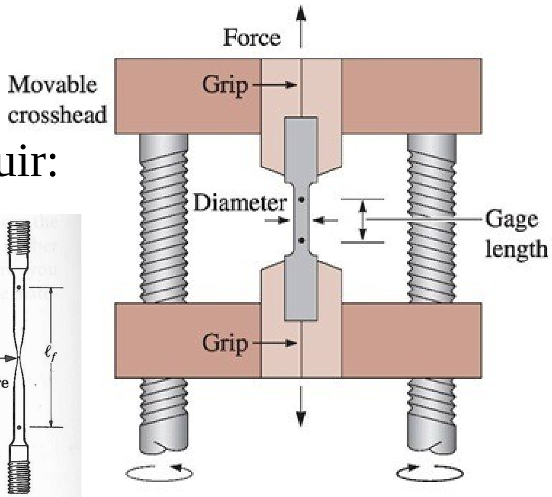
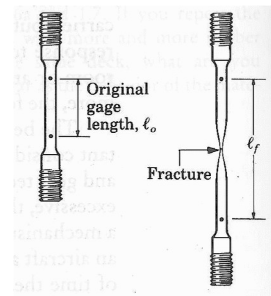
Ensayo de Tensión: Diagrama Esfuerzo - Deformación.

El Ensayo de Tensión mide la resistencia de un material a una fuerza estática o gradualmente aplicada.



De la **Curva Esfuerzo - Deformación Ingenieril** se puede conseguir:

- Esfuerzo de Cedencia
- Esfuerzo Máximo Tensil o Resistencia a la Tensión.
- Esfuerzo de Ruptura.
- Módulo de Elasticidad o Módulo de Young.
- Módulo de Resilencia.
- Tenacidad.
- Ductilidad.
- Relación de Poisson



$$\sigma = \frac{F}{A_0} \qquad \varepsilon = \frac{l - l_0}{l_0}$$

TABLE 6-1 ■ *The results of a tensile test of a 1.263 cm diameter aluminum alloy test bar, initial length (l_0) = 5 cm*

		Calculated	
Load (N)	Δl (cm)	Stress (MPa)	Strain (cm/cm)
0	0.000	0	0
4450	0.0025	35.5	0.0005
13350	0.0075	106.5	0.0015
22240	0.0125	177.5	0.0025
31150	0.0175	248.6	0.0035
33360	0.075	266.2	0.0150
35140	0.2	280.4	0.0400
35580 (maximum load)	0.3	284	0.0600
35360	0.4	282.2	0.0800
33800 (fracture)	0.5125	269.8	0.1025

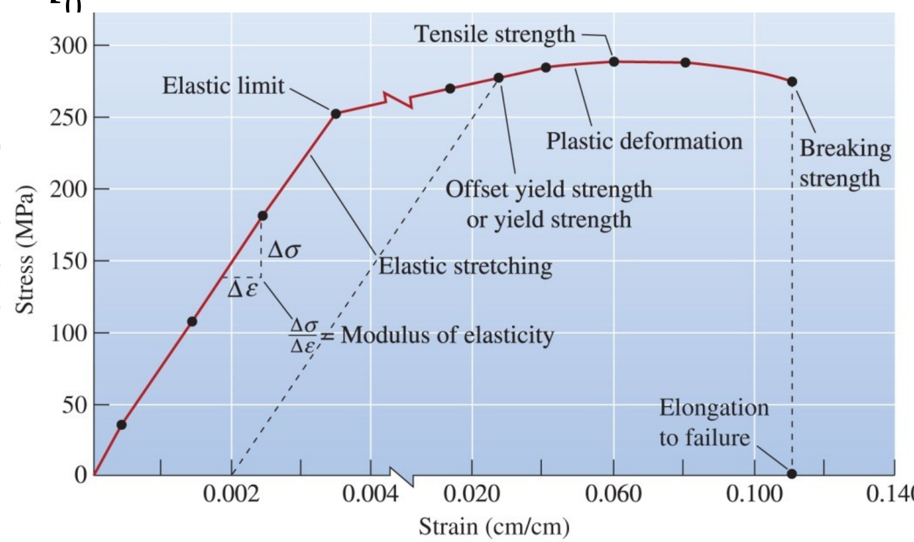


Figure 6-7 The engineering stress–strain curve for an aluminum alloy from Table 6-1.

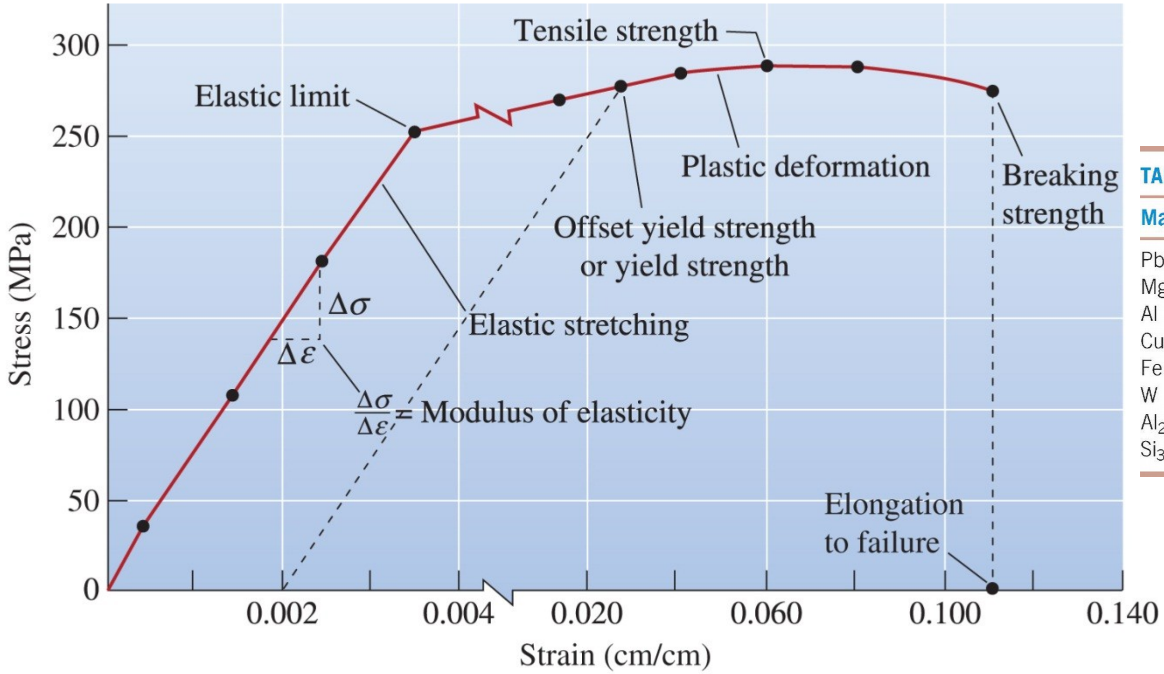


Figure 6-7 The engineering stress–strain curve for an aluminum alloy from Table 6-1.

