



**CIVE.3110 Engineering Materials Laboratory  
Fall 2016**



# **Tensile/Tension Test – Advanced Topics –**

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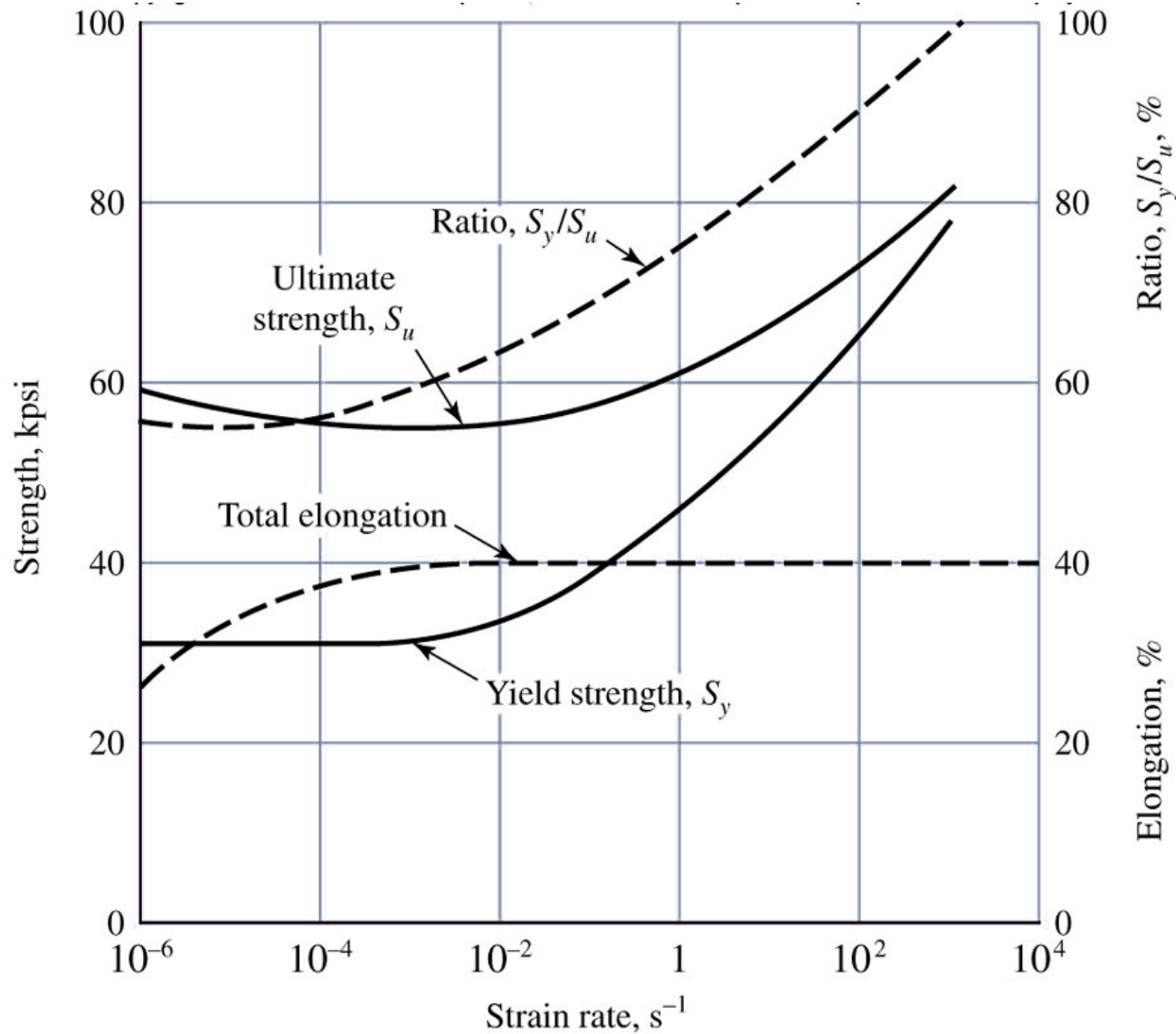
**SERG**

