Elements of Materials Science and Engineering

Chapter 6 Mechanical Testing and Properties

6.1 Introduction

- Tensile Strength → Tensile Test
- Flexural Strength → Bend Test for brittle materials
- Hardness → Hardness Test
- Toughness → Impact Test
- Fatigue Life → Fatigue Test
- Creep rate → Creep Test

6-2 The Tensile Test: Use of the Stress-Strain Diagram

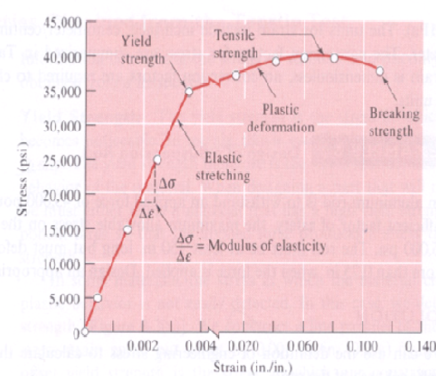

FIGURE 6-2 The stress-strain curve for an aluminum alloy from Table 6-1.

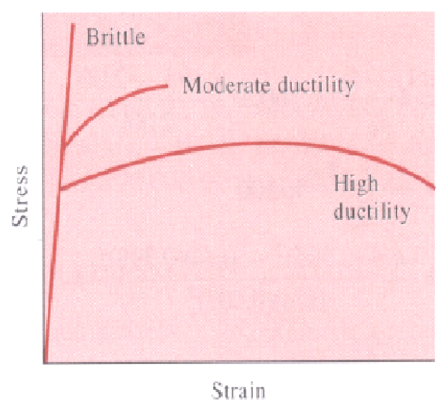

FIGURE 6-7 The stress-strain behavior of brittle materials compared with that of more ductile materials.

Chapter 6 Mechanical Testing and Properties

6.2 Tensile Test

$$\text{Engineering stress} = \sigma = \frac{F}{A_0}$$

$$\text{Engineering strain} = \varepsilon = \frac{l - l_0}{l_0}$$

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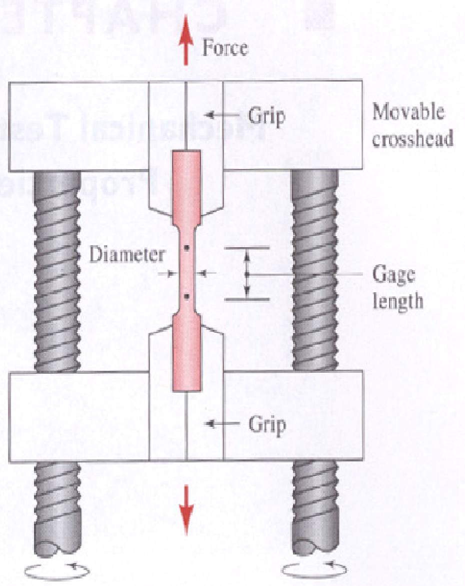

FIGURE 6-1 A unidirectional force is applied to a specimen in the tensile test by means of the moveable crosshead.

TABLE 6-1 The results of a tensile test of a 0.505-in. diameter aluminum alloy test bar

Measured		Calculated	
Load (lb)	Gage Length (in.)	Stress (psi)	Strain (in./in.)
0	2.000	0	0
1000	2.001	5,000	0.0005
3000	2.003	15,000	0.0015
5000	2.005	25,000	0.0025
7000	2.007	35,000	0.0035
7500	2.030	37,500	0.0150
7900	2.080	39,500	0.0400
8000 (maximum load)	2.120	40,000	0.0600
7950	2.160	39,700	0.0800
7600 (fracture)	2.205	38,000	0.1025

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6.2-3 Tensile Test & the properties obtained from the Tensile Test

6-2 The Tensile Test: Use of the Stress-Strain Diagram

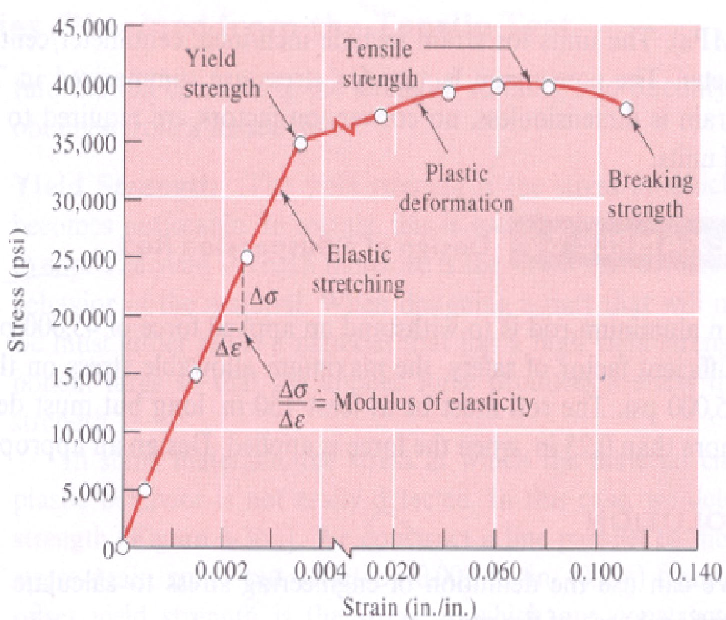

FIGURE 6-2 The stress-strain curve for an aluminum alloy from Table 6-1.

$$\text{Engineering stress} = \sigma = \frac{F}{A_0}$$

$$\text{Engineering strain} = \varepsilon = \frac{l - l_0}{l_0}$$

TABLE 6-2 Units and conversion factors

1 pound (lb) = 4.448 newtons (N)
1 psi = pounds per square inch
1 MPa = megapascal = meganewtons per square meter (MN/m^2) = newtons per square millimeter (N/mm^2)
1 GPa = 1000 MPa = gigapascal
1 ksi = 1000 psi = 6.895 MPa
1 psi = 0.006895 MPa
1 MPa = 0.145 ksi = 145 psi

•**Note: in Metals, Yield stress** is usually the stress required **for dislocations to slip**.

