## Outline

- Yield Strength
- Plastic Deformation
- Mechanical Behavior
- Example
- True Stress and True Strain

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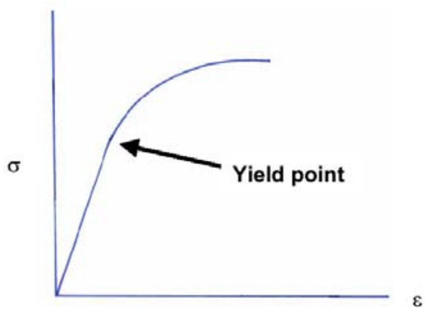
# Plastic deformation

What happens if we continue to apply tensile loading beyond the elastic limit? *(i.e., stretching atomic bonds to the point of breaking)*



**Plastic deformation**:

- stress and strain are not proportional
- the deformation is not reversible
- deformation occurs by breaking and re-arrangement of atomic bonds (*in crystalline materials primarily by motion of dislocations*, *Chapter 7*)

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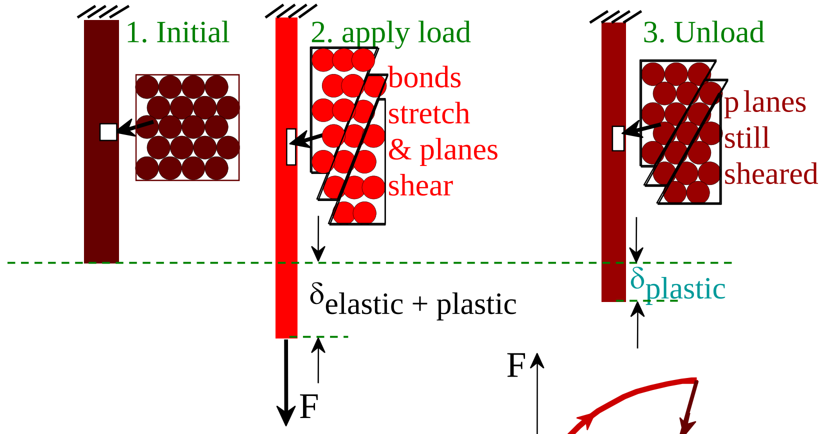
# Plastic Deformation: *metals*



1. Initial

2. apply load

bonds stretch & planes shear

3. Unload

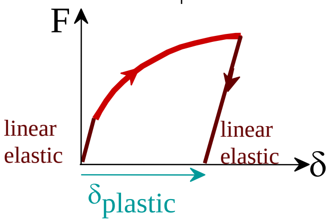
planes still sheared

$\delta_{\text{elastic + plastic}}$

$\delta_{\text{plastic}}$

F

Plastic means permanent!



F

linear elastic

linear elastic

δ

$\delta_{\text{plastic}}$

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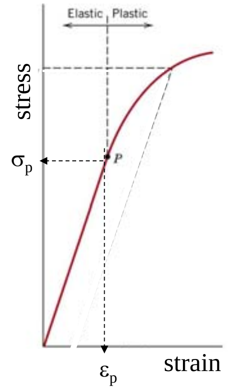
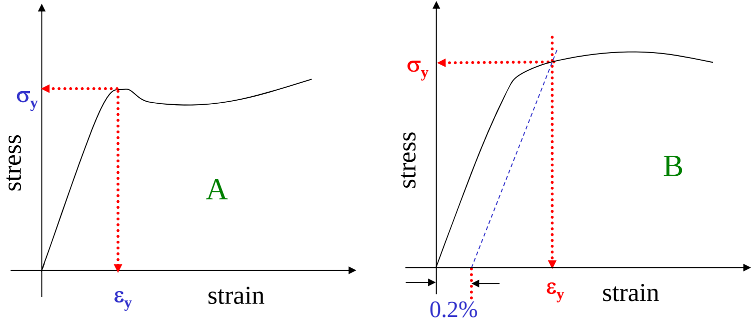
# Proportional Limit:



- Proportional limit is the point where the stress-strain curve becomes nonlinear (the strain deviates from being proportional to the stress).
- The gradient of this portion of the stress-strain curve equals to the elastic modulus of the material.
- The stress and strain values at this point are known as the proportional-limit stress and strain, respectively.
- This is the point beyond which **Hooke's law** can no longer be used to relate stress and strain in axial or shear deformation.

# Yield Strength

- The yield point corresponds to the point where the material begins to have permanent deformation.



