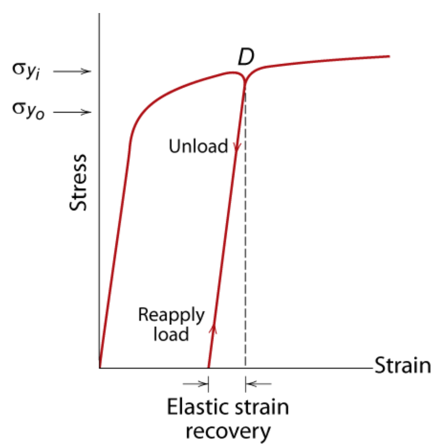
Chapter 6: Mechanical properties of metals

Outline

- Elastic recovery during plastic deformation
- Hardness
- Variability of material properties
- Design/safety factors

Elastic recovery during plastic deformation

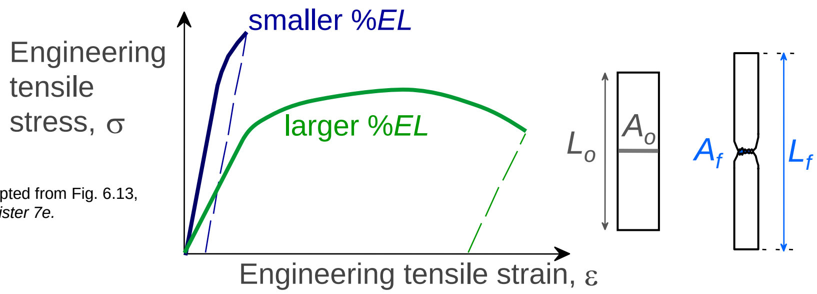
- Schematic tensile stress-strain diagram showing elastic strain recovery



Ductility, %EL

- Plastic tensile strain at failure:

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$



Adapted from Fig. 6.13, *Callister 7e.*

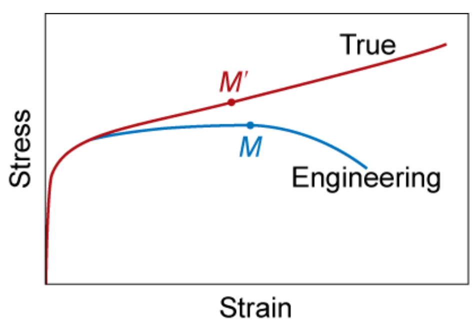
- Another ductility measure:

$$\%RA = \frac{A_o - A_f}{A_o} \times 100$$

True stress & strain

Note: S.A. changes when sample stretched

- True stress $\sigma_T = F/A_i$ $\qquad \sigma_T = \sigma(1+\varepsilon)$
- True Strain $\varepsilon_T = \ln(\ell_i/\ell_o)$ $\qquad \varepsilon_T = \ln(1+\varepsilon)$



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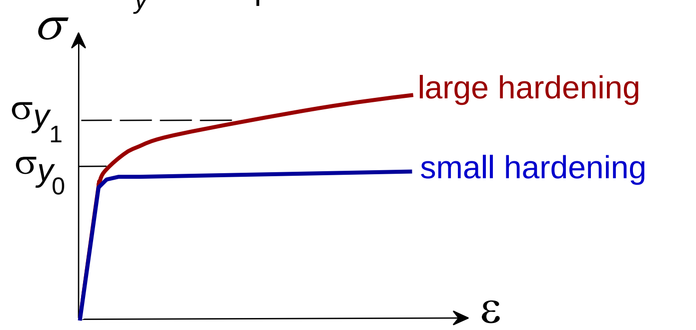
Hardening

- An increase in σ_y due to plastic deformation.



- Curve fit to the stress-strain response:

$$\sigma_T = K(\varepsilon_T)^n$$

hardening exponent:
n = 0.15 (some steels)
to n = 0.5 (some coppers)

"true" stress (F/A)

"true" strain: $\ln(L/L_o)$

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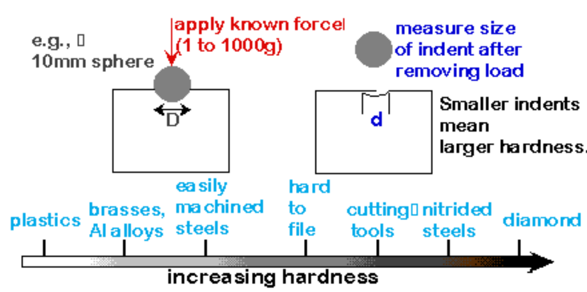
Hardness