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6.2-3 Tensile Test & the properties obtained from the Tensile Test

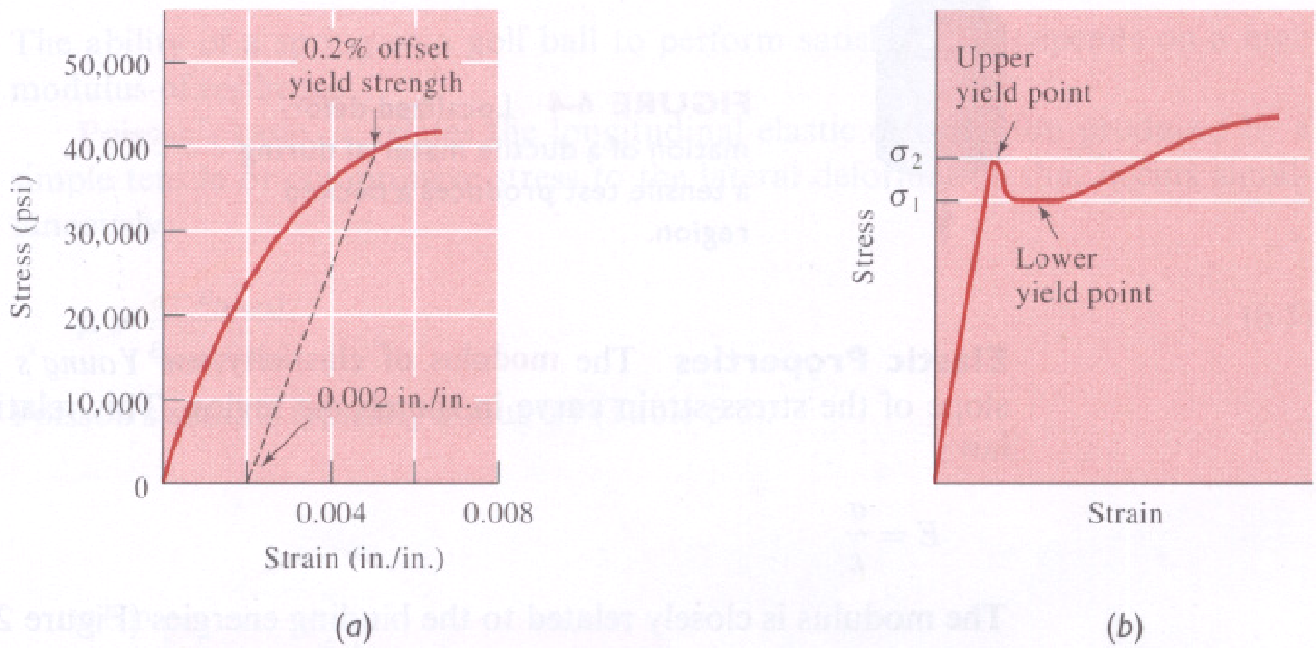

FIGURE 6-3 (a) Determining the 0.2% offset yield strength in gray cast iron and (b) upper and lower yield point behavior in a low-carbon steel.

Note: **Young's modulus is a measure of the stiffness of the material**.

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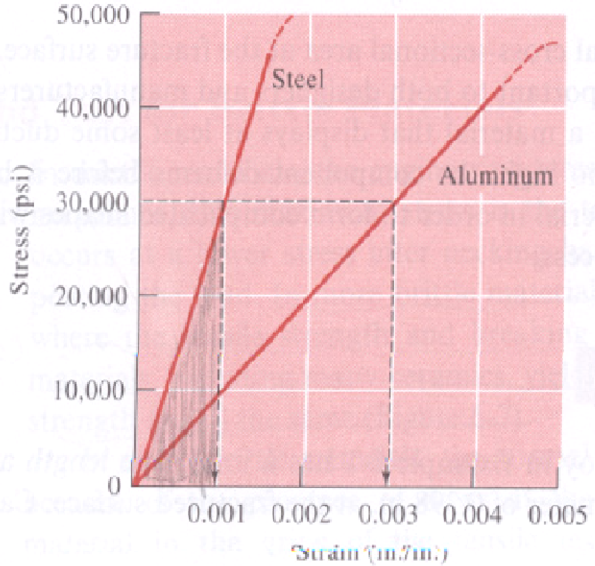
6.2-3 Tensile Test & the properties obtained from the Tensile Test

E_r=1/2(yield strength)(strain at yielding)

$$Poisson's\ ratio : \mu = \frac{-\varepsilon_{lateral}}{\varepsilon_{longitudinal}}$$



stiffness: steel > Alum

FIGURE 6-5 Comparison of the elastic behavior of steel and aluminum.

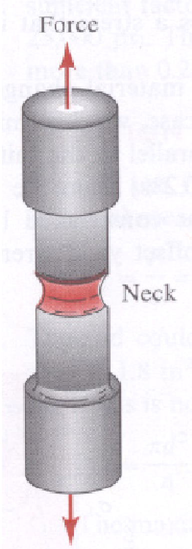


FIGURE 6-4 Localized deformation of a ductile material during a tensile test produces a necked region.

Chapter 6 Mechanical Testing and Properties

6.2-3 Tensile Test & the properties obtained from the Tensile Test

E_r=1/2(yield strength)(strain at yielding)

$$Poisson's\ ratio : \mu = \frac{-\varepsilon_{lateral}}{\varepsilon_{longitudinal}}$$

TABLE 6-3 Elastic properties and melting temperature (T_m) of selected materials

Material	T_m (°C)	E (psi)	E (GPa)	μ
Pb	327	2.0×10^6	(13.8)	0.45
Mg	650	6.5×10^6	(44.8)	0.29
Al	660	10.0×10^6	(69.0)	0.33
Cu	1085	18.1×10^6	(124.8)	0.36
Fe	1538	30.0×10^6	(206.9)	0.27
W	3410	59.2×10^6	(408.3)	0.28
Al_2O_3	2020	55.0×10^6	(379.3)	0.26
Si_3N_4		44.0×10^6	(303.4)	0.24

