Materials for Automobiles

Lecture no 3

8 August 2011

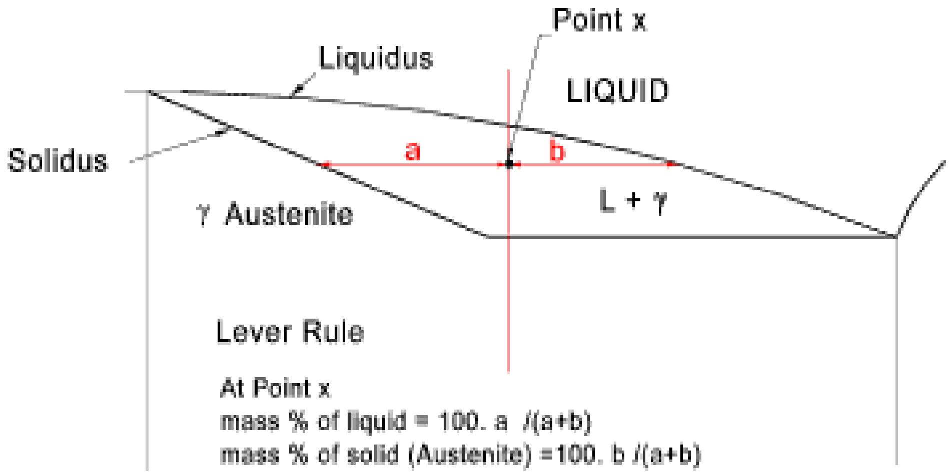
Plan

1	Revision
2	Tensile testing
3	Hardness testing

Revision

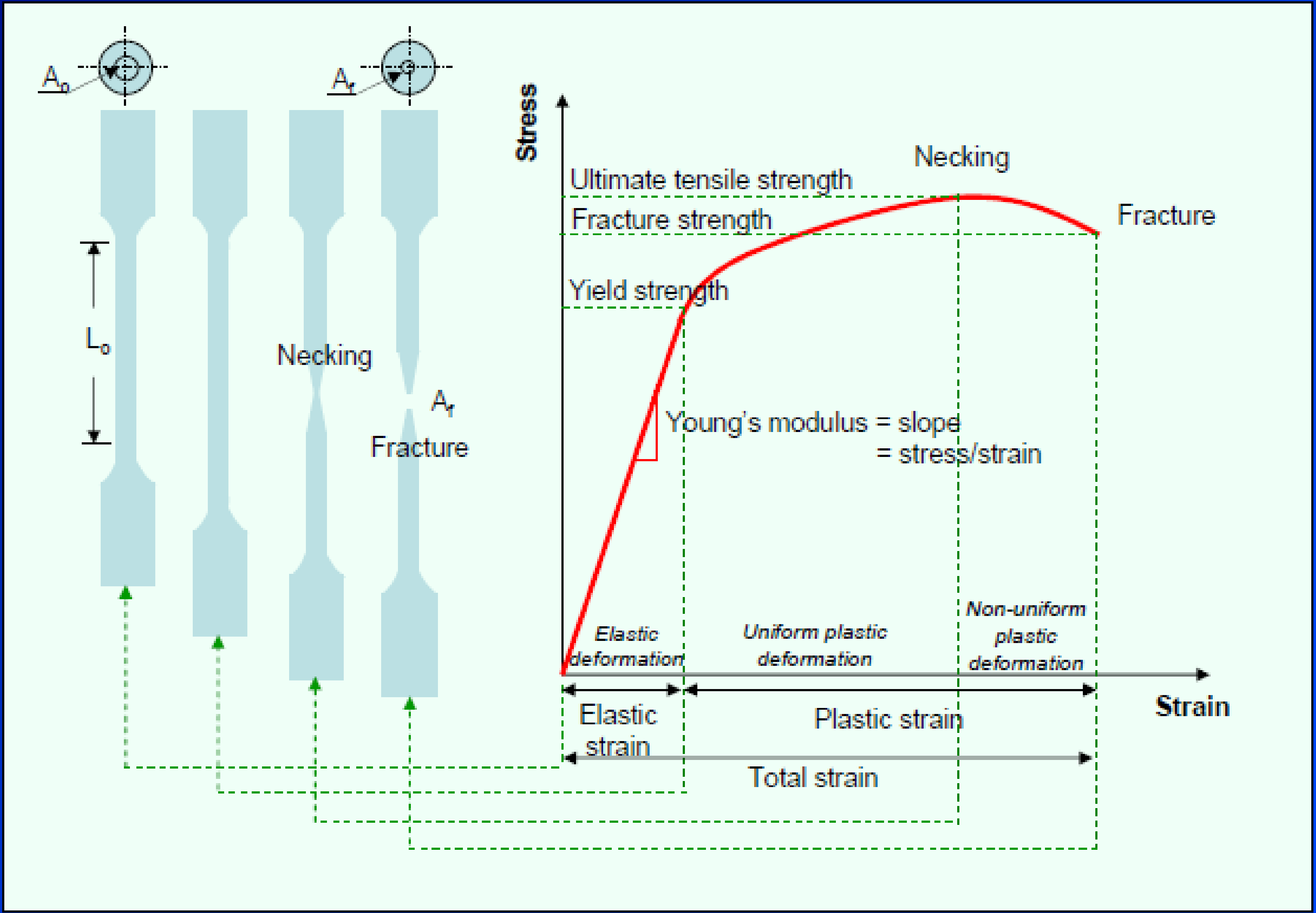
No.	Statement	T/F
1	All materials need not be specified for processing properties	
2	A bolted joint functions similar to a friction clutch transmission	
3	Cab exterior is superior painted for appearance purpose only	
4	Material for road springs of a truck needs to be max tough	
5	The propeller shaft stress is affected directly by truck over load	
6	Steel castings with 'mushy zone' are crack prone during solidification	
7	Proeutectoid cementite is found in 0.4% C steel on cooling	
8	Austenite is found in some special alloy steels at room temperature	
9	Pig iron making is an oxidation process	
10	Steel making from Pig iron is an oxidation process	
11	Piping does not occur if there is no shrinkage on solidification	
12	Con cast Steel needs always high reduction ratio over 10:1	
13	ladle refining have improved inclusion content but have increased manufacturing time	
14	Rolling gives uniform properties	
15	Hot working temperature for steel is less than 723 deg. C.	