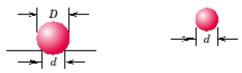
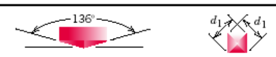
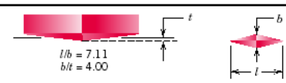
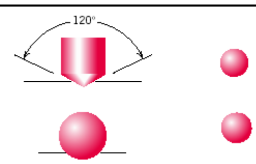
- Hardness: a measure of a material's resistance to localized plastic deformation or cracking in compression
- Simple and inexpensive
- Non destructive
- Can obtain other mechanical properties



Hardness tests

- Mohs scale: 1 talc<2Gypsum<3calcite<4fluorite........ <10diamond

Table 6.4 Hardness Testing Techniques

Test	Indenter	Shape of Indentation: Side View	Shape of Indentation: Top View	Load	Formula for Hardness Number[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$HK = 14.2P/l^2$
Rockwell and Superficial Rockwell	Diamond cone; $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in. diameter steel spheres			60 kg, 100 kg, 150 kg (Rockwell); 15 kg, 30 kg, 45 kg (Superficial Rockwell)	

Hardness tests (*continue*)

- Rockwell and superficial rockwell
  - No major sample damage
  - Each scale runs to 130 but only useful in range 20-100.
  - Minor load 10 kg
  - Major load 60 (A), 100 (B) & 150 (C) kg
    - A = diamond, B = 1/16 in. ball C = diamond
- Examples:

  80HRB,60 HR30W

- 20<hardness<100

Table 6.5a Rockwell Hardness Scales

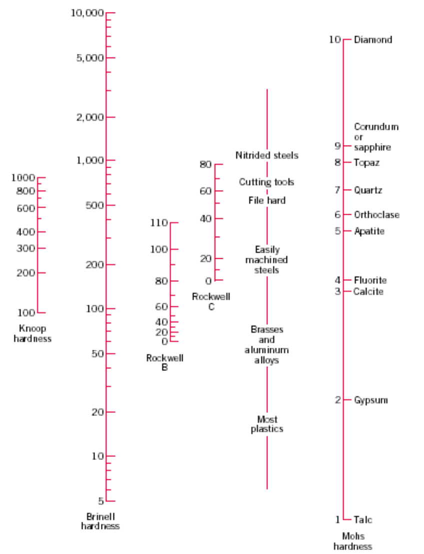
Scale Symbol	Indenter	Major Load (kg)
A	Diamond	60
B	$\frac{1}{16}$ in. ball	100
C	Diamond	150
D	Diamond	100
E	$\frac{1}{8}$ in. ball	100
F	$\frac{1}{16}$ in. ball	60
G	$\frac{1}{16}$ in. ball	150
H	$\frac{1}{8}$ in. ball	60
K	$\frac{1}{8}$ in. ball	150

Table 6.5b Superficial Rockwell Hardness Scales

Scale Symbol	Indenter	Major Load (kg)
15N	Diamond	15
30N	Diamond	30
45N	Diamond	45
15T	$\frac{1}{16}$ in. ball	15
30T	$\frac{1}{16}$ in. ball	30
45T	$\frac{1}{16}$ in. ball	45
15W	$\frac{1}{8}$ in. ball	15
30W	$\frac{1}{8}$ in. ball	30
45W	$\frac{1}{8}$ in. ball	45

Hardness tests (*continue*)

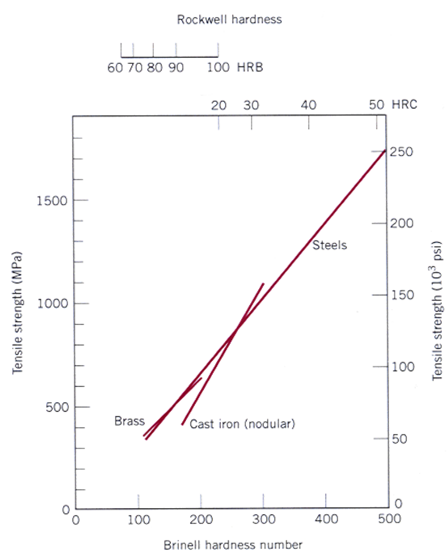
- Brinell: 10-mm sphere of steel or tungsten carbide
- Knoop and vickers microhardness
- Hardness conversion



Correlation between hardness and tensile strength

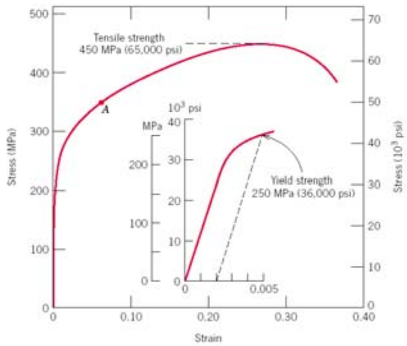
- Relations between hardness and tensile strength for steel, brass, and cast iron.

