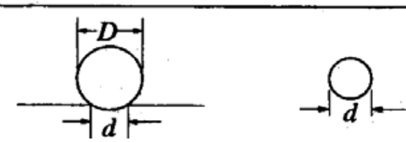
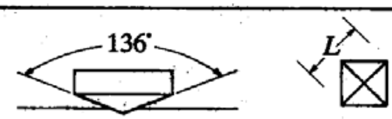
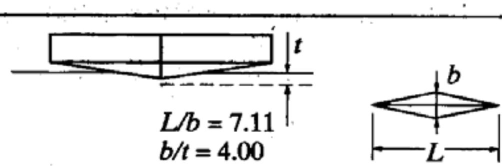
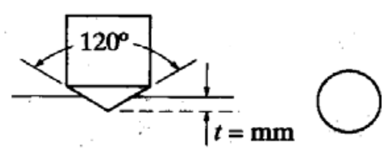
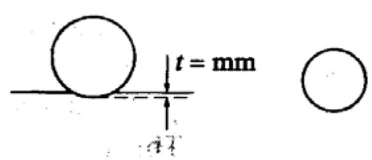


(b)

- Even ductile material suffer brittle fracture under certain conditions, such as notched form, sudden load, and below ductile-to-brittle transition temperature.
- Impact energy measured should be used only as a comparative value.
- One of the aims of manufacturing processes is to prevent the formation of cracks.
- Cracks must be kept in compression during the service of the part.

Hardness

FIGURE 2.12 General characteristics of hardness-testing methods and formulas for calculating hardness. The quantity P is the load applied. *Source*: H. W. Hayden, et al., *The Structure and Properties of Materials*, Vol. III (John Wiley & Sons, 1965).

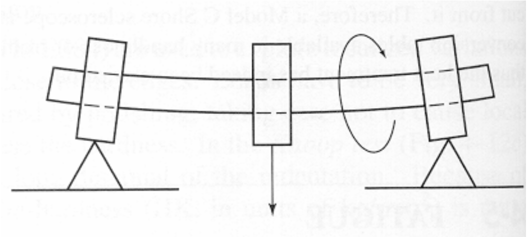
Test	Indenter	Shape of indentation: Side view / Top view	Load, P	Hardness number
Brinell	10-mm steel or tungsten carbide ball		500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid		1-120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid		25g-5kg	$HK = \frac{14.2P}{L^2}$
Rockwell			kg	
A C D	Diamond cone		60 150 100	HRA HRC HRD $= 100 - 500t$
B F G	$\frac{1}{16}$ - in. diameter steel ball		100 60 150	HRB HRF HRG $= 130 - 500t$
E	$\frac{1}{8}$ - in. diameter steel ball		100	HRE $= 130 - 500t$