Lever Rule

- The lever rule can be applied to any phase region an provides an indication of the proportions of the constituent parts at any point on the phase diagram.
- 

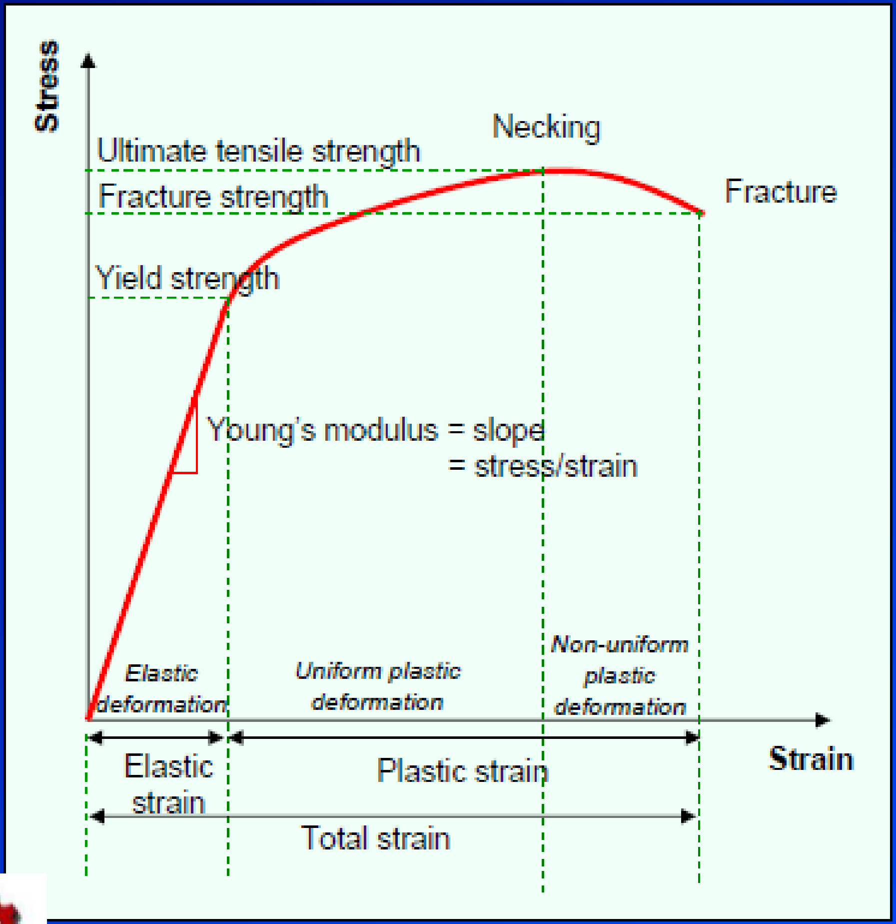
- Applying the lever rule to the eutectoid point (0,80% C at 723°C)
  Wt% Ferrite = 100 (6,67 -0,8)/ 6,67- 0,02) = 88%
  Wt% Cementite = 100 (0,8- 0,02) /6,67- 0,02) = 12%

Engineering stress-strain curve



Engineering stress-strain curve

- Basic design information on the strength of materials.
- An acceptance test for the specification of materials.



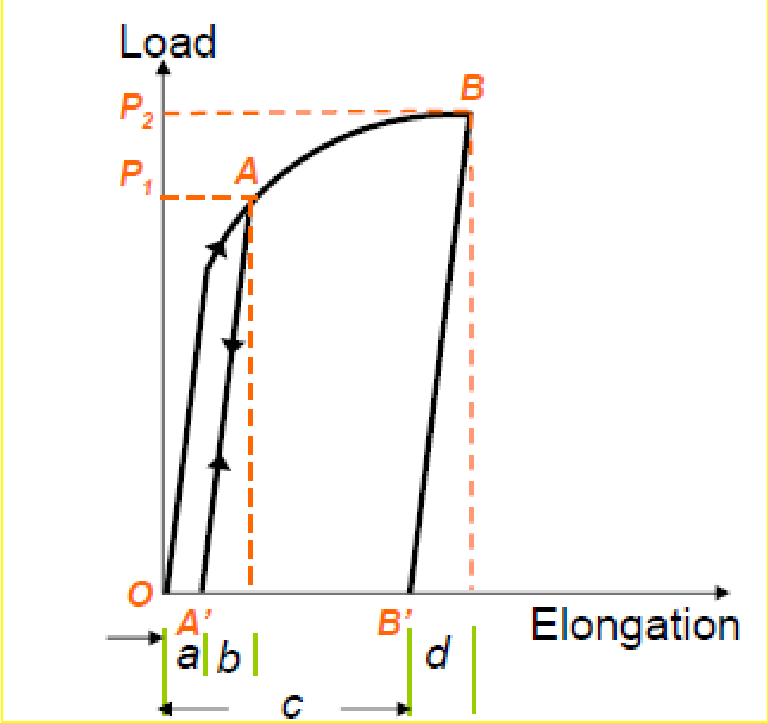
Average longitudinal tensile stress

$$s = \frac{P}{A_o} \qquad \textit{Eq.1}$$

Average linear strain

$$e = \frac{\delta}{L_o} = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o} \qquad \textit{Eq.2}$$