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

Material	T_m (°C)	E (psi)	Poisson's ratio (ν)
Pb	327	2.0×10^6	0.45
Mg	650	6.5×10^6	0.29
Al	660	10.0×10^6	0.33
Cu	1085	18.1×10^6	0.36
Fe	1538	30.0×10^6	0.27
W	3410	59.2×10^6	0.28
Al_2O_3	2020	55.0×10^6	0.26
Si_3N_4		44.0×10^6	0.24

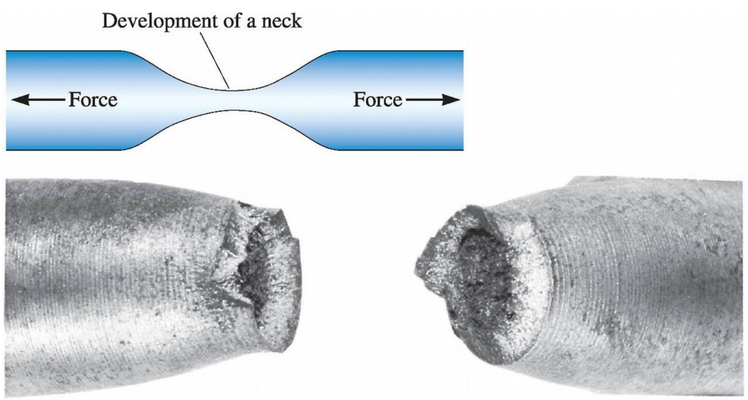


Figure 6-9 Localized deformation of a ductile material during a tensile test produces a necked region. The micrograph shows a necked region in a fractured sample. (*This article was published in Materials Principles and Practice, Charles Newey and Graham Weaver (Eds.), Figure 6.9, p. 300, Coyright Open University.*)

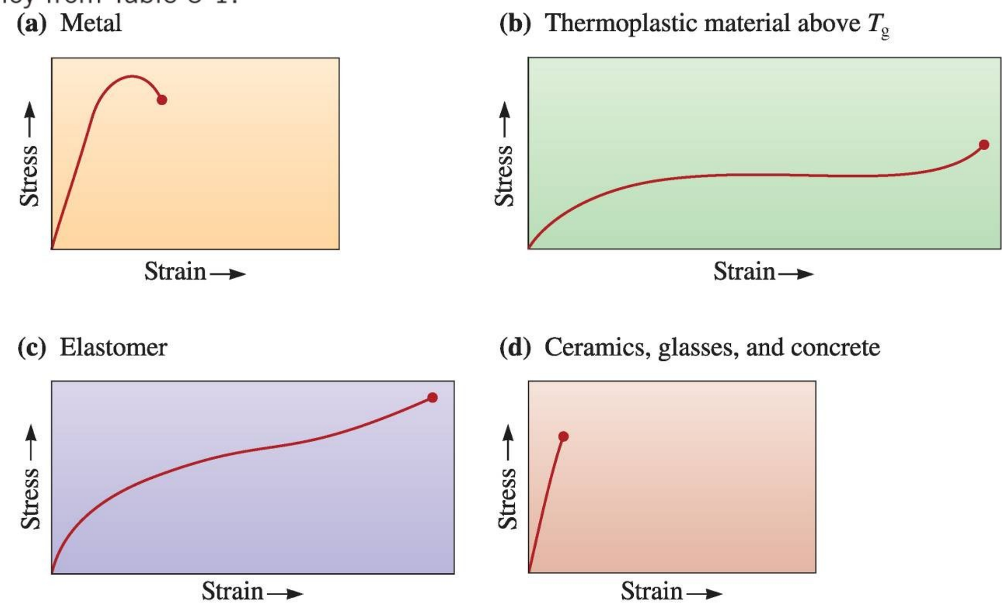
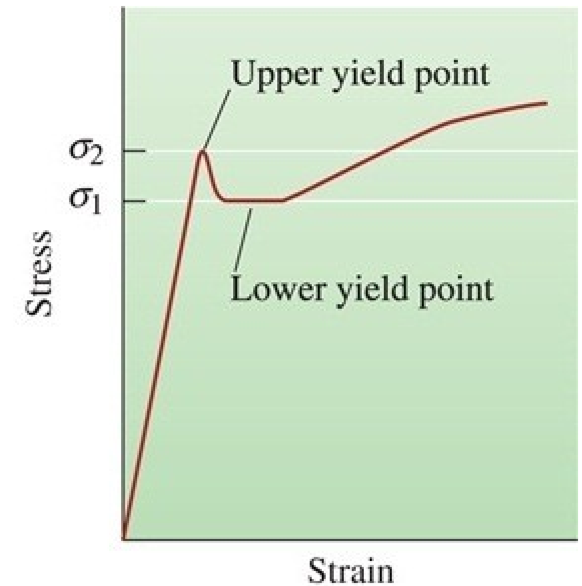


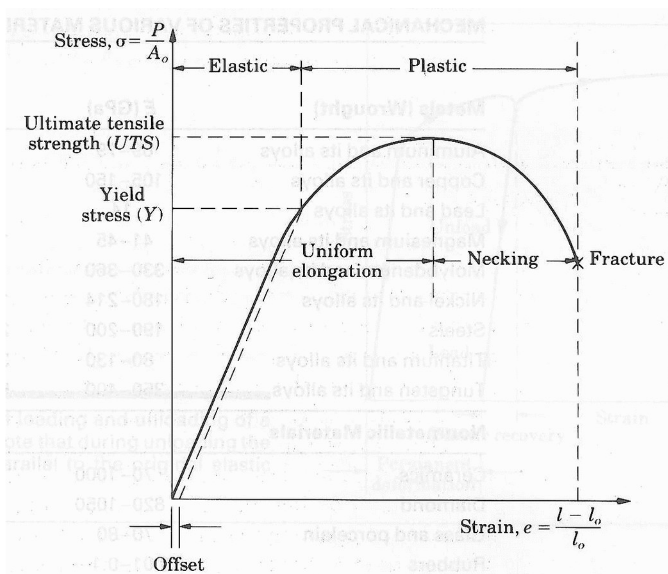
Figure 6-6 Tensile stress–strain curves for different materials. Note that these are *qualitative*. The magnitudes of the stresses and strains should not be compared.

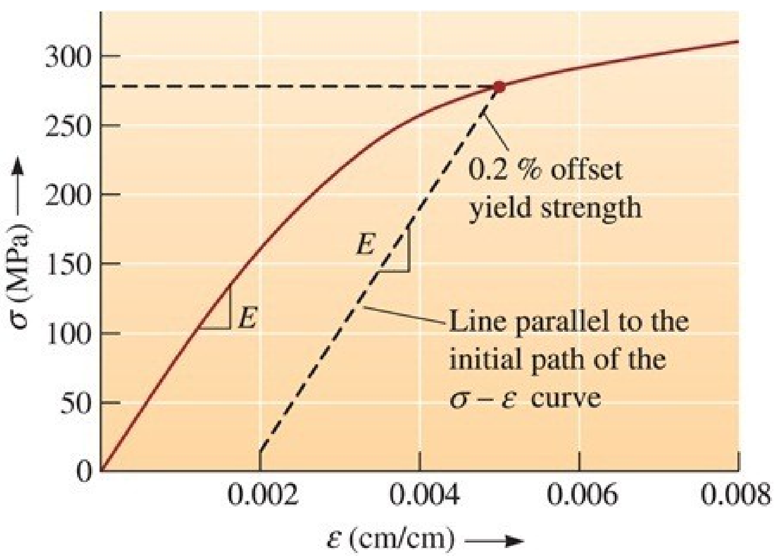
Esfuerzo de Cedencia o de Tracción (σ_y)es el esfuerzo que divide los comportamientos elástico y plástico del material.