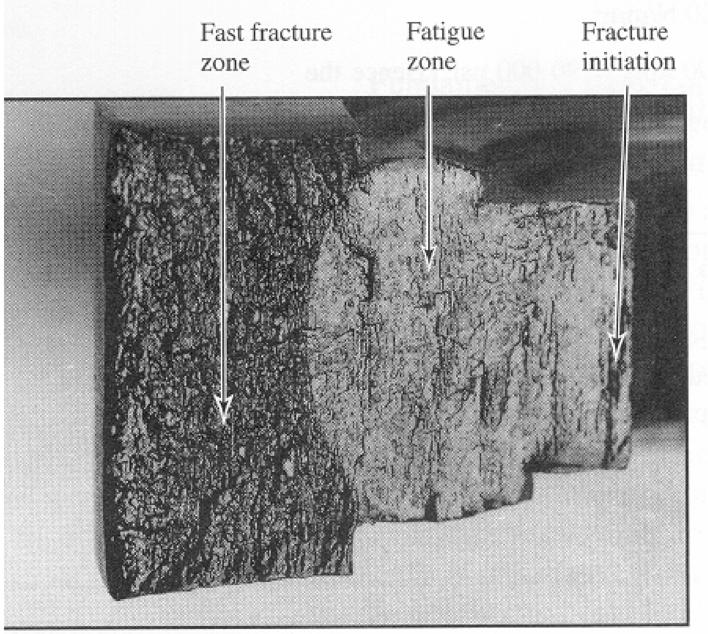
Hardness and Strength

- Studies have shown that (in the same units) the hardness of a cold-worked metal is about three times its yield stress (YS), for annealed metals, it is about five times.
- A relationship has been established between the ultimate tensile strength (UTS) and the Brinell hardness (HB) for steels. In SI units the relationship is
  - HB=~(3-3.5) UTS, where UTS and HB are both in MPa.

- For example, a cold-draw bar has a Brinell hardness of HB=190 kg/mm^2, the tensile strength is
  - UTS= 190/3.5 = 54.28 kg/mm^2 = 531.9 N/mm^2

Fatigue





- Fatigue is caused by stresses much smaller than the tensile strength.
- Fatigue failure starts from a microscopic initial defect, such as microcracks, irregular grain boundaries, and impurity inclusions.
- Stress concentration high enough to cause local damage.
- Fatigue process consists of three stages: initiation, fatigue, fast fracture.
- Fatigue failure has a statistical nature

S-N Curves

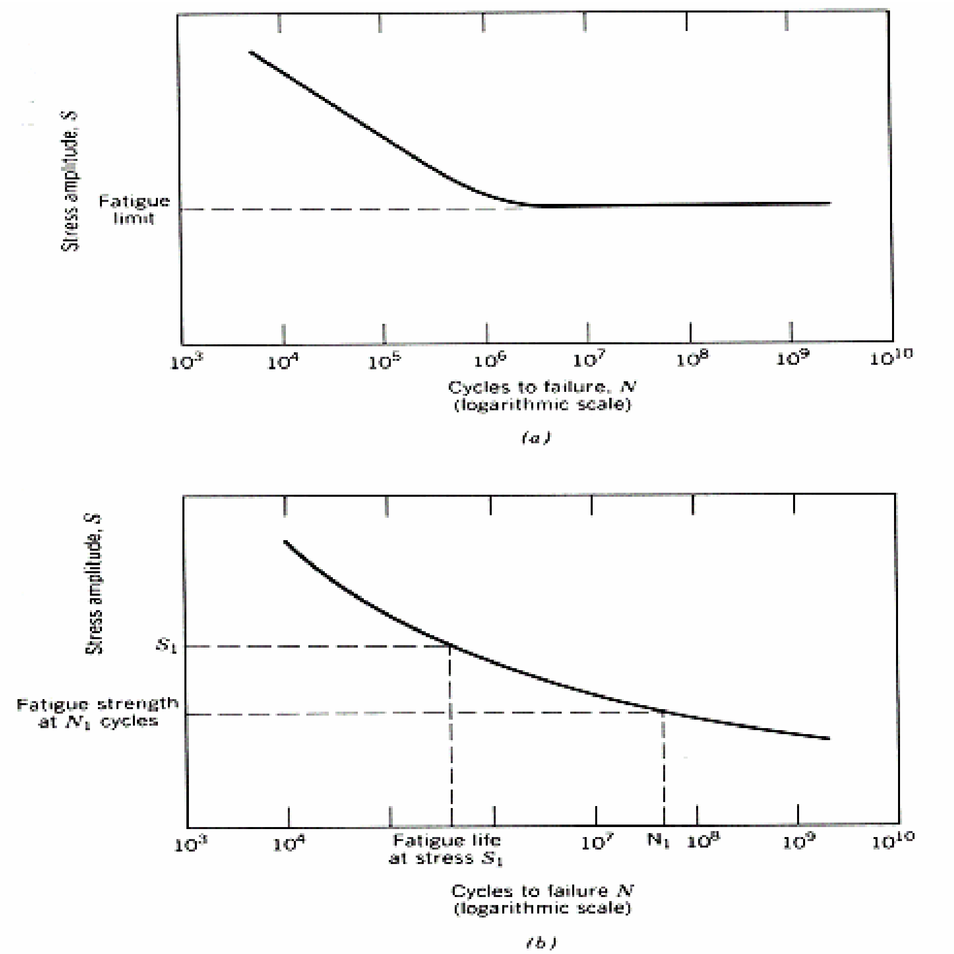


Figure 8.19 Stress amplitude (S) versus logarithm of the number of cycles to fatigue failure (N) for (a) a material that displays a fatigue limit, and (b) a material that does not display a fatigue limit.