- Some materials have a well-defined yield region (A), others (B) do not.
- In the absence of a distinct yield point, a 0.2% offset is used to obtain an approximate yield point.
- *Although the **yield** and the **proportional** limit points **are close** to each other, they **do not correspond** to the same location on the stress-strain curve.*

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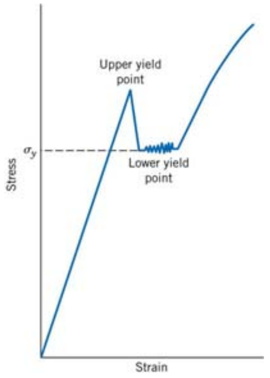
# Yield Strength



- For a low-carbon steel, the stress vs. strain curve includes both an upper and lower yield point.
- The yield strength is defined in this case as the average stress at the **lower yield** point.

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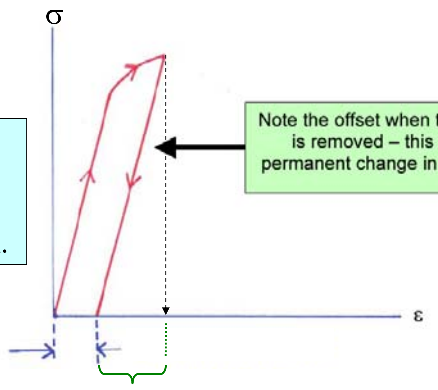
# Plastic Deformation

Suppose a tensile load is applied to a specimen and then released after the yield point was reached!

Plastic deformation is Irreversible: when the stress is removed, the material does not return to its original dimension.



Note the offset when the load is removed – this is a permanent change in shape.

**Elastic recovery**

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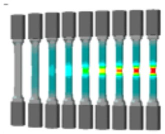
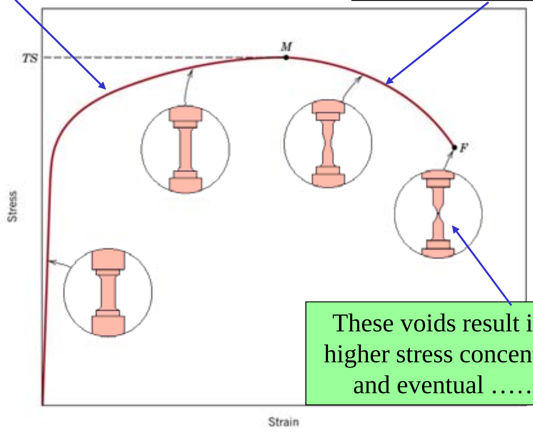
# Mechanical Behavior

As plastic deformation proceeds, the force increases due to …………..

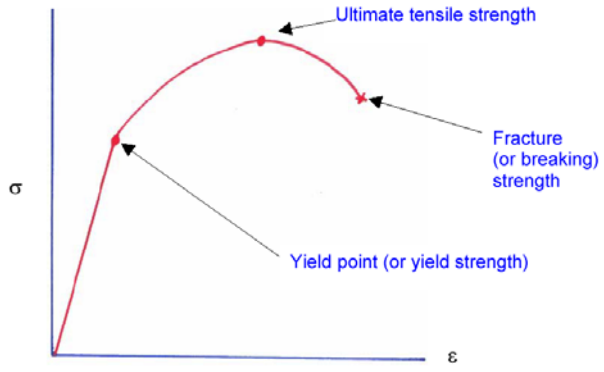
**As more of the stress becomes concentrated in the neck, formation of voids occur**





These voids result in even higher stress concentrations and eventual ………..

# Mechanical Behavior



• *For structural applications, the yield stress is usually a more important property than the tensile strength, since once it is passed, the structure has deformed beyond acceptable limits.*

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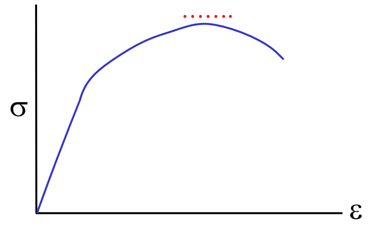
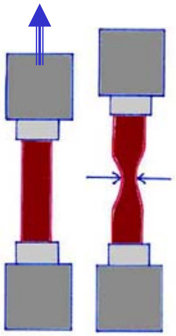
# Mechanical Behavior





Question: In ductile metals, the σ - ε curve eventually turns down after reaching the ultimate tensile strength (UTS). Does this mean the specimen is becoming "weaker"?