Esfuerzo Máximo Tensil o Resistencia a la Tensión (σ_{max} o σ_{UTS}) es el esfuerzo obtenido con la fuerza más alta conseguida, a partir de aquí se produce el encuellamiento.

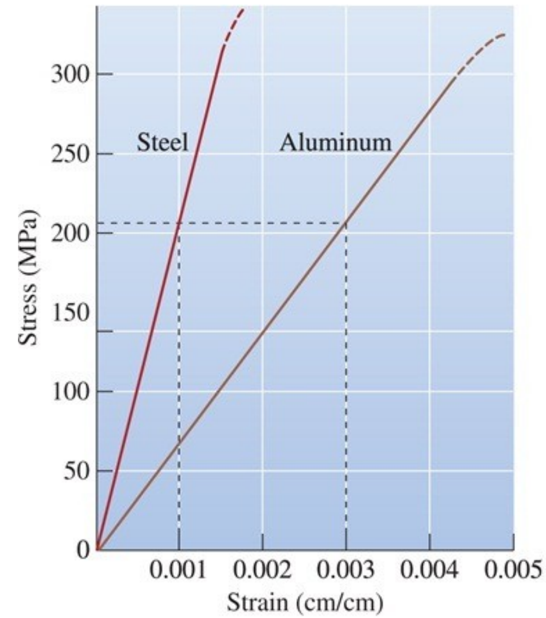
Esfuerzo de Ruptura o Último (σ_{ult}) es el esfuerzo al cual sucede la fractura catastrófica del material, es menor que el σ_{UTS} en la curva de esfuerzo-deformación ingenieril.





Módulo de Elasticidad o de Young (E)es la pendiente de la curva esfuerzo-deformación en la zona elástica.

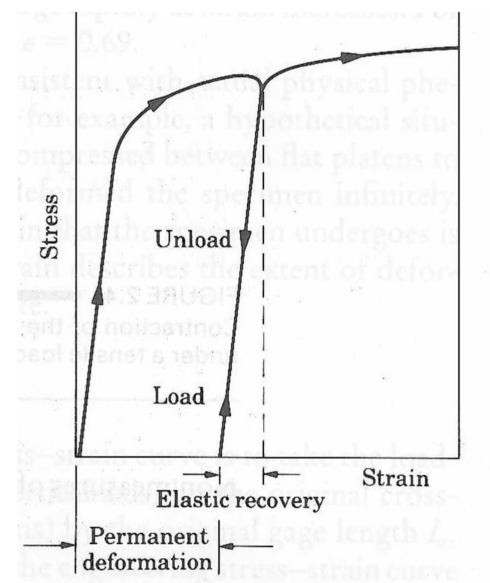
$$E = \frac{\sigma_y}{\varepsilon_y}$$



Módulo de Resilencia (E_r)es la energía elástica que un material absorbe durante la aplicación de una carga que lo deforma elásticamente y su capacidad para devolver dicha energía cuando se retira la carga.

$$E_r = \frac{\sigma_y \varepsilon_y}{2}$$

Tenacidad (U_T)es la energía total que absorbe el material antes de romperse, es el área total debajo de la curva esfuerzo-deformación. (ensayo de impacto).



Relación de Poisson (μ)relaciona la deformación elástica longitudinal producida por un esfuerzo simple a tensión o compresión, con la deformación lateral que ocurre simultáneamente (aprox. 0.3).

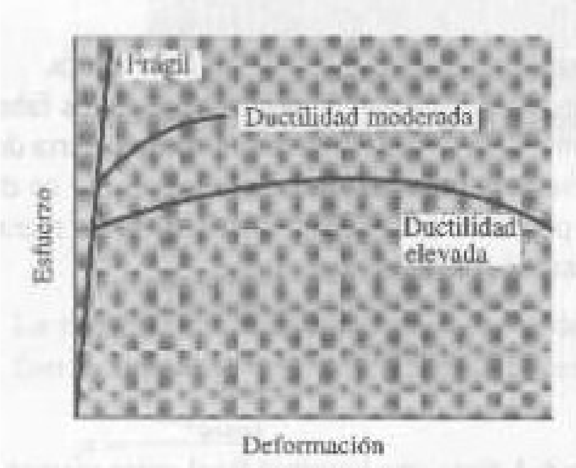
$$\mu = \frac{-\ \varepsilon_{lateral}}{\varepsilon_{longitudinal}}$$

TABLA 6-3 Propiedades elásticas y temperaturas de fusión (T_m) de materiales seleccionados

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

Ductilidad mide el grado de deformación que puede soportar un material sin romperse. Se mide mediante % de Elongación (%E) o mediante el % en Reducción de Área (%RA).

$$\%E = \frac{l_f - l_0}{l_0} \times 100 \qquad \%RA = \frac{A_0 - A_f}{A_0} \times 100$$



Efecto de la Temperatura, las propiedades a la tensión dependen de la temperatura.

La Curva Esfuerzo Real - Deformación Real, se consigue debido a que se toma como referencia el área instantánea.

$$\sigma_r = k\varepsilon_r^n$$

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

$$\sigma_r = \frac{F}{A_0}\left(\varepsilon_n + 1\right)$$

$$\varepsilon_r = \ln\left(\frac{l}{l_0}\right) = \ln\left(\varepsilon_n + 1\right)$$

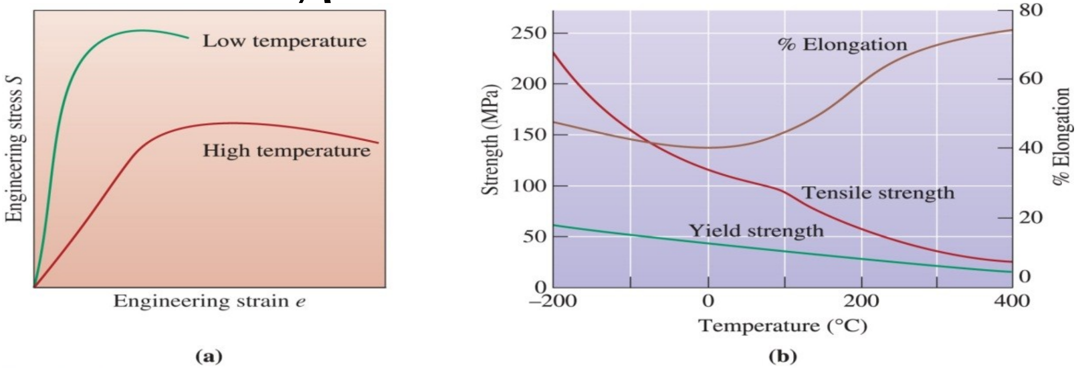
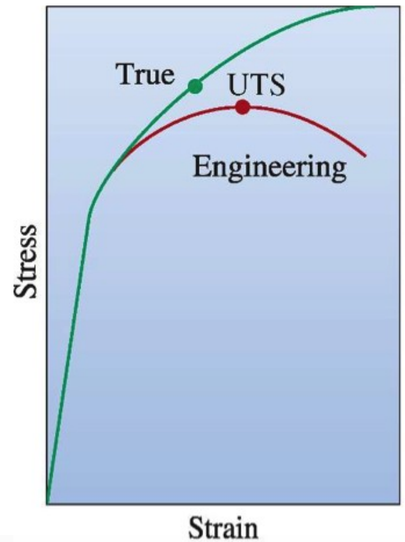


Figure 6-13 The effect of temperature (a) on the stress–strain curve and (b) on the tensile properties of an aluminum alloy.