Recoverable elastic strain and plastic strain



- Loading of tensile sample beyond yield point to ***A*** and then unloading give the unloading curve ***AA'*** with its slope parallel to the elastic Young's modulus.
- ***Recoverable elastic strain b*** on unloading is given by

$$b = \frac{\sigma_1}{E} = \frac{P_1 / A_o}{E}$$

Eq.3

- ***Permanent plastic strain a***
- Loading and unloading following ***OABB'*** gives ***plastic deformation c*** whereas ***elastic deformation*** under loading is ***d***.

Tensile strength

Tensile strength *or ultimate tensile strength (UTS)* s_u *is the maximum load* P_{max} *divided by the original cross-sectional area* A_o *of the specimen.*

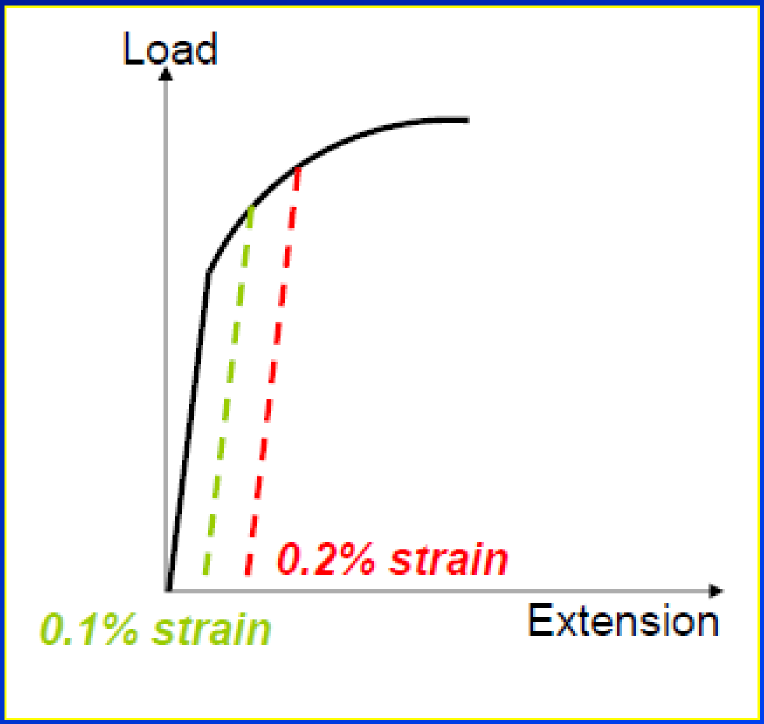
$$s_u = \frac{P_{max}}{A_o} \qquad \text{Eq.4}$$

- Tensile strength is the most value quoted from tensile test results.
- Useful for ***specifications***, ***quality control*** of a product.
- In engineering design, ***safety factor*** should be applied.

Note: yield stress is more practical for ductile materials. But it has little relation to ***complex conditions of stress***.

Yield strength of materials

The offset yield strength can be determined by the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic line offset by a strain of 0.2 or 0.1%. (e = 0.002 or 0.001)



$$s_o = \frac{P_{(strain\ offset=0.002)}}{A_o} \quad \text{Eq.5}$$

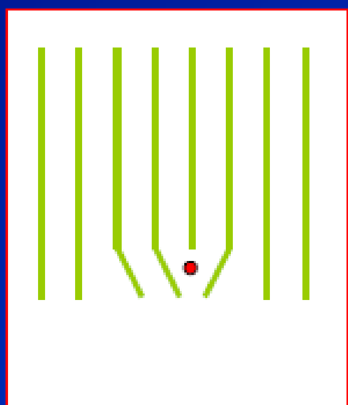
In Great Britain, the offset yield stress is referred to ***proof stress*** either at 0.1 or 0.5%strain.

Used for design and specification purposes to avoid the practical difficulties of measuring the elastic limit or proportional limit.