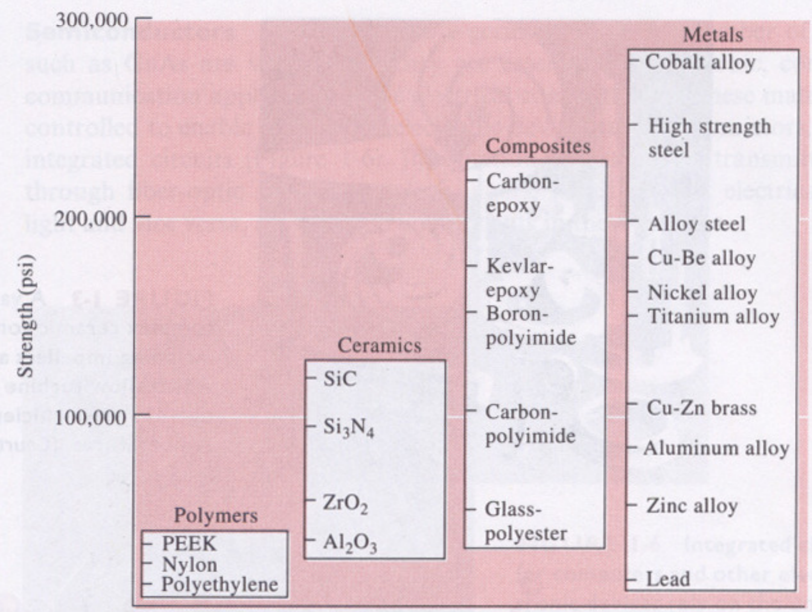


FIGURE 1-1 Representative strengths of various categories of materials.

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6.2-3 Tensile Test & the properties obtained from the Tensile Test

Effect of Temperature

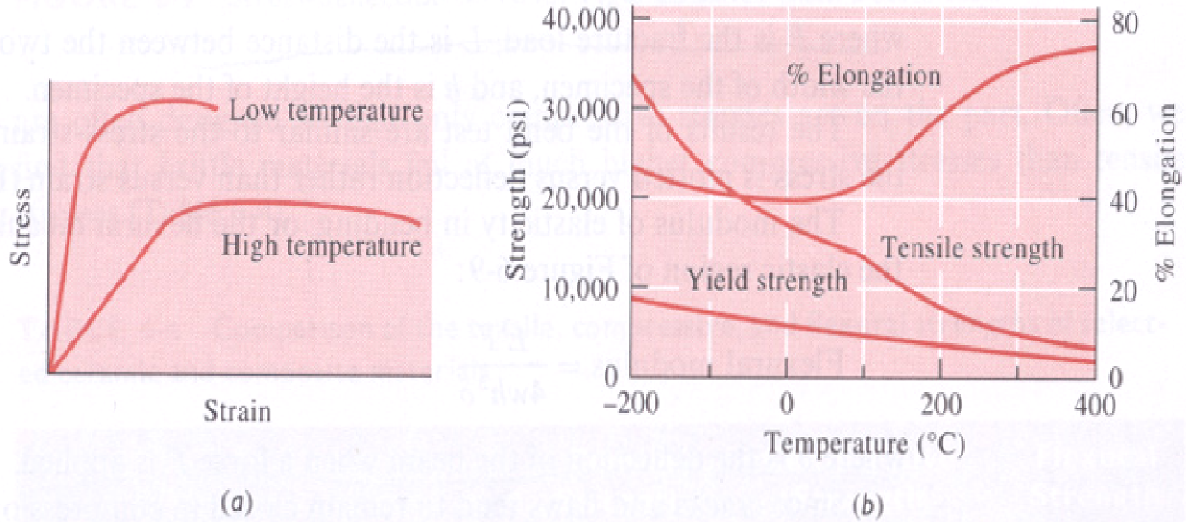

FIGURE 6-6 The effect of temperature (a) on the stress-strain curve and (b) on the tensile properties of an aluminum alloy.

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6.4 The Bend Test for Brittle Material

•Due to **the presence of flaw at the surface,** in many brittle materials, the normal tensile test cannot easily be performed.

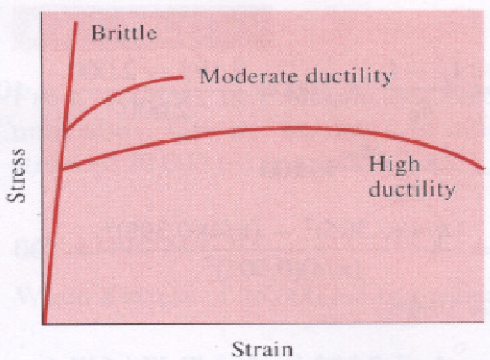

FIGURE 6-7 The stress-strain behavior of brittle materials compared with that of more ductile materials.

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6.4 The Bend Test for Brittle Material

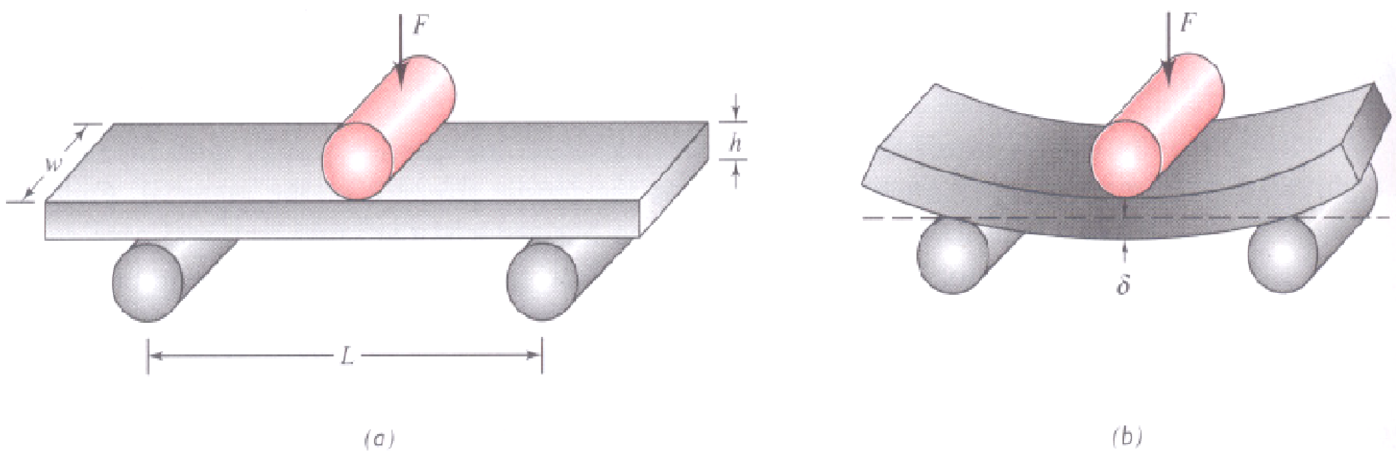

FIGURE 6-8 (a) The bend test often used for measuring the strength of brittle materials, and (b) the deflection δ obtained by bending.