- Shows the stress level S as a function of the number of cycles to failure N.
- For steel, curve level off after $N=10^6$ cycles.
- There is a fatigue limit or endurance limit, denoted by S_n.
- Fatigue limit can be calculated based on reliability, size, and surface finish.
- Some idea on number of cycles:

  N=5000 rpm * 60 min/hr * 24 hr/day * 365 days/yr *10 years $=26*10^9$ cycles

The Effect of Manufacturing Processes

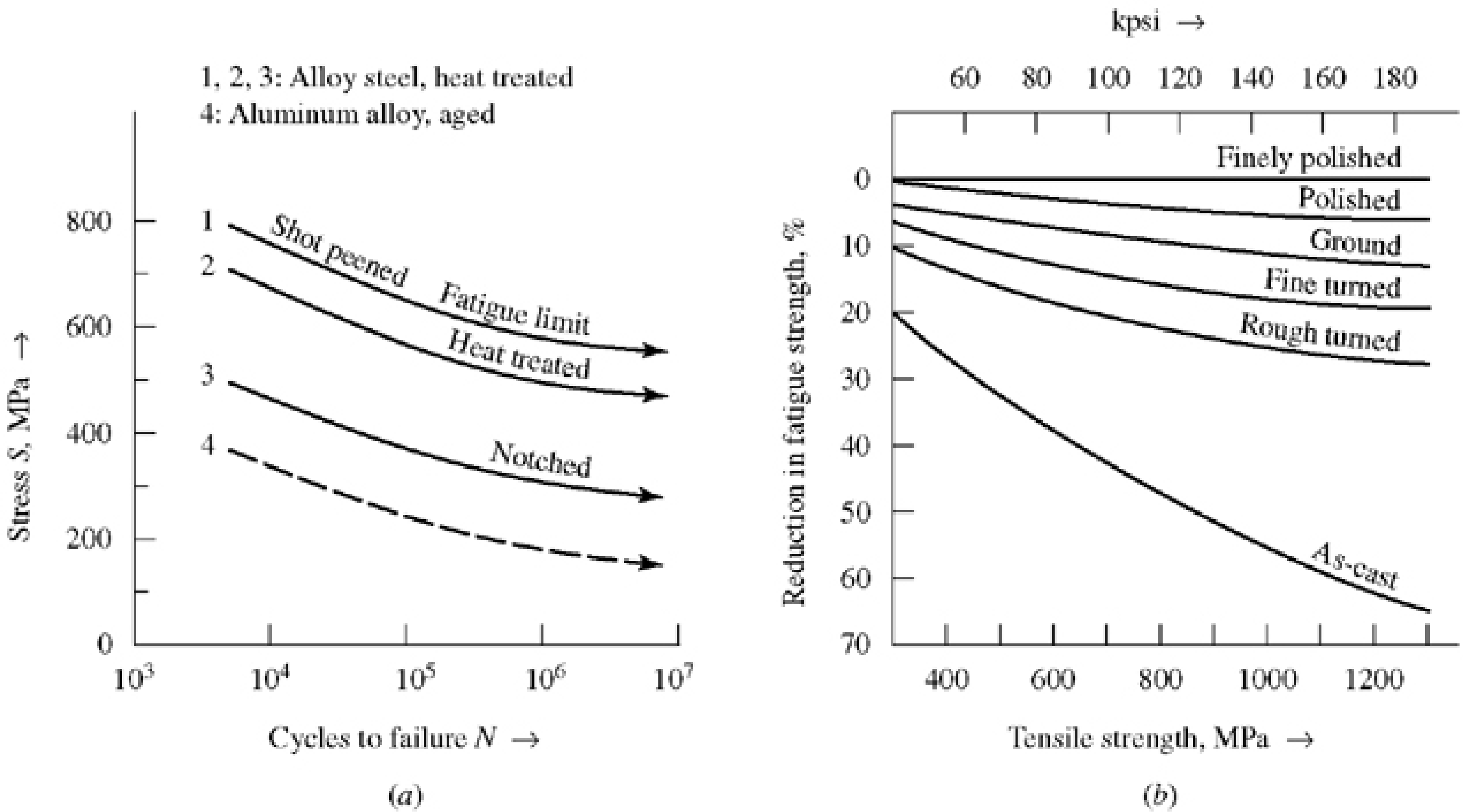
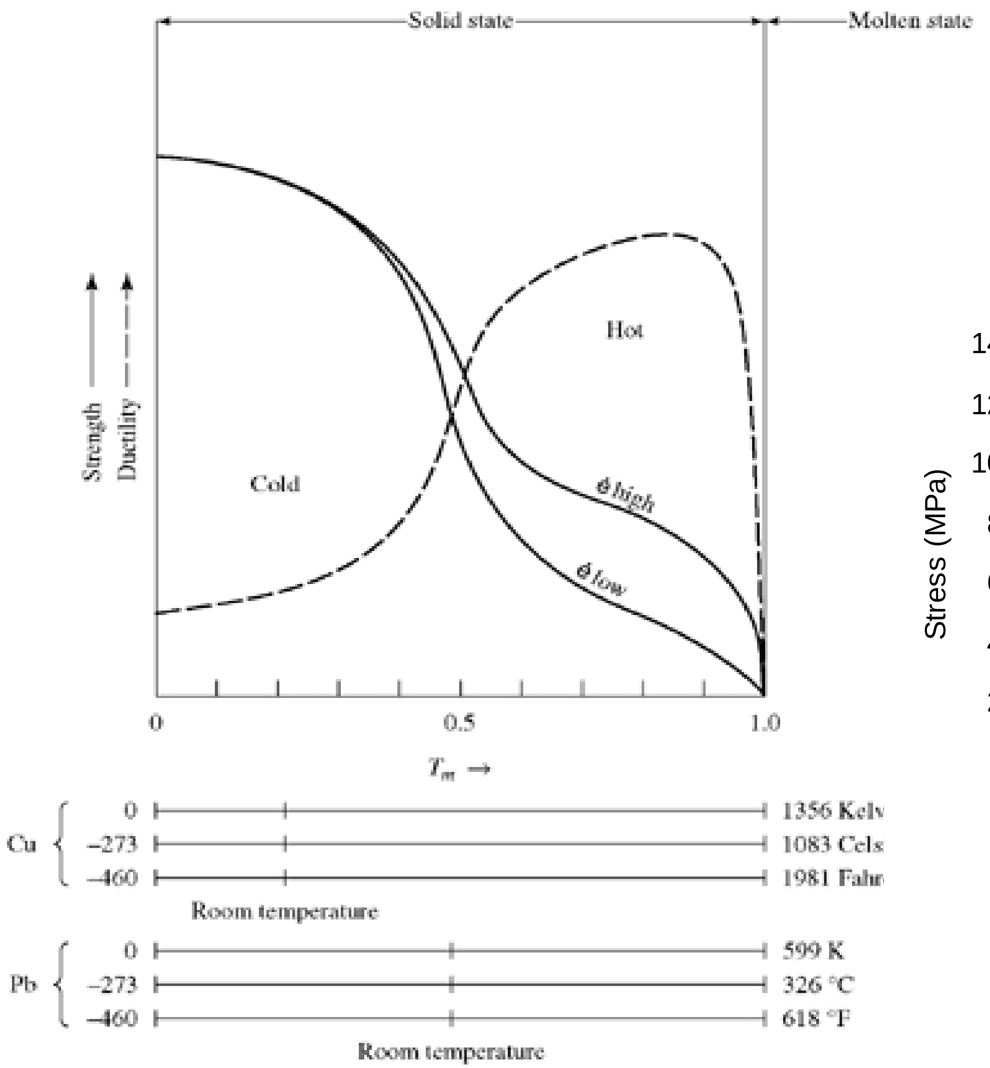
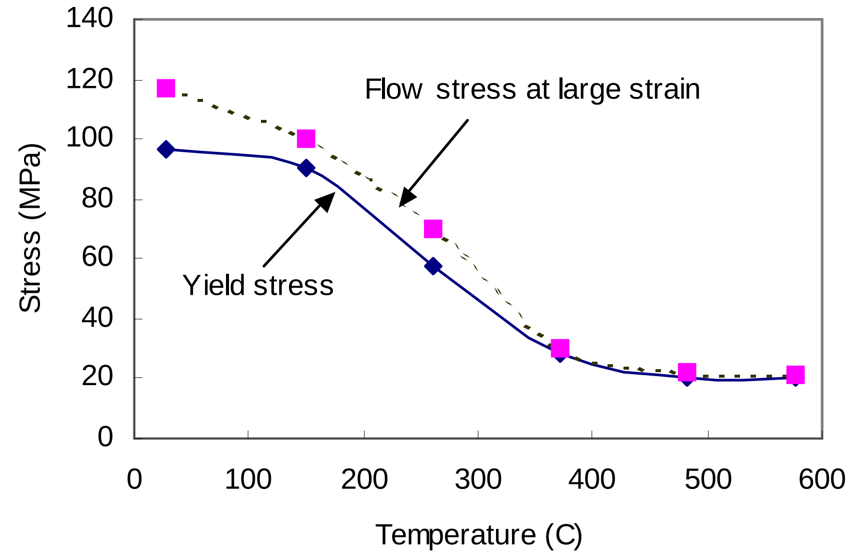