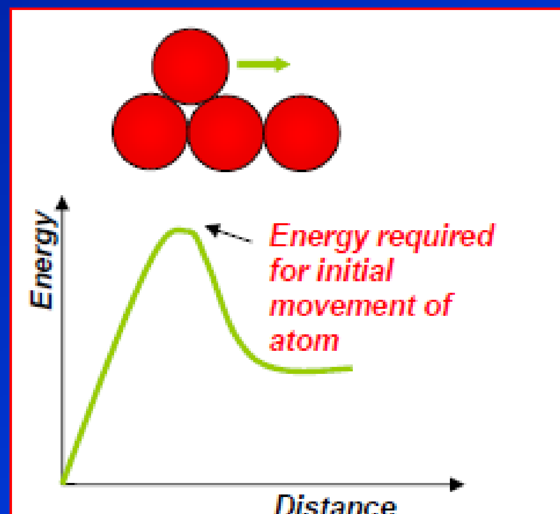
Yield strength of materials

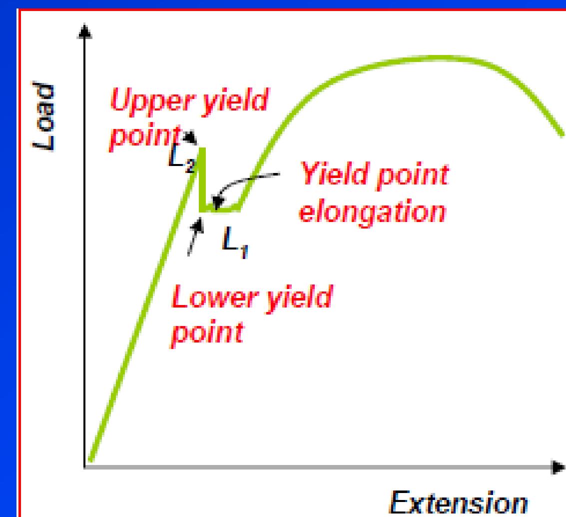
- **BCC** lattice materials (**Fe**) show a yield point phenomenon → ***Upper and lower yield points*** (depending on testing machine).
- ***Condition:*** Polycrystalline & small amounts of interstitial solute atoms.

Upper yield point $\frac{L_2}{A_o}$ **Lower yield point** $\frac{L_1}{A_o}$



Interstitial solute atom





At yield point, localised internal friction requires more energy for interstitial atom to move dislocation, after that dislocation are free from interstitial atom (carbon, nitrogen)

Ductility

Ductility is a qualitative, subjective property of a material.

In general, ductility is of interest in three different ways

1) ***For metal working operation*** : indicating amount of deformation can be applied without failure.
2) ***For stress calculation or the prediction of severe load*** : indicating the ability of the metal to flow plastically before failure.
3) ***For indication of any changes in heat treatments or processing conditions in metal***.

Ductility

% Elongation:

% elongation is a measure of ductility, which is given by:

$$\% \text{ elongation} = 100 * (L_f - L_0) / L_o$$

where,

L_o = Initial length

L_f = Final Length

Ductility

% Reduction in Area:

% reduction in area is a measure of ductility, which is given by:

$$\% \text{ reduction in area} = 100 * (A_o - A_f)/ A_o$$

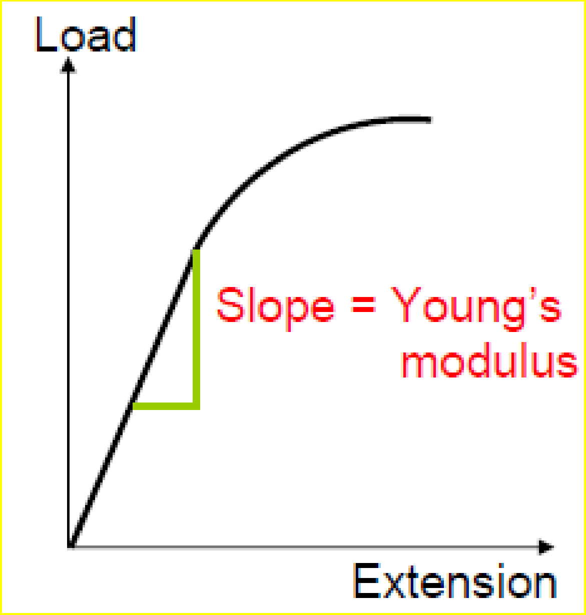
where,

A_o = Initial area

A_f = Final area

Modulus of elasticity

Modulus of elasticity or ***Young's modulus*** is a measure of material stiffness (given by the slope of the stress-strain curve).



- Modulus of elasticity is determined by the binding forces between atoms (structure insensitive property)
- Cannot change ***E***, but can improve by forming composites.
- Only slightly affected by alloying addition, heat treatment or cold work.

Temp ↑ ***Young's modulus*** ↓

Young's modulus ↑

Stiffness ↑

Deflection ↓

Table 8-1 Typical values of modulus of elasticity at different temperatures

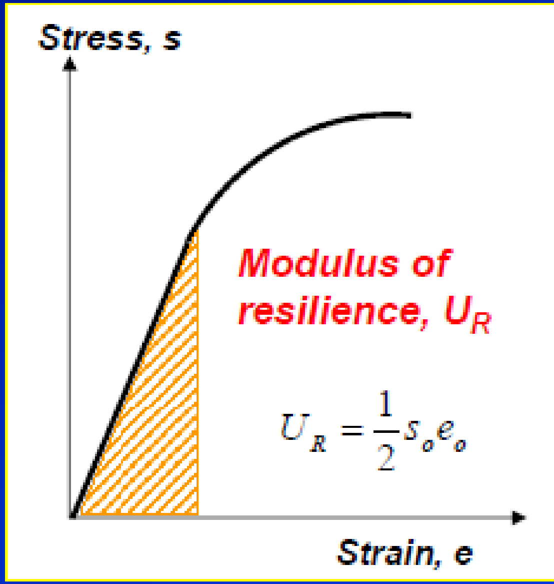
Material	Modulus of elasticity, GPa				
	Room temp.	477 K	700 K	810 K	922 K
Carbon steel	207	186	155	134	124
Austenitic stainless steel	193	176	159	155	145
Titanium alloys	114	97	74	70	
Aluminum alloys	72	66	54		

Resilience And Toughness

- **Resilience**: The ability of a material to absorb energy with in elastic limit.
- **Toughness** : The ability of a material to absorb energy in the plastic range.