$$\text{Flexural strength} = \frac{3FL}{2wh^2}, \quad \text{where } F \text{ is fracture Load.}$$

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6.4 The Bend Test for Brittle Material

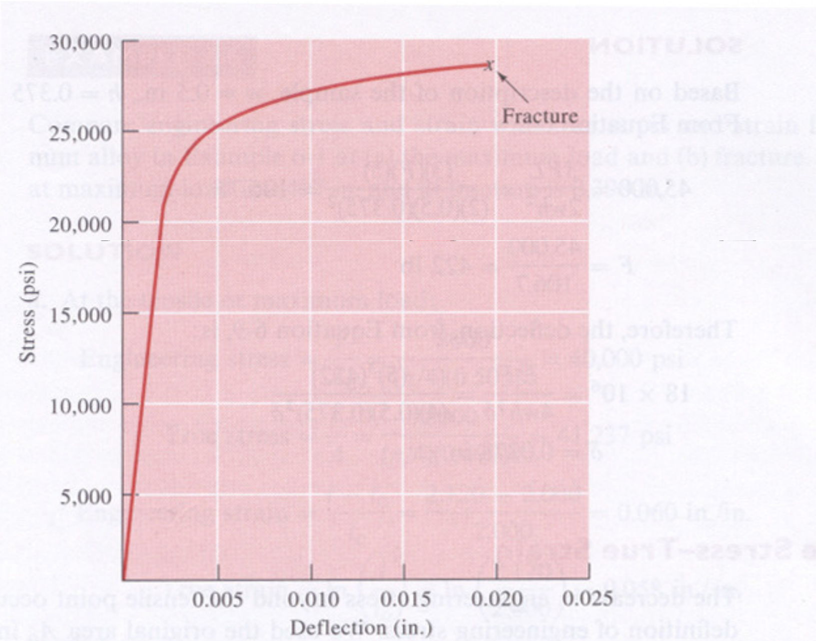
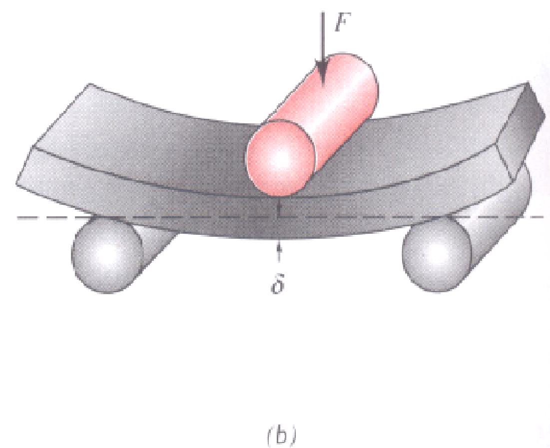


FIGURE 6-9 Stress-deflection curve for MgO obtained from a bend test.



en used for measuring the strength of brittle
tained by bending.

where δ is deflection

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6.5 True Stress-True Strain

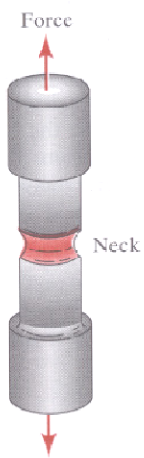

FIGURE 6-4 Localized deformation of a ductile material during a tensile test produces a necked region.

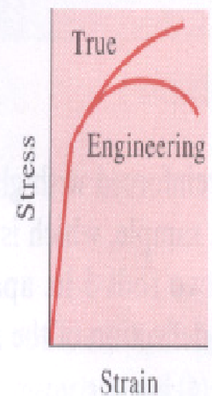

FIGURE 6-10 The relationship between the true stress–true strain diagram and the engineering stress–engineering strain diagram.

$$\text{Engineering stress} = \sigma = \frac{F}{A_0}$$

$$\text{Engineering strain} = \varepsilon = \frac{l - l_0}{l_0}$$

$$\text{True stress} = \sigma_t = \frac{F}{A'}$$

$$\text{True strain} = \varepsilon_t = \int_{l_0}^{l'} \frac{dl}{l} = \ln\left(\frac{l'}{l_0}\right) = \ln\left(\frac{A_0}{A'}\right)$$

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6.6 The Hardness Test

$$\text{Brinell Hardness: HB} = \frac{F}{(\pi/2)D(D-\sqrt{D^2 - D_i^2})}$$

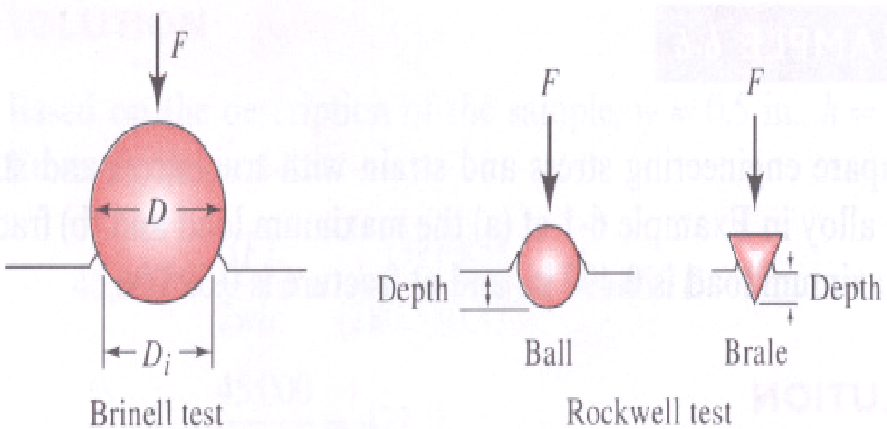

FIGURE 6-11 The Brinell and Rockwell hardness tests.