- For most steels:
  TS (MPa)=3.45xHB
  TS (psi)=500xHB



Example

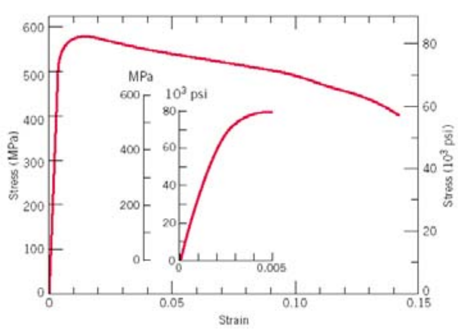
- Estimate the Brinell and Rockwell hardnesses for brass and carbon steel



The stress–strain behavior for the brass specimen

Example

- Estimate the Brinell and Rockwell hardnesses for brass and carbon steel



Tensile stress-strain behavior for a plain carbon steel

Variability of material properties

- Factors that lead to scatter in measured material properties
- The average

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

- The standard deviation

$$s = \left[\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1} \right]^{1/2}$$

where n is the number of data points

Example

- Determine the average and standard deviation of tensile strength

Sample Number	Tensile Strength (MPa)
1	520
2	512
3	515
4	522

$$\overline{TS} = \frac{\sum_{i=1}^{4} (TS)_i}{4}$$

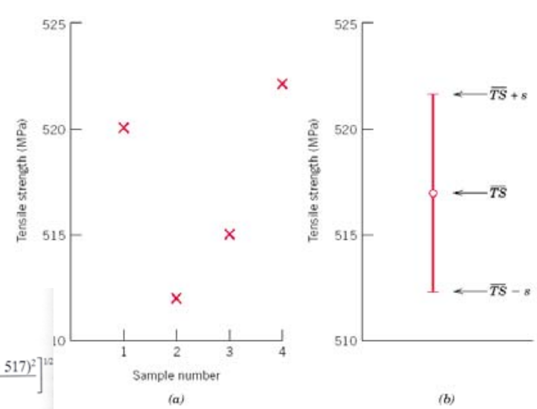
$$= \frac{520 + 512 + 515 + 522}{4}$$

$$= 517 \text{ MPa}$$

$$s = \left[\frac{\sum_{i=1}^{4} \{(TS)_i - \overline{TS}\}^2}{4 - 1} \right]^{1/2}$$

$$= \left[\frac{(520 - 517)^2 + (512 - 517)^2 + (515 - 517)^2 + (522 - 517)^2}{4 - 1} \right]^{1/2}$$

$$= 4.6 \text{ MPa}$$



Design/safety factors

- **Design uncertainties mean we do not push the limit.**
- **Factor of safety, N**

$$\sigma_{working} = \frac{\sigma_y}{N}$$

Often N is between 1.2 and 4

- **Ex: Calculate a diameter, d, to ensure that yield does not occur in the 1045 carbon steel rod below. Use a factor of safety of 5.**

$$\sigma_{working} = \frac{\sigma_y}{N}$$

$$\frac{220,000N}{\pi\left(d^2/4\right)}$$

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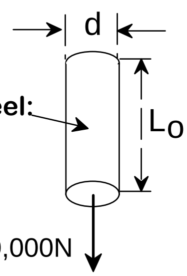
1045 plain carbon steel:
σ_y=310MPa
TS=565MPa



Summary

- **Stress and strain: These are size-independent measures of load and displacement, respectively.**
- **Elastic behavior: This reversible behavior often shows a linear relation between stress and strain. To minimize deformation, select a material with a large elastic modulus (E or G).**
- **Plastic behavior: This permanent deformation behavior occurs when the tensile (or compressive) uniaxial stress reaches σ_y.**
- **Toughness: The energy needed to break a unit volume of material.**
- **Ductility: The plastic strain at failure.**