Resilience

- **Resilience** is an ability of a material to **absorb energy when elastically deformed** and to return it when unloaded.
- Usually measured by **modulus of resilience** (strain energy per unit volume required to stress the material from zero to the yield stress So

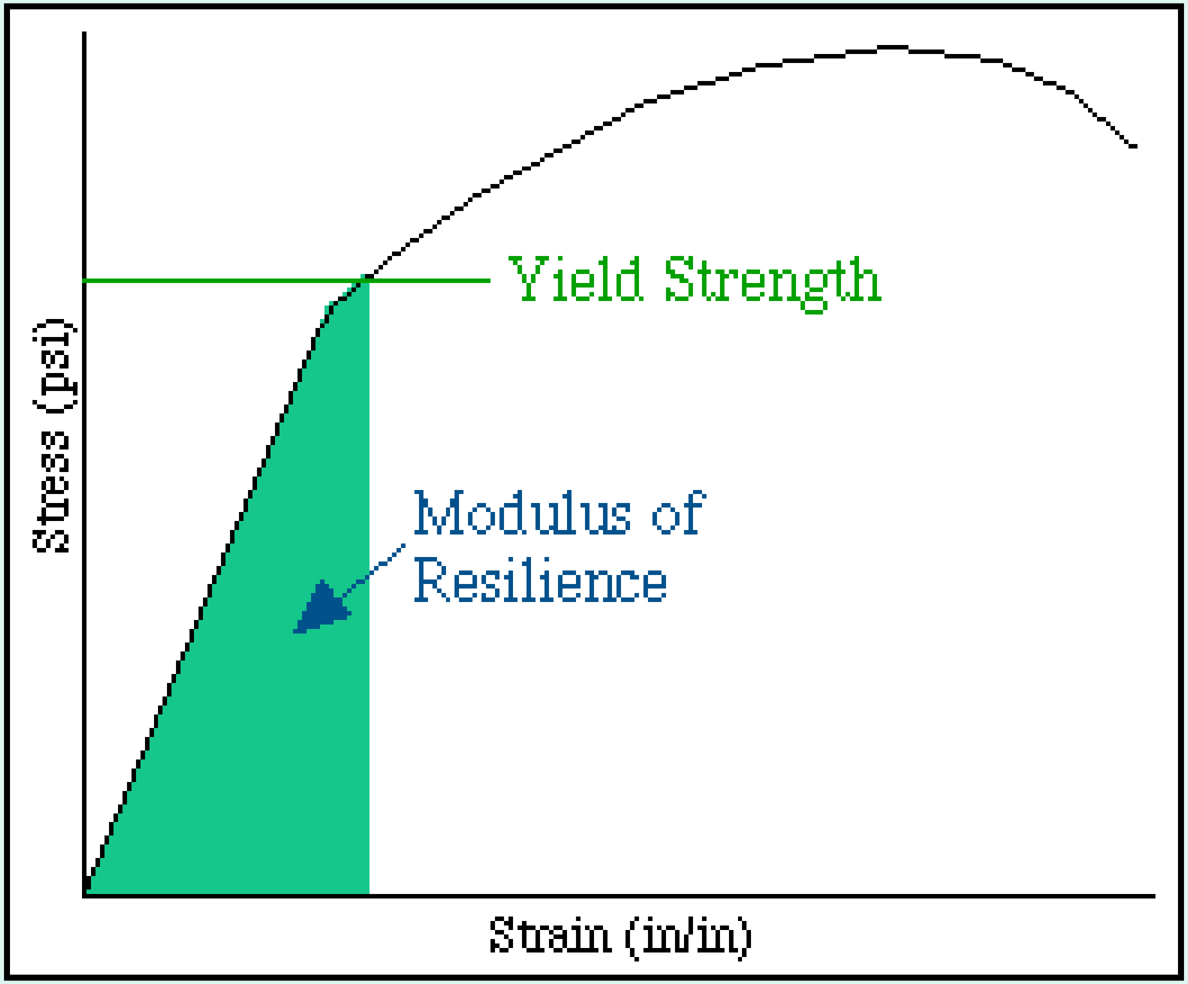


$$U_R = \frac{1}{2} s_o e_o = \frac{s_o^2}{2E}$$ Eq.9

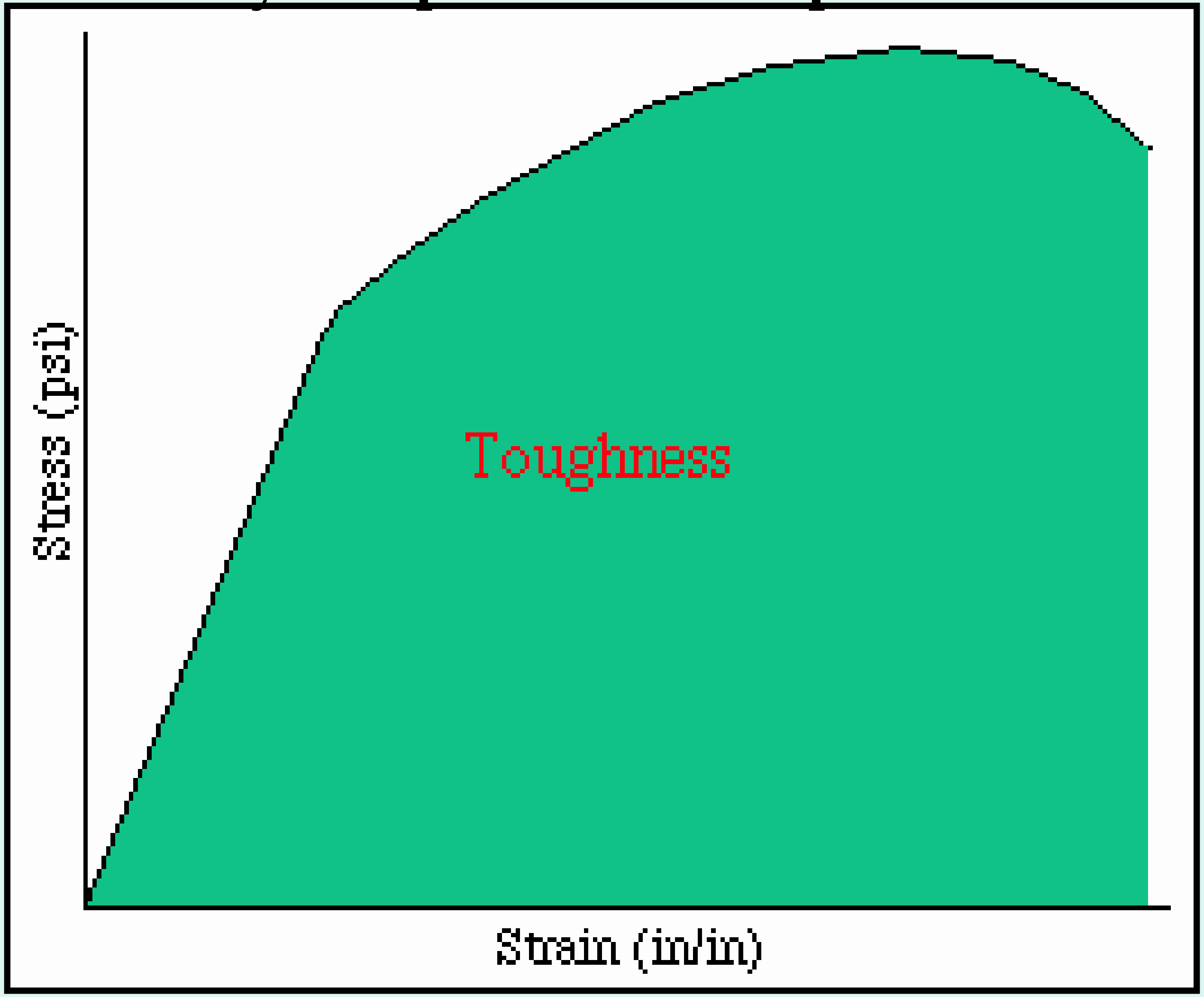