figure 4.14

High-Temperature Properties



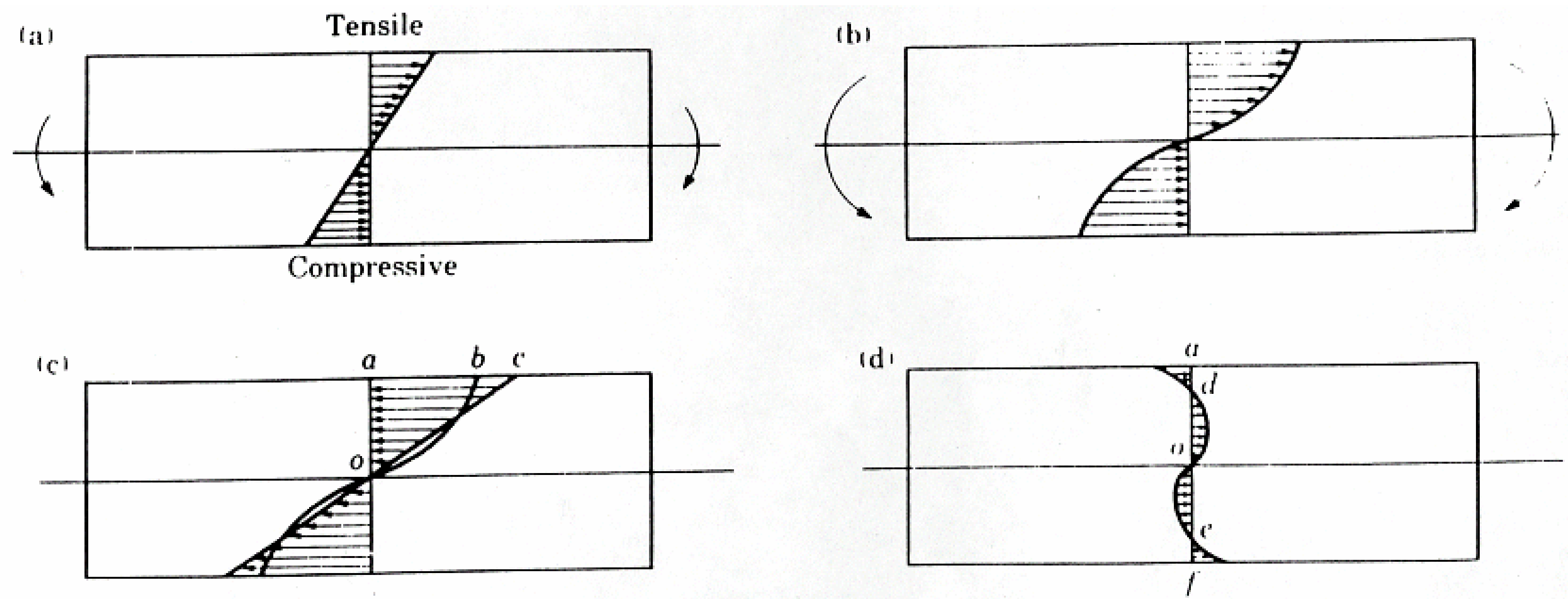
Homologous temperature



- High temperature property of AA5754

Residual Stresses

- When a part is subjected to deformation that is not uniform throughout, it develops residual stresses. These are stresses that remain within the part after it has been formed and has had all external forces removed.



- Often residual stresses are caused by plastic deformation, because only elastic strain can be recovered and plastic strain cannot be recovered after the external forces are removed.

Effects of Residual Stresses