TABLE 6-5 Comparison of typical hardness tests

Test	Indentor	Load	Application
Brinell	10-mm ball	3000 kg	Cast iron and steel
Brinell	10-mm ball	500 kg	Nonferrous alloys
Rockwell *A*	Brale	60 kg	Very hard materials
Rockwell *B*	1/16-in. ball	100 kg	Brass, low-strength steel
Rockwell *C*	Brale	150 kg	High-strength steel
Rockwell *D*	Brale	100 kg	High-strength steel
Rockwell *E*	1/8-in. ball	100 kg	Very soft materials
Rockwell *F*	1/16-in. ball	60 kg	Aluminum, soft materials
Vickers	Diamond pyramid	10 kg	Hard materials
Knoop	Diamond pyramid	500 g	All materials

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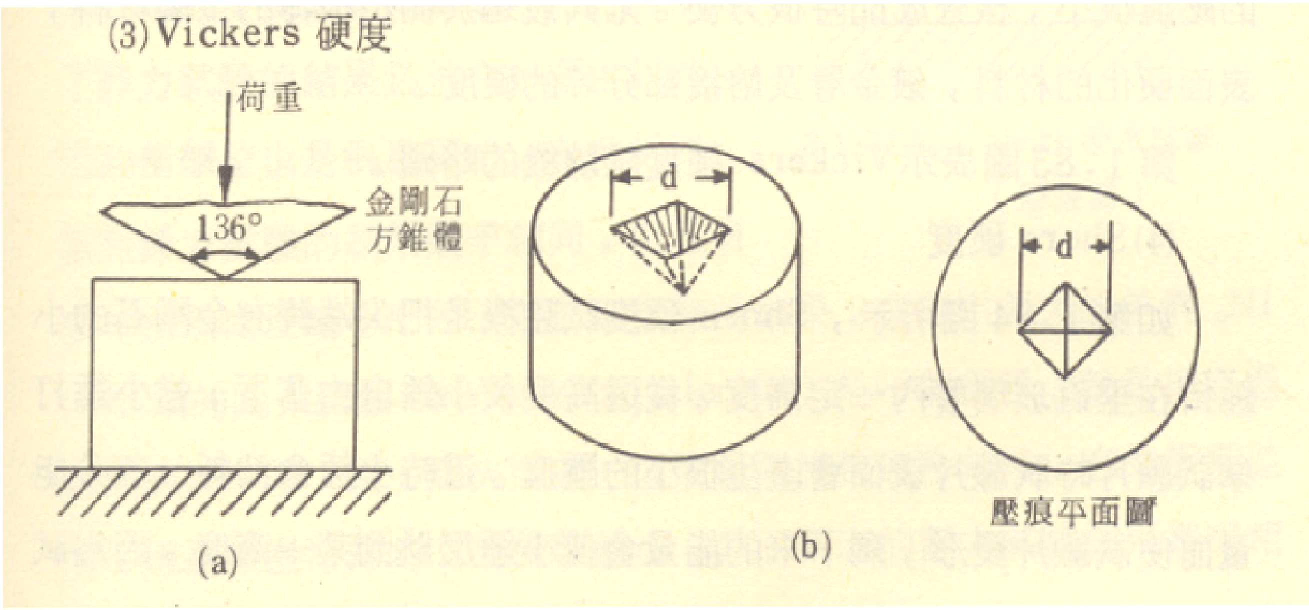
6.6 The Hardness Test



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6.7 The Impact Test ➔ impact strength

To evaluate the brittleness of a material subjected to a sudden blow.

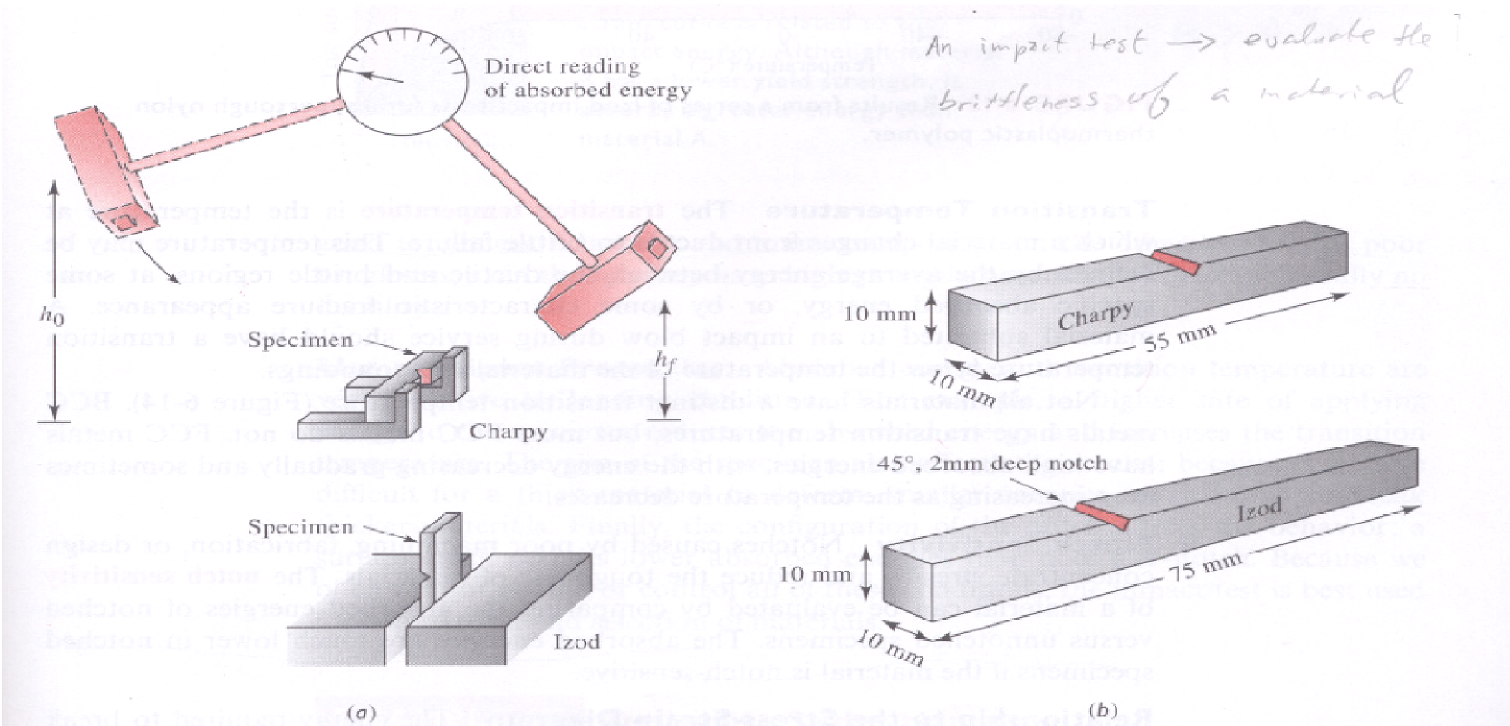

FIGURE 6-12 The impact test: (a) the Charpy and Izod tests, and (b) dimensions of typical specimens.