TABLE 2.2
TYPICAL VALUES FOR *K* AND *n* AT ROOM TEMPERATURE

	K (MPa)	*n*
Aluminum		
1100–O	180	0.20
2024–T4	690	0.16
6061–O	205	0.20
6061–T6	410	0.05
7075–O	400	0.17
Brass		
70–30, annealed	900	0.49
85–15, cold-rolled	580	0.34
Cobalt-base alloy, heat-treated	2070	0.50
Copper, annealed	315	0.54
Steel		
Low-C annealed	530	0.26
4135 annealed	1015	0.17
4135 cold-rolled	1100	0.14
4340 annealed	640	0.15
304 stainless, annealed	1275	0.45
410 stainless, annealed	960	0.10



$$\sigma_r = k\varepsilon_r^n$$

$$\sigma_r = \frac{F}{A_0}\left(\varepsilon_n + 1\right)$$

$$\varepsilon_r = \ln\left(\frac{l}{l_0}\right) = \ln\left(\varepsilon_n + 1\right)$$

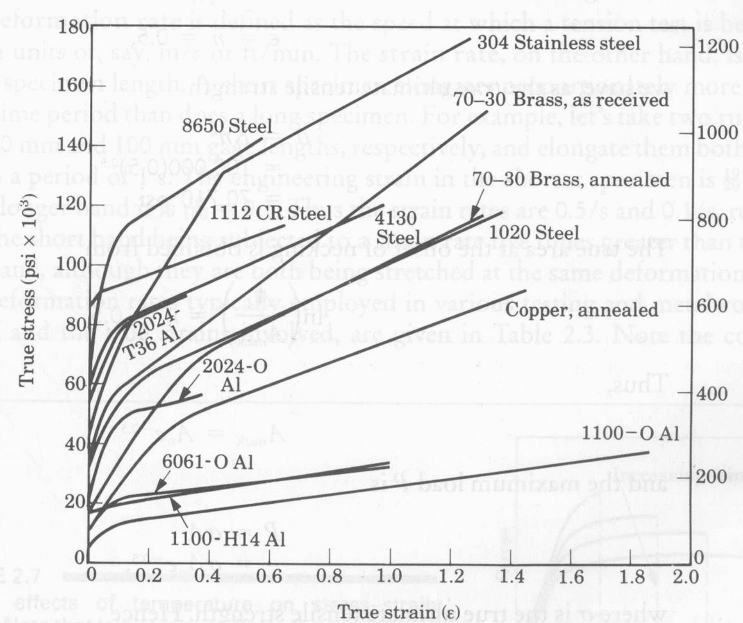


FIGURE 2.6
True stress–true strain curves in tension at room temperature for various metals. The curves start at a finite level of stress because the elastic regions have too steep a slope to be shown in this figure. Thus each curve starts at the yield stress, *Y*, of the material.

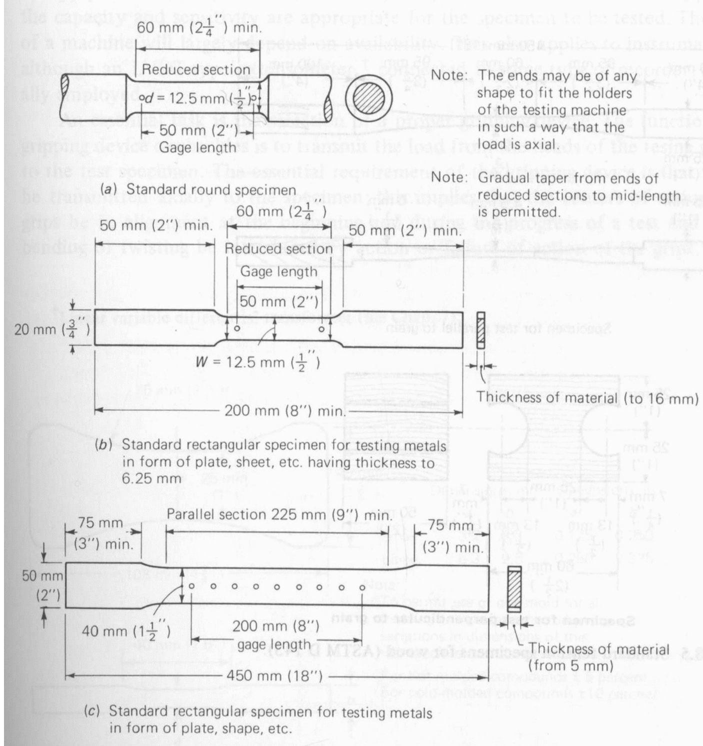


Figure 8.3 Standard (ductile) metal tension specimen (ASTM E 8).

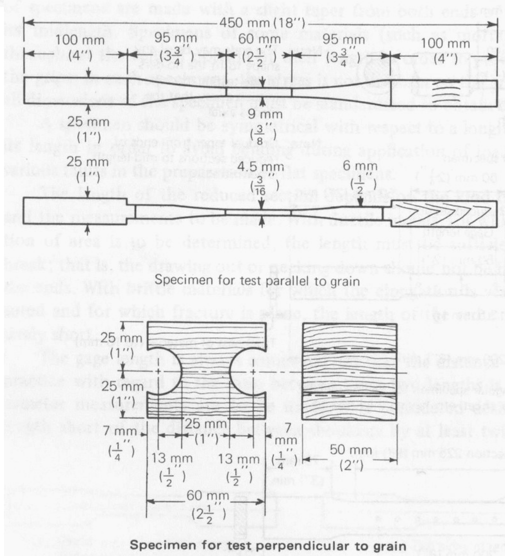


Figure 8.5 Standard tension specimens for wood (ASTM D 143).