- Spring back, distortion, etc.

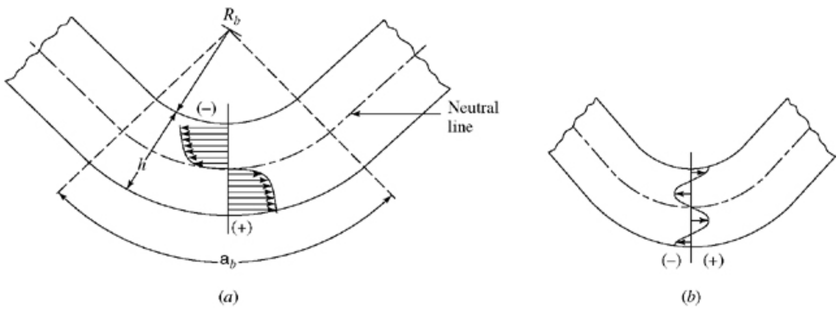
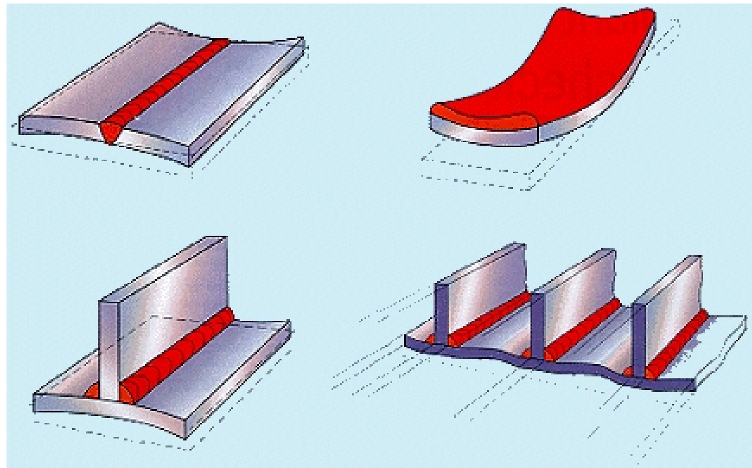


figure 10.11



- Increased fatigue strength
  - Shot peening process

Other Properties of Materials

- Physical properties
  - Density
  - Friction
  - Wear
  - Lubrication
  - Electrical properties, magnetic properties
  - Thermal properties
- Chemical properties

ASM Handbooks
Metal's Handbook
etc.

MatWeb, the **FREE** materials information database with data on **26,412 materials** including metals, plastics, ceramics, and composites.

http://www.matweb.com/