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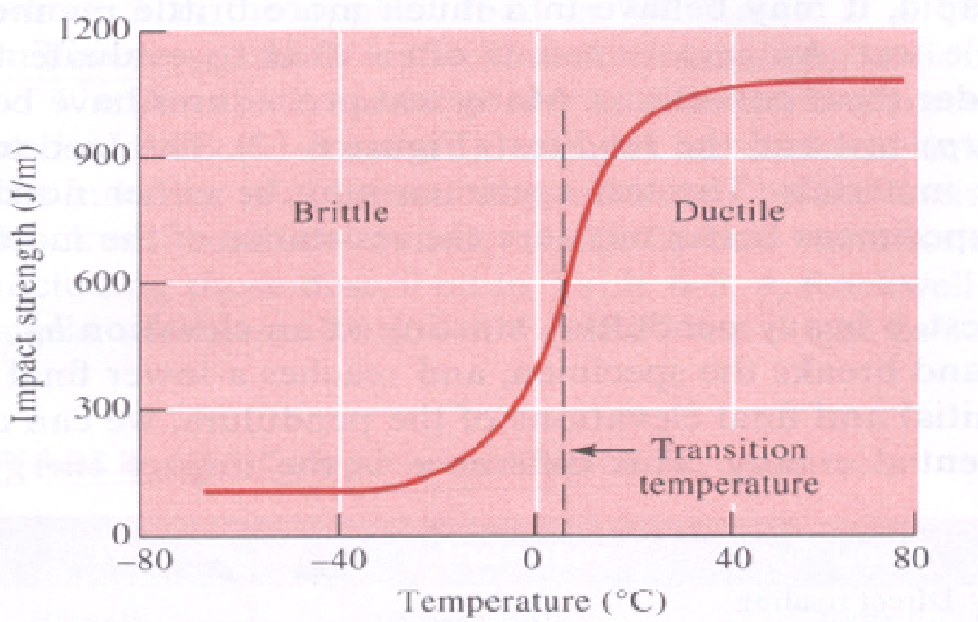
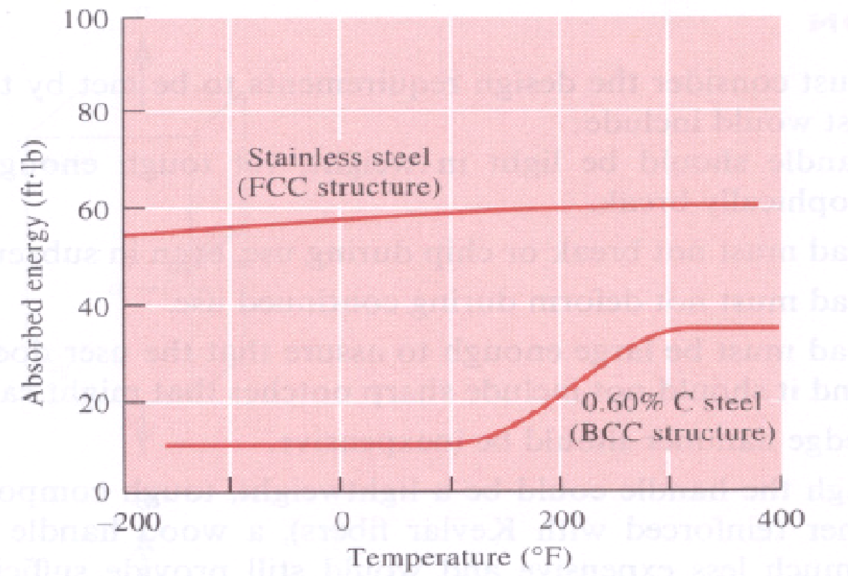
6.7 The Impact Test ➔ impact strength

Impact strength vs. Temperature





Note: BCC metals have transition temperature, but most FCC metals do not.

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6.7 The Impact Test ➔ impact strength

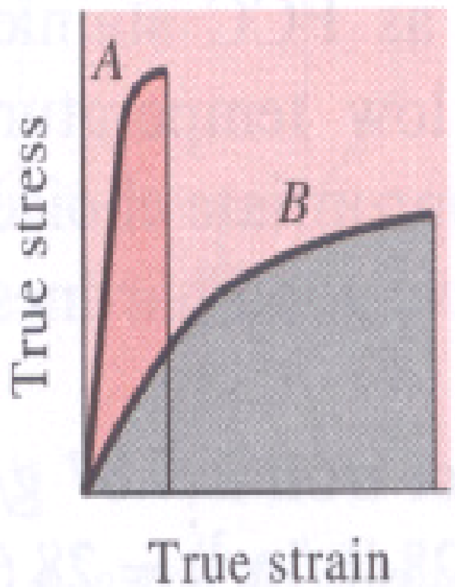

FIGURE 6-15 The area contained within the true stress–true strain curve is related to the impact energy. Although material *B* has a lower yield strength, it absorbs a greater energy than material *A*.

Yield Strength: A > B Impact Strength: B > A

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6.11 The Fatigue Test → Fatigue Life, Fatigue Strength