Table 8-2 Modulus of resilience for various materials

Material	E, GPa	s_0, MPa	Modulus of resilience, U_R, kPa
Medium-carbon steel	207	310	232
High-carbon spring steel	207	965	2250
Duralumin	72	124	107
Copper	110	28	3.5
Rubber	0.0010	2.1	2140
Acrylic polymer	3.4	14	28

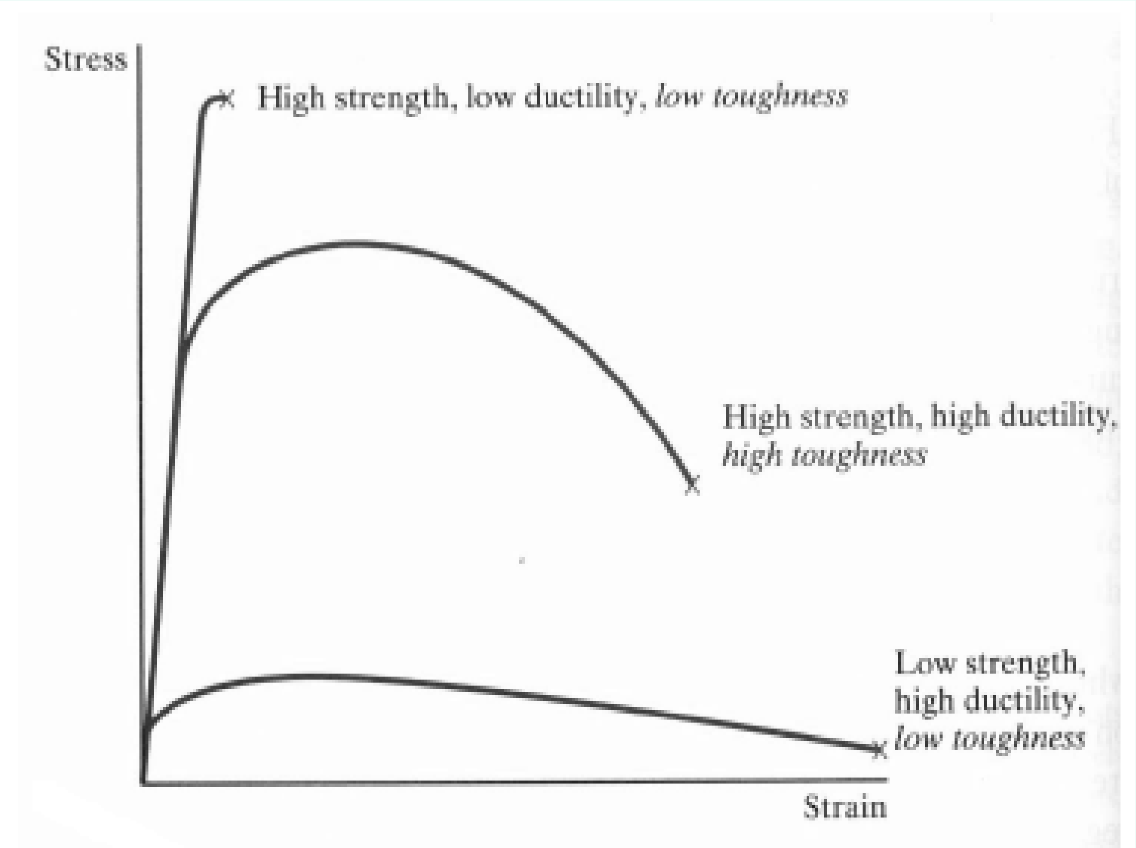
Modulus of resilience - the area under the linear part of the curve, measuring the stored elastic energy.