TABLE 2.1
MECHANICAL PROPERTIES OF VARIOUS MATERIALS AT ROOM TEMPERATURE

Metals (Wrought)	*E* (GPa)	*Y* (MPa)	*UTS* (MPa)	Elongation in 50 mm (%)
Aluminum and its alloys	69–79	35–550	90–600	45–4
Copper and its alloys	105–150	76–1100	140–1310	65–3
Lead and its alloys	14	14	20–55	50–9
Magnesium and its alloys	41–45	130–305	240–380	21–5
Molybdenum and its alloys	330–360	80–2070	90–2340	40–30
Nickel and its alloys	180–214	105–1200	345–1450	60–5
Steels	190–200	205–1725	415–1750	65–2
Titanium and its alloys	80–130	344–1380	415–1450	25–7
Tungsten and its alloys	350–400	550–690	620–760	0
Nonmetallic Materials				
Ceramics	70–1000	—	140–2600	0
Diamond	820–1050	—	—	—
Glass and porcelain	70–80	—	140	0
Rubbers	0.01–0.1	—	—	
Thermoplastics	1.4–3.4	—	7–80	1000–5
Thermoplastics, reinforced	2–50	—	20–120	10–1
Thermosets	3.5–17	—	35–170	0
Boron fibers	380	—	3500	0
Carbon fibers	275–415	—	2000–3000	0
Glass fibers	73–85	—	3500–4600	0
Kevlar fibers	62–117	—	2800	0

Note: In the upper table the lowest values for *E*, *Y*, and *UTS* and the highest values for elongation are for pure metals. Multiply gigapascals (GPa) by 145,000 to obtain pounds per square in. (psi), megapascals (MPa) by 145 to obtain psi.

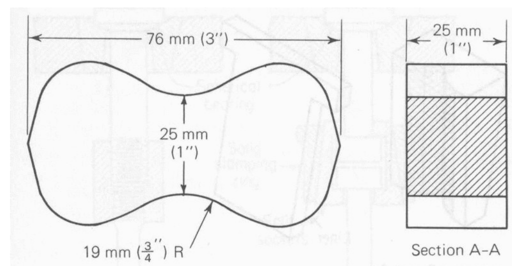


Figure 8.6 Standard tension specimen for portland cement mortar (ASTM 190).

TENSION TEST OF METAL — LOG SHEET

APPARATUS:
Machine: 250-kN Olsen UTM (No. 12)
Dial extensometer: Federal (No. 61), with multiplier of 2

TEST SPEED:
To yield strength: 1.25 mm/min
After yielding: 5.00 mm/min

SPECIMEN: Mild steel
Mark or ID: 618
Total length: 470 mm
Length between shoulders: 285 mm
Gage length: 200 mm
Number of divisions: 8
Diameter of ends: 32 mm
Diameter of reduced section: 25.23 mm

OBSERVATIONS:
Elongation in gage length: 62.5 mm
per div.: 5.0, 5.5, 6.2, 8.8, 19.5, 6.7, 5.8, 5.0 mm
Percent elongation: 100(62.5/200) = 31.25%
Percent reduction in area: 100(500-187.5)/500 = 62.50%
Type of fracture: Three-quarter cup cone, fine-grained in center, silky at edge
Modulus of elasticity: 202 E6/1.02 E-3 = 198 GPa

Load kN	Deform. mm	Stress MPa	Strain m/m
14.5	0.050	29	0.000125
27.5	0.100	55	0.000250
39.0	0.150	78	0.000375
52.5	0.200	105	0.000500
63.0	0.250	126	0.000625
75.5	0.300	151	0.000750
89.0	0.350	178	0.000875
101.0	0.400	202*	0.001000
112.5	0.450	225	0.001125
124.0	0.500	248	0.001250
134.0	0.550	268	0.001375
134.5	0.576	269	0.001440
133.5	0.600	267	0.001500
133.0	0.752	266	0.001880
131.5	1.000	263	0.002500
134.0	1.248	268	0.003120
134.0	1.876	268	0.004690
134.5	2.500**	269	0.006250
134.5	2.5	269	0.0125
157.5	5.0	315	0.0250
175.5	7.5	351	0.0375
200.0	12.5	400	0.0625
212.5	17.5	425	0.0875
221.0	22.5	442	0.1125
225.0	27.5	450	0.1375
226.5	32.5	453	0.1625
226.5	37.5	453	0.1875
225.5	42.5	451	0.2125
224.5	47.5	449	0.2375
220.5	52.5	441	0.2625
164.5***	62.5	329	0.3125

Operator: H.D.
Recorder: G.H.
Date: 80-03-21
Temperature: 22°C

* Data used for *E*
** Extensometer removed
*** Specimen ruptured

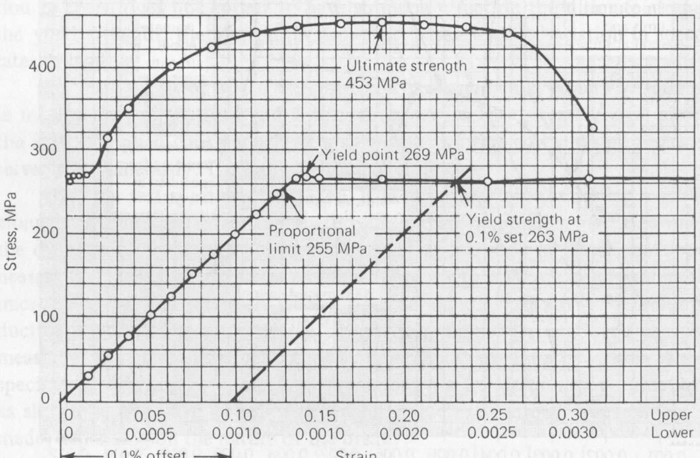


Figure 8.18 Log sheet with stress-strain diagram.

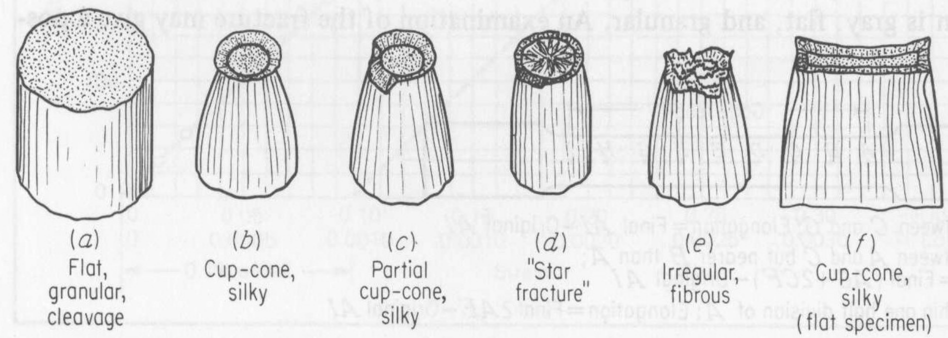


Figure 8.20 Typical tensile fractures of metals.

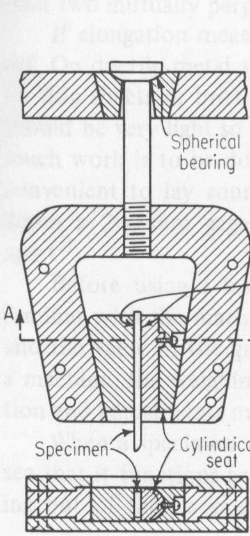


Figure 8.11 Templin grips.