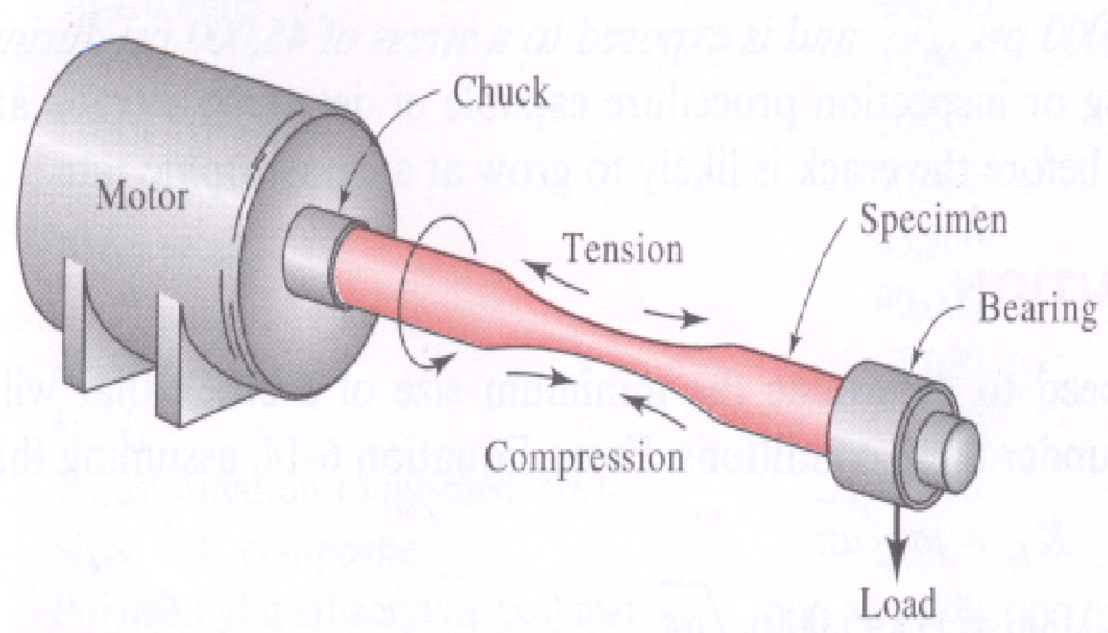

FIGURE 6-18 The rotating cantilever beam fatigue test.

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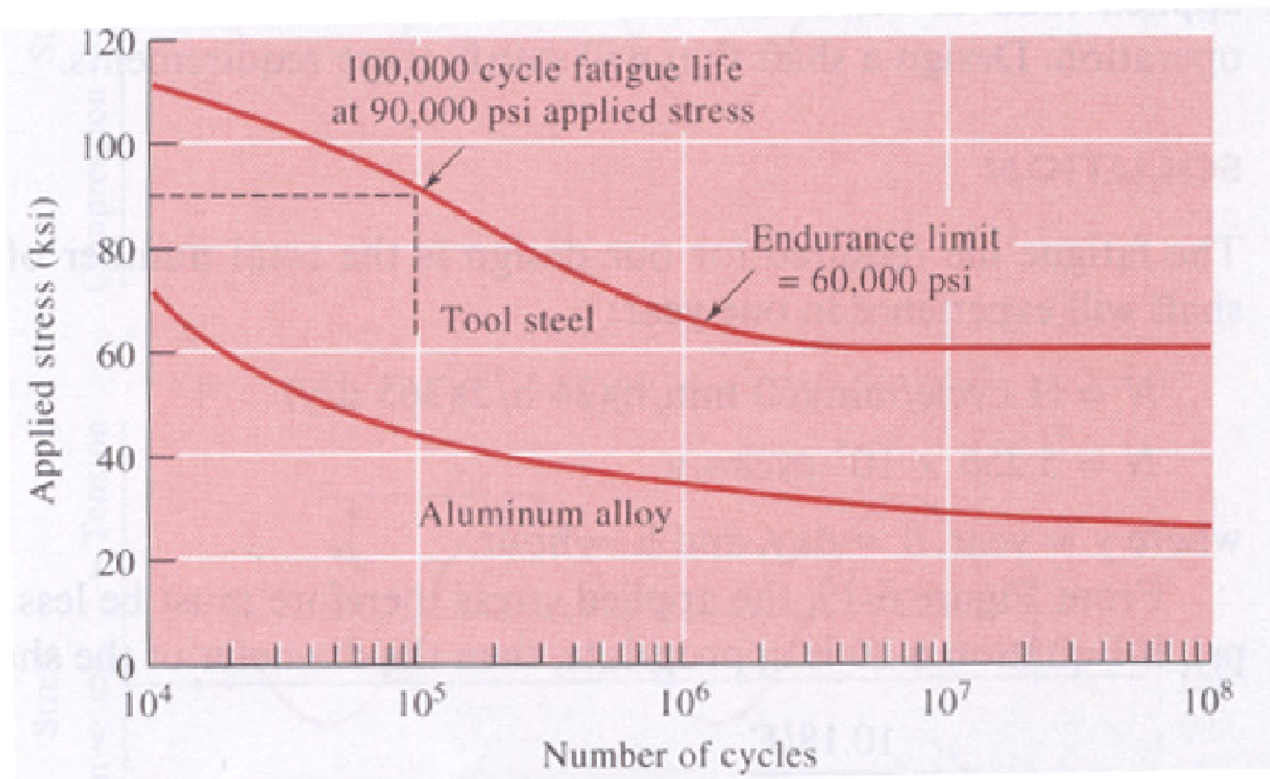
6.11 The Fatigue Test

S-N curve



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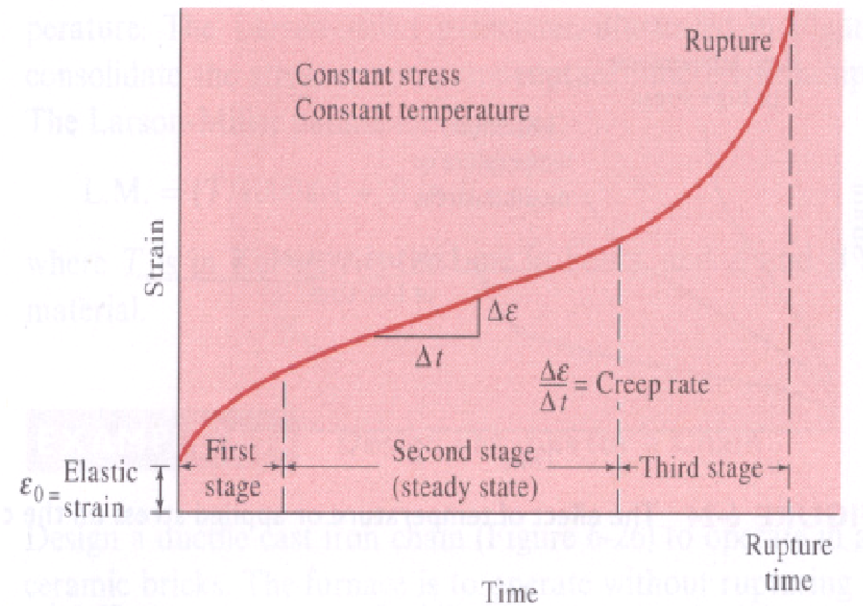
6.14 The Creep Test:

Apply stress to a material at an elevated temperature



Creep: Plastic deformation at high temperature

- **a typical creep curve showing the strain produced as a function of time for a constant stress and temperature.**