Toughness - the total area under the curve, which measures the energy absorbed by the specimen in the process of breaking.

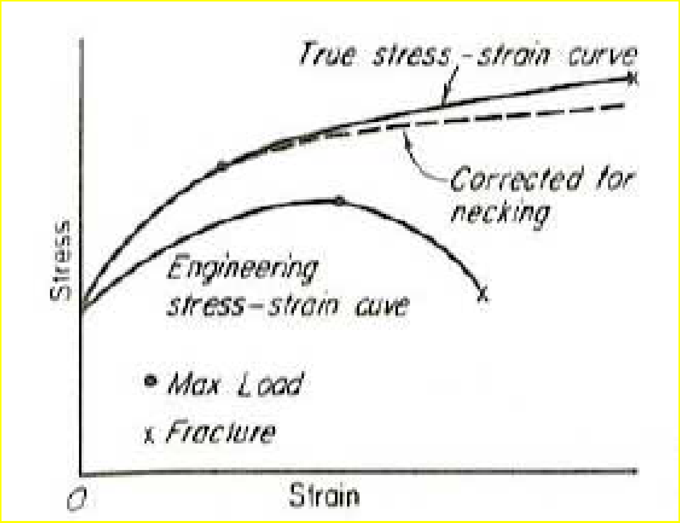


Toughness – the total area under the stress-strain curve



True-stress-true-strain curve

- **True stress-strain curve** gives a true indication of deformation characteristics because it is ***based on the instantaneous dimension*** of the specimen.
- The ***true stress-strain curve*** is also known as the ***flow curve***.



Comparison of engineering and the true stress-strain curves

- In ***engineering stress-strain curve***, stress drops down after necking since it is based on the original area.
- In ***true stress-strain curve***, the stress however increases after necking since the cross-sectional area of the specimen decreases rapidly after necking.

True stress

$$\sigma = \frac{P}{A_o}(e+1) = s(e+1)$$

Eq.12

True strain

$$\varepsilon = \ln(e+1)$$

Eq.13

Note: these equations are used for data upto the onset of necking. Beyond necking, use the actual measurements of load, cross-sectional area, diameter.

Power-law flow curve

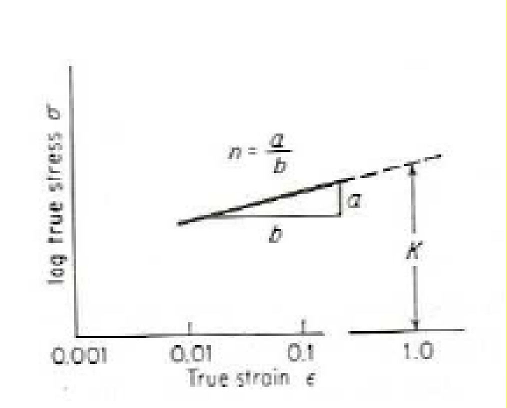
• The flow curve of many metals in the region of uniform plastic deformation can be expressed by the ***simple power law***.

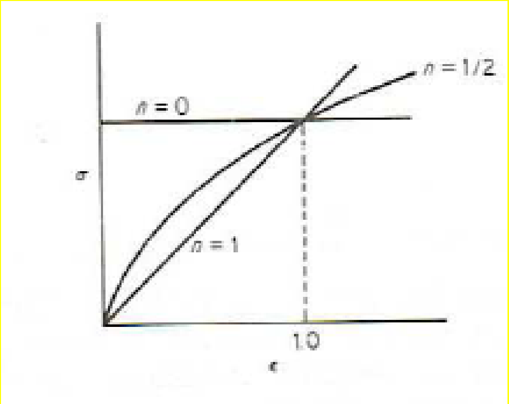
$$\sigma = K\varepsilon^n$$

Eq.20

Where ***n*** is the strain hardening exponent
K is the strength coefficient

• ***Log-log plot of true stress-strain curve*** from yield point up to the maximum load will result in a straight line where ***n*** is the slope and ***K*** is the true stress at ε = 1.0.





n = 0 perfectly plastic solid
n = 1 elastic solid
For most metals, 0.1< ***n*** < 0.5

True Stress and True Strain

- **True stress**, σ, is the load,P, divided by the instantaneous area of the specimen, A_i.
- **True Strain:** Change in gage length with respect to the instantaneous gage length over which the change occurs.
- True strain, ε, is determined from the rate of change in gauge length with respect to the instantaneous gauge length, L_i.
- Up to strain where necking begins, specimen deforms with a constant volume in gauge section.
- Constant Volume gives:

$$A_o L_o = A_i L_i$$

Poisson's ratio

When pulled in tension (X), a sample gets longer and thinner, i.e., *a contraction in the width (Y) and breadth (Z)*

Poisson's ratio: when strained in the (X) direction how much strain occurs in the lateral directions (Y & Z)

True Strain:

- **True Strain:** Change in gage length with respect to the instantaneous gage length over which the change occurs.