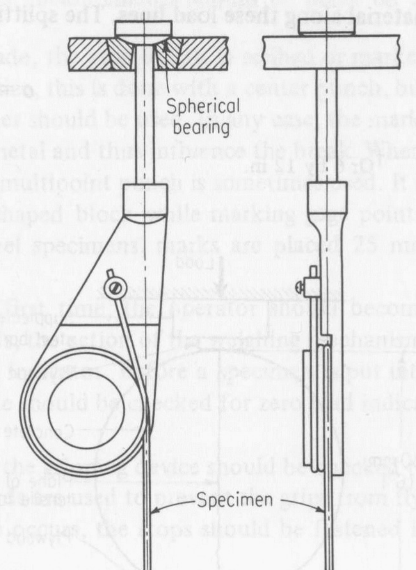


Figure 8.12 Snubbing device for testing wire.

Ensayo de Dureza.

El Ensayo de Dureza mide la resistencia de la superficie de un material a ser penetrado por un objeto duro.

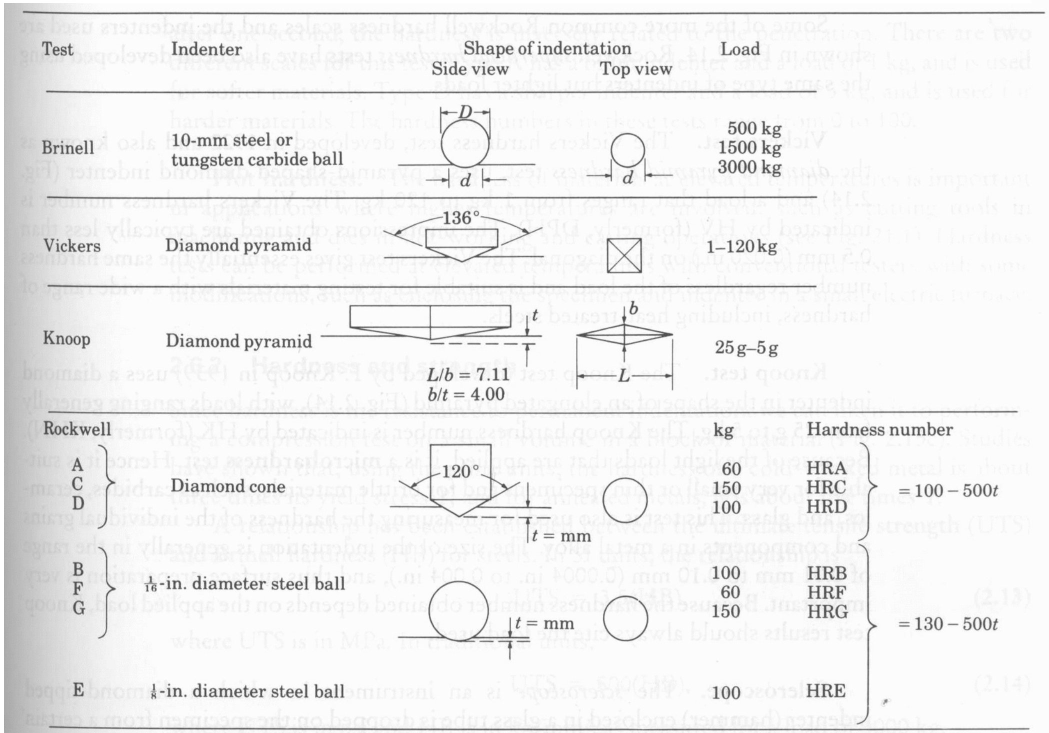


FIGURE 2.14
General characteristics of hardness testing methods. *Source:* H. W. Hayden, et al., *The Structure and Properties of Materials*, Vol. III, John Wiley & Sons, 1965.

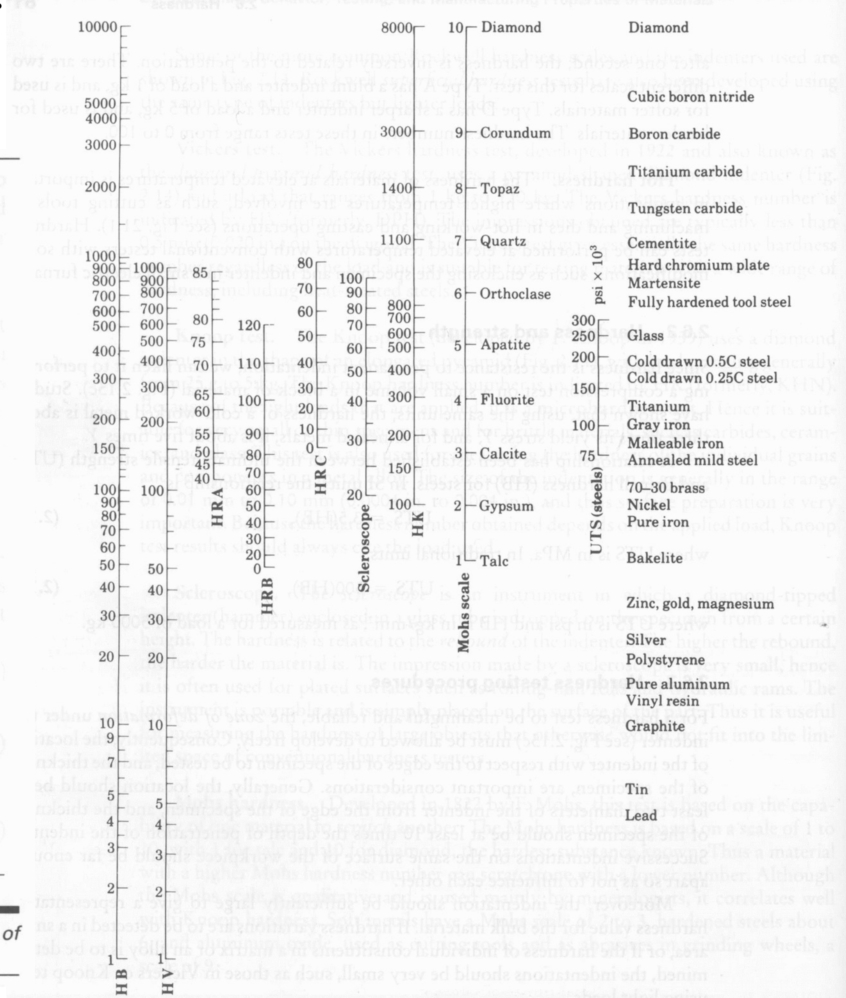


FIGURE 2.16
Chart for converting various hardness scales. Note the limited range of most scales. Because of the many factors involved, hardness conversions are approximate.

$$HB = \frac{F}{\left(\pi/2\right) D \left(D - \sqrt{D^2 - D_i^2}\right)}$$

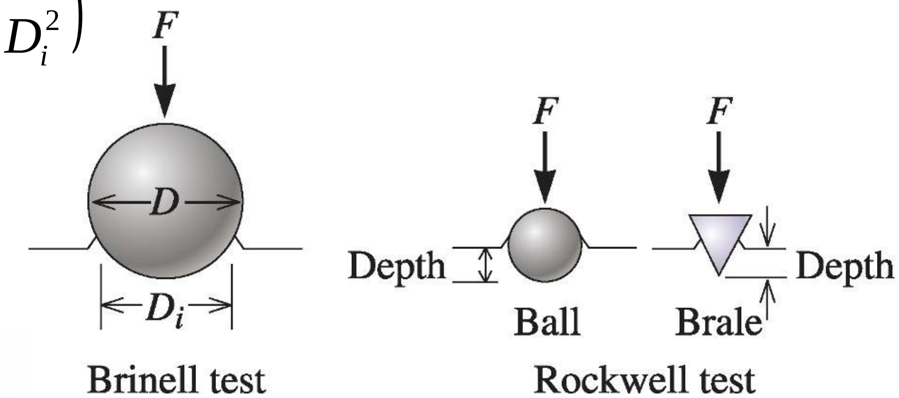


Figure 6-19
Indenters for the Brinell and Rockwell hardness tests.