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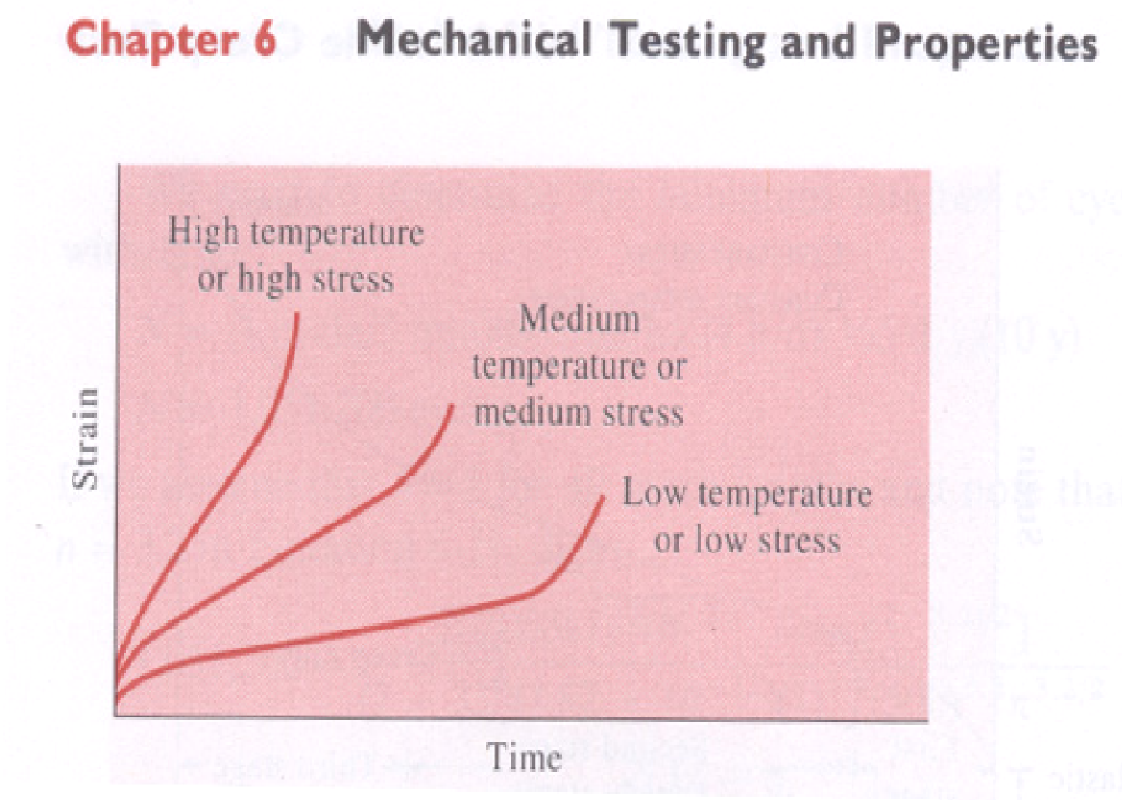
6.14 The Creep Test:



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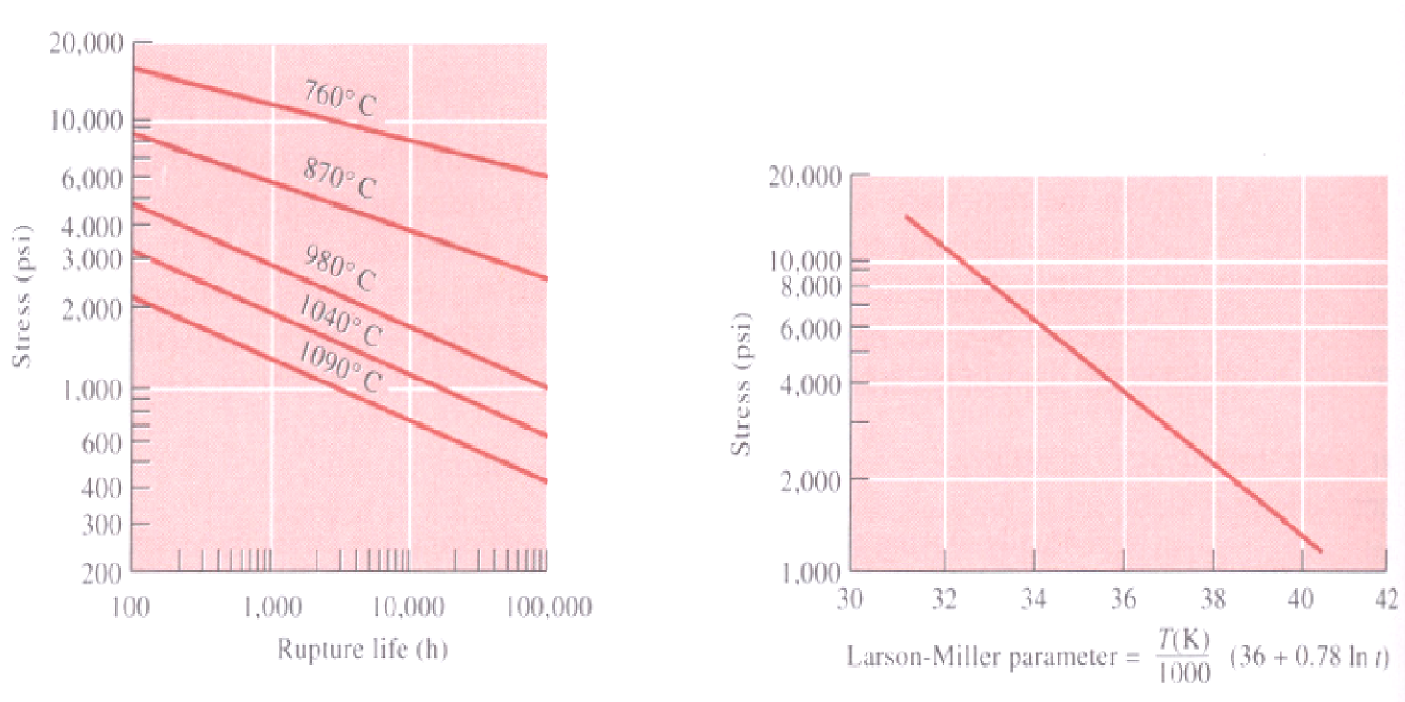
6.15 Use of Creep Data



(a) Stress-rupture curves for an iron-chromium-nickel alloy

(b) The Larson-Miller parameter for ductile cast iron