True Stress

$$\sigma = \frac{P}{A_i}; \quad A_i = \frac{A_o L_o}{L_i}$$

$$\sigma = \frac{P L_i}{A_o L_o};$$

$$S = \frac{P}{A_o};$$

$$L_i = L_o + \Delta L;$$

$$\frac{L_i}{L_o} = \frac{L_o + \Delta L}{L_o} = (1 + e)$$

$$\sigma = S(1 + e)$$

Assumes constant volume. Valid for all strains up to point where necking begins; Hence, valid for $S < S_u$.

Special Case,
True Fracture Stress:

$$\sigma_f = \frac{P_f}{A_f}$$

True Strain

$$d\varepsilon = \frac{dL_i}{L_i}$$

$$\varepsilon = \ln\left(\frac{L_i}{L_o}\right)$$

$$L_i = L_o + \Delta L;$$

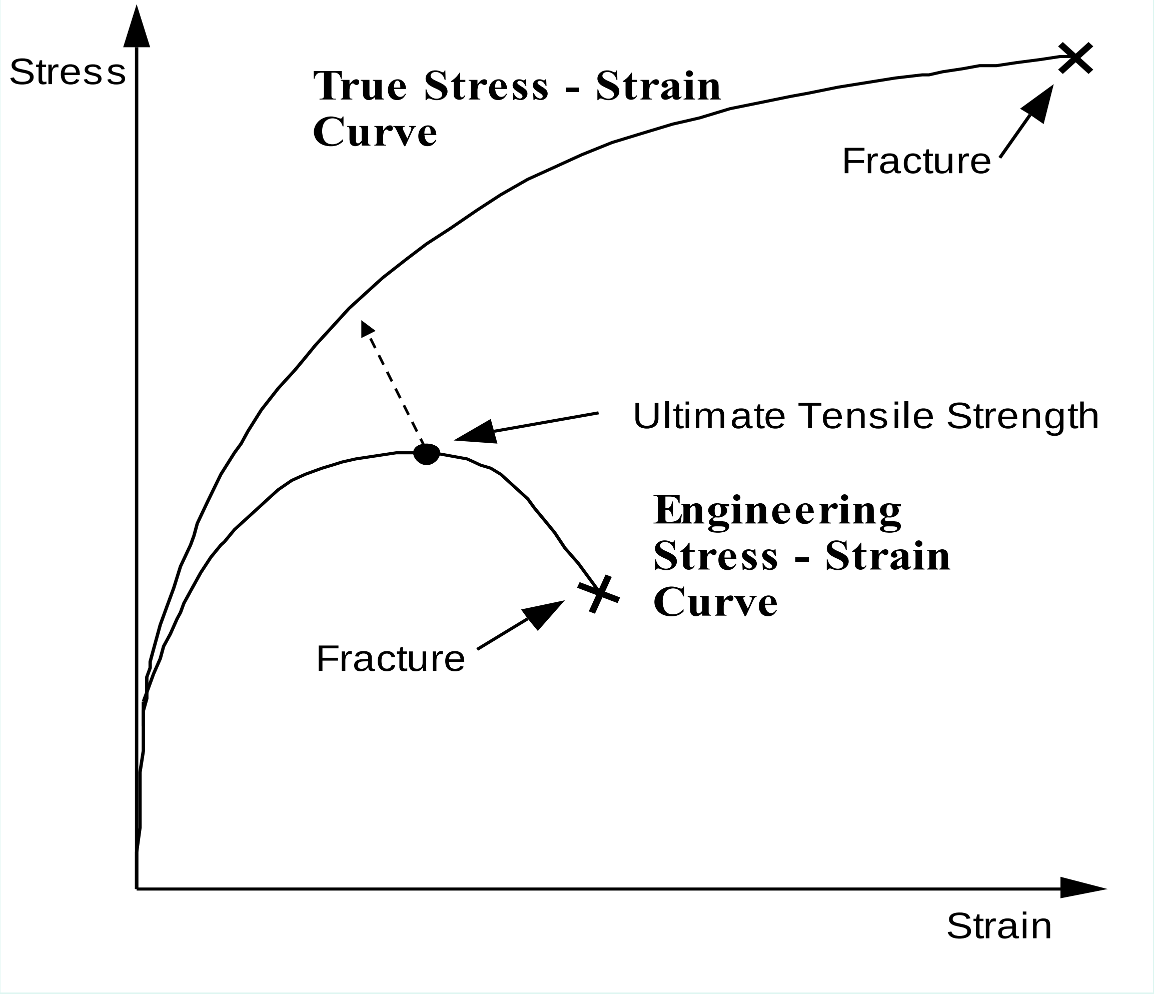
$$\varepsilon = \ln(1+e)$$

Assumes constant volume.
Valid for all strains up to point where necking begins;
Hence, valid for S < Su.

Special Case,
True Fracture Strain:

$$\varepsilon_f = \ln\left(\frac{A_o}{A_f}\right)$$

Engineering Vs. True Stress-Strain Curves



Criterion for necking

Increase in true stress (due to reduction in cross-sectional area) as the specimen elongates is more than to load carrying capacity due to strain hardening.

Summary

No	Details
1	Tensile strength, yield strength and modulus of elasticity are used for design calculations
2	Percentage elongation is specified for formability requirement. Percentage elongation is also specified for structural purposes as a guide for ensuring minimum toughness.
3	Modulus of Elasticity is a material property , it does not change significantly with hardness or alloying. It does decrease with significant increase in temperature
4	True stress and true strain are required for understanding the plastic flow region