we know that the gauge area decreases during plastic deformation due to necking

*Recall the definition of stress: "engineering" stress = $F/A_o$ where $A_o$ is the initial cross-sectional area*

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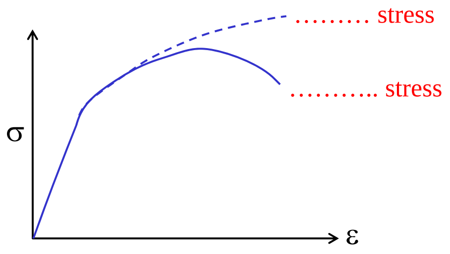
# Engineering Stress vs. True Stress

*Since the actual cross-sectional area is reduced, use of the initial area gives a lower value than the actual one (the ratio is $A_o/A_c$).*



• Even though the true stress-strain curve gives a more accurate picture of the breaking strength of a material, it is difficult to obtain measurements of *the actual area in real-time*.

• Usually, the reported values are the engineering stress.

• True fracture strength > tensile strength

  ✓ *but the engineering σ - ε diagram does not show this*

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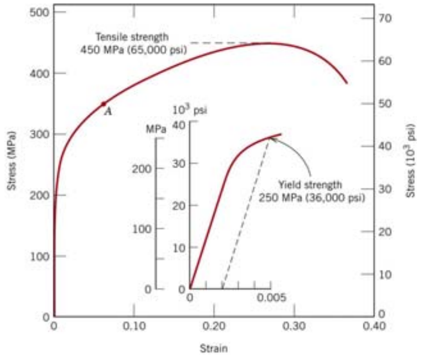
# Example



From the tensile σ - ε behaviour for a specimen of brass shown in the figure, determine the following:

a) modulus of elasticity

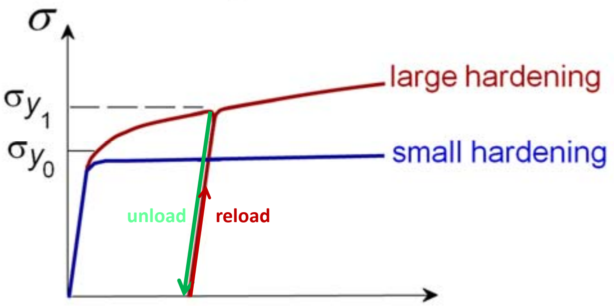
b) yield strength at a strain offset of 0.002

c) maximum load that can be sustained by a cylindrical specimen having an original diameter of 12.8 mm

d) change in length of a specimen originally 250 mm long that is subjected to a tensile stress of 345 MPa

# Strain Hardening

- An increase in $\sigma_y$ due to plastic deformation.



- Curve fit to the stress-strain response:

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

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

"true" stress (F/A)

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

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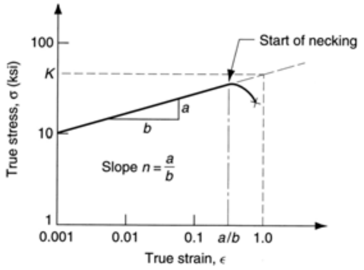
# True Stress-True Strain Curve



*True stress-strain curve plotted on log-log scale*

| Material | n | K MPa | K psi |
|---|---|---|---|
| Low-carbon steel (annealed) | 0.26 | 530 | 77,000 |
| Alloy steel (Type 4340, annealed) | 0.15 | 640 | 93,000 |
| Stainless steel (Type 304, annealed) | 0.45 | 1275 | 185,000 |
| Aluminum (annealed) | 0.20 | 180 | 26,000 |
| Aluminum alloy (Type 2024, heat treated) | 0.16 | 690 | 100,000 |
| Copper (annealed) | 0.54 | 315 | 46,000 |
| Brass (70Cu–30Zn, annealed) | 0.49 | 895 | 130,000 |

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

Because it is a straight line in a log-log plot

K: strength coefficient

n: strain-hardening exponent

- The ……… the slope the stronger when material is strained

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# Safety Factors in Design

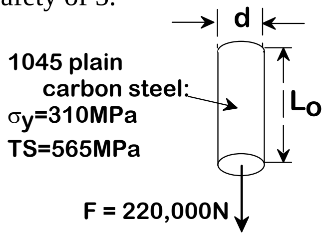
- Design uncertainties mean we do not push the limit.
- Factor of safety, N

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

Often N is between 1.2 and 4

- Example:

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.



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Next time:

Toughness, Hardness…