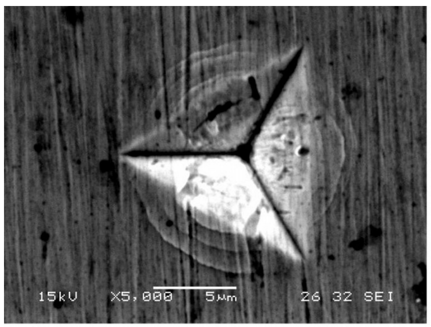


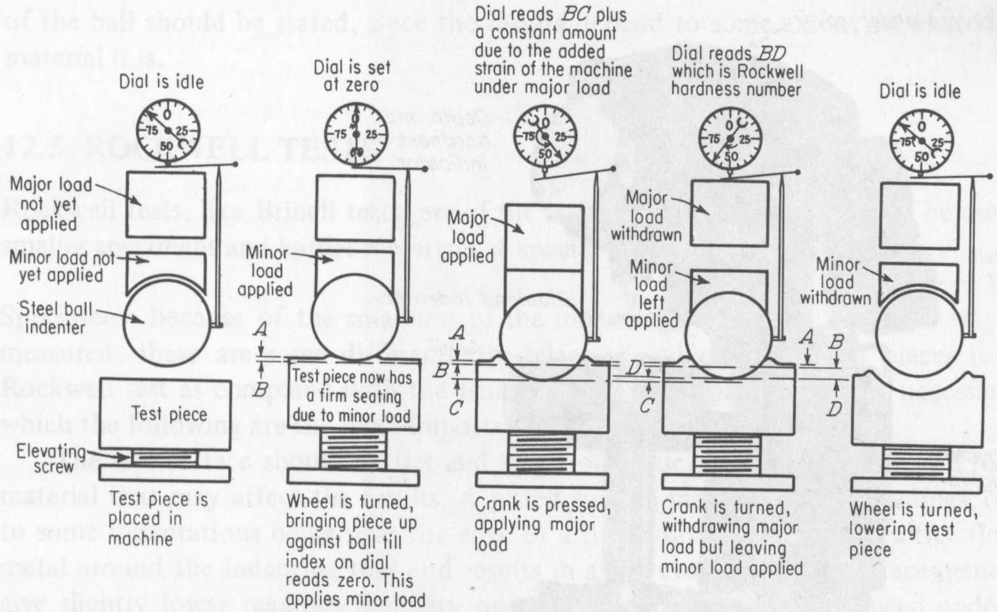
Figure 6-20 An indentation in a $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ bulk metallic glass made using a Berkovich tip in a nanoindenter. (*Courtesy of Gang Feng, Villanova University.*)

$$\sigma_{\max}(MPa) = 3{,}5HB \qquad \sigma_{\max}(kpsi) = 0{,}5HB$$

$$\sigma_y(MPa) = 3{,}1HB \qquad \sigma_y(kpsi) = 0{,}45HB$$

TABLE 6-5 ■ *Comparison of typical hardness tests*

Test	Indenter	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 square pyramid	10 kg	All materials
Knoop	Diamond elongated pyramid	500 g	All materials



AB = Depth of hole made by minor load.
AC = Depth of hole made by major load and minor load combined.
DC = Recovery of metal upon withdrawal of major load. This is caused by elastic recovery of the metal under test, and does not enter the hardness number.
BD = Difference in depth of holes made = Rockwell hardness number.

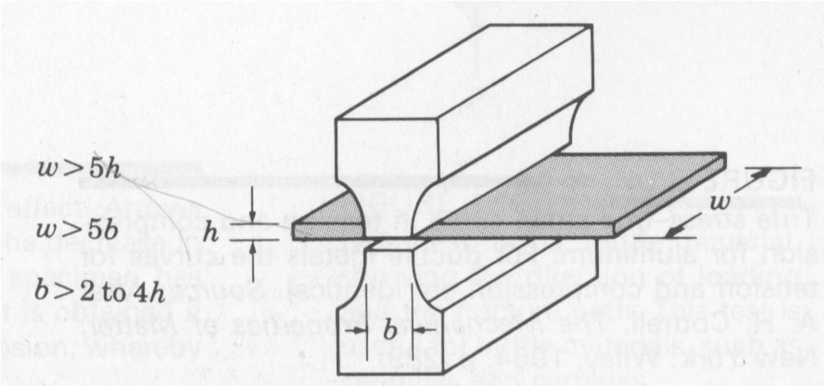
Figure 12.8 Procedure in using Rockwell tester.

Table 12.5 Rockwell hardness scales and prefix letters†

Group	Scale symbol and prefix letter	Indenter	Major load, kg	Dial numerals	Typical applications of scales
1 Common scales	B	$\frac{1}{16}$-in ball (1.6-mm)	100	Red	Copper alloys, soft steels, aluminum alloys, malleable iron
	C	Diamond cone	150	Black	Steel, hard cast iron, pearlitic malleable iron, deep case-hardened steel
2	A	Diamond cone	60	Black	Cemented carbides, thin steel, shallow case-hardened steel
	D	Diamond cone	100	Black	Thin steel, medium case-hardened steel
	E	$\frac{1}{8}$-in ball (3.2-mm)	100	Red	Cast iron, aluminum and magnesium alloys, bearing metals
	F	$\frac{1}{16}$-in ball (1.6-mm)	60	Red	Annealed copper alloys, thin soft sheet metals
	G		150	Red	Phosphor bronze, beryllium copper, malleable iron
	H	$\frac{1}{8}$-in ball (3.2-mm)	60	Red	Aluminum, lead, zinc
	K		150	Red	
3	L	$\frac{1}{4}$-in ball (6.4-mm)	60	Red	
	M		100	Red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effort
	P		150	Red	
	R	$\frac{1}{2}$-in ball (12.7-mm)	60	Red	
	S		100	Red	
	V		150	Red	

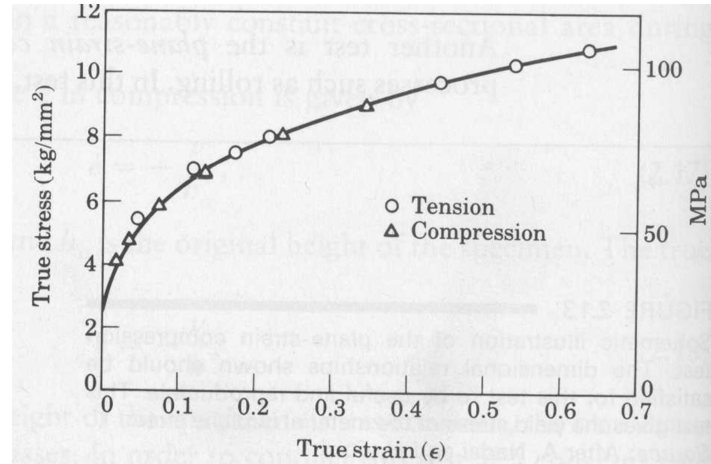
†Based on ASTM E 18.

Ensayo de Compresión.



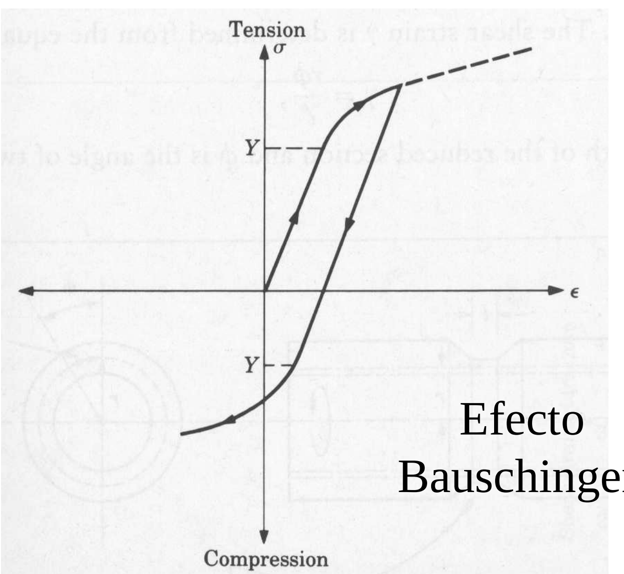
$$\dot{\varepsilon} = -\frac{v}{h_0}$$

Coinciden para materiales dúctiles.



$$Y' = \frac{2}{\sqrt{3}} Y = 1.15Y$$

Y es el Esfuerzo Real.



Efecto Bauschinger.

Pruebas:

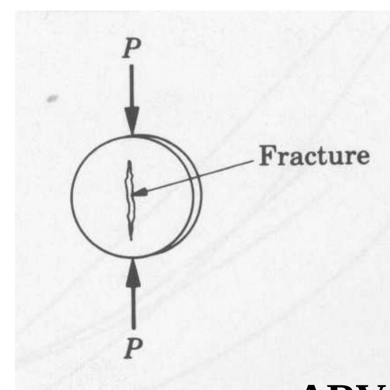
Ensayo de Compresión.

Ensayo de Comprensión de Esfuerzo Plano.

Ensayo de Fatiga.

Ensayo de Disco.

$$\sigma = \frac{2P}{\pi d t}$$



Ensayo de Flexión.

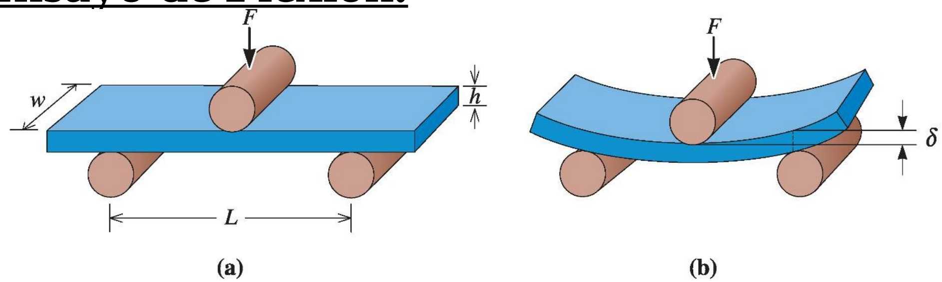


Figure 6-16 (a) The bend test often used for measuring the strength of brittle materials, and (b) the deflection δ obtained by bending.

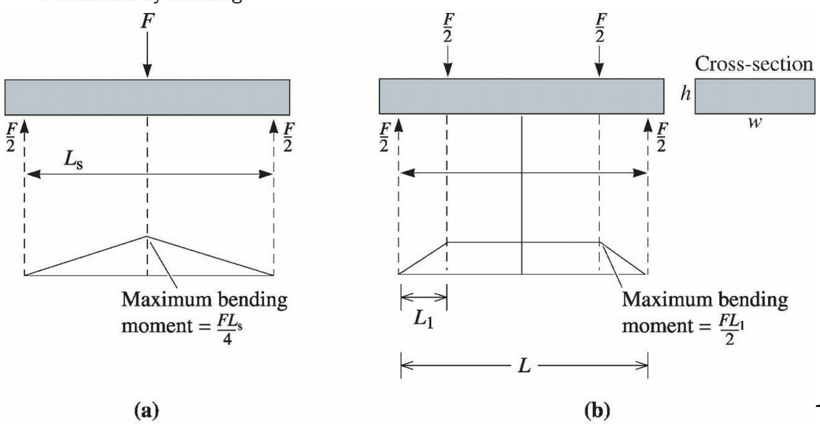
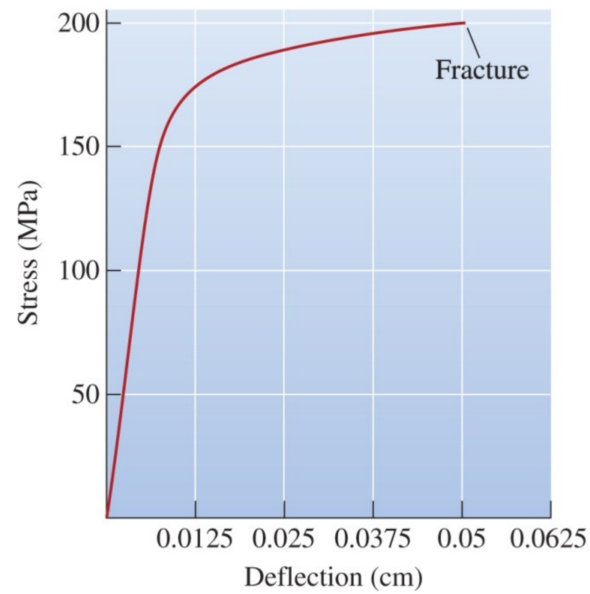


Figure 6-18 (a) Three-point and (b) four-point bend test setup.



$$\sigma_f = \frac{3FL}{2wh^2}$$

$$E_f = \frac{L^3 F}{4wh^3\delta}$$

Donde:
σ_f es el esfuerzo a la flexión
E_f es el módulo de flexión
δ es la deflexión de la viga

$$\sigma_f = \frac{Mc}{I}$$

Donde:
σ_f es el esfuerzo de ruptura transversal o módulo de ruptura
M es el momento de flexión
c es la mitad de la profundidad
I es el momento de inercia.

TABLE 6-4 *Comparison of the tensile, compressive, and flexural strengths of selected ceramic and composite materials*

Material	Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)
Polyester—50% glass fibers	159	221	310
Polyester—50% glass fiber fabric	255	186[a]	317
Al_2O_3 (99% pure)	207	2586	345
SiC (pressureless-sintered)	172	3861	552

[a] *A number of composite materials are quite poor in compression.*