# Tensile Test

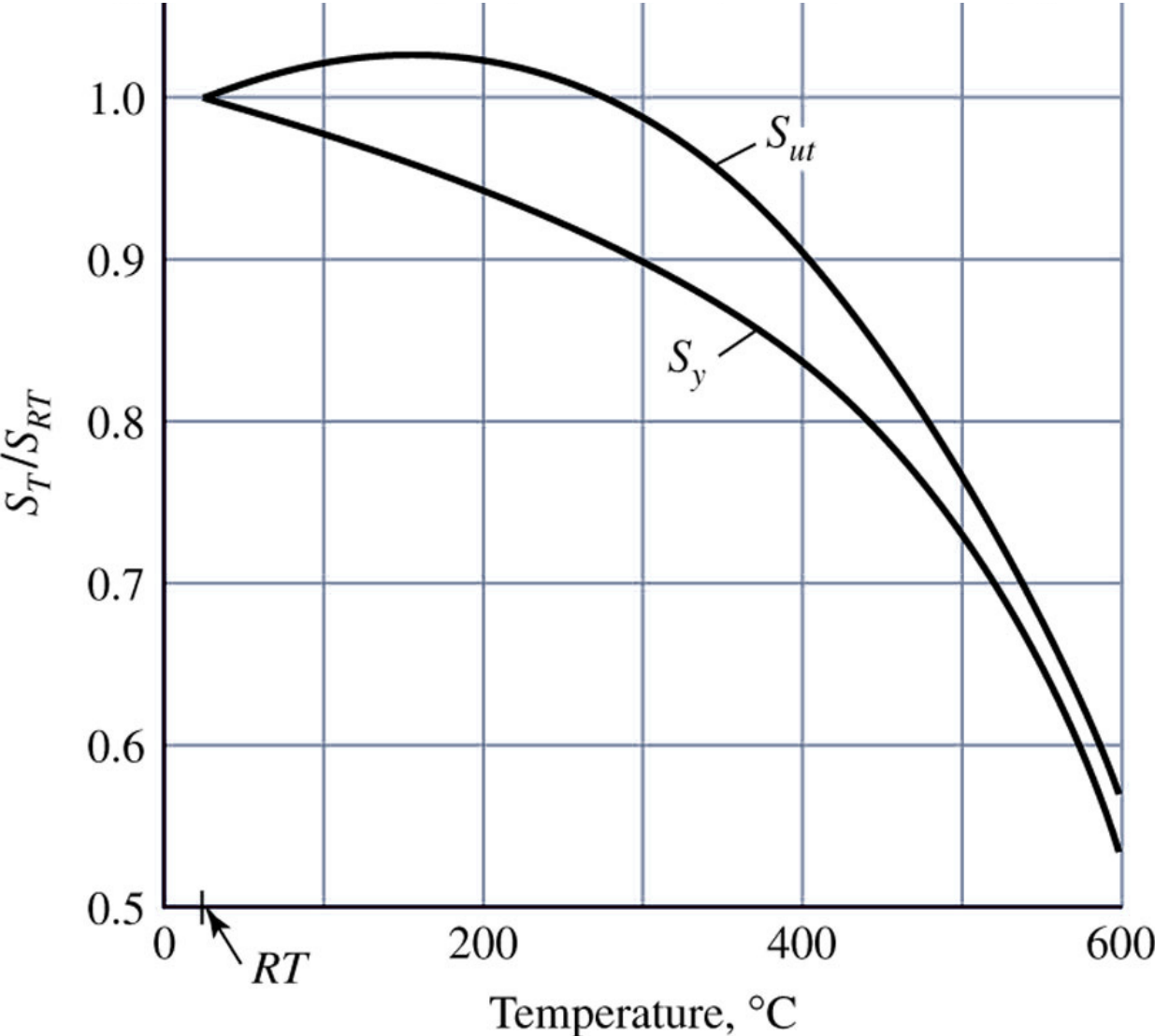
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- **Strain rate** – Rapid stress application, as in an **impact** test, measures the ability of the material to absorb energy as it fails.
- **Temperature effect** – At high temperatures, materials deform continuously under an applied stress, as measured by the **creep** test.
- Repeated application of stresses below the failure stress determined in a tensile test can cause **fatigue** failure.
- **Strain/work hardening (cold working)** – Dislocation movements and dislocation generation within the crystal structure of metals increase the strength of metals.
- **Necking** – Ductile materials exhibit necking before ultimate fracture.
- **Statistical significance** – Tensile test result varies from one to another even for same material. Test result should be interpreted statistically.
- **Fracture toughness** – The materials response to the presence of cracks and flaws that act as stress concentrators is measured by **fracture** toughness.

# Influence of Strain Rate



# Temperature Effect



# Strain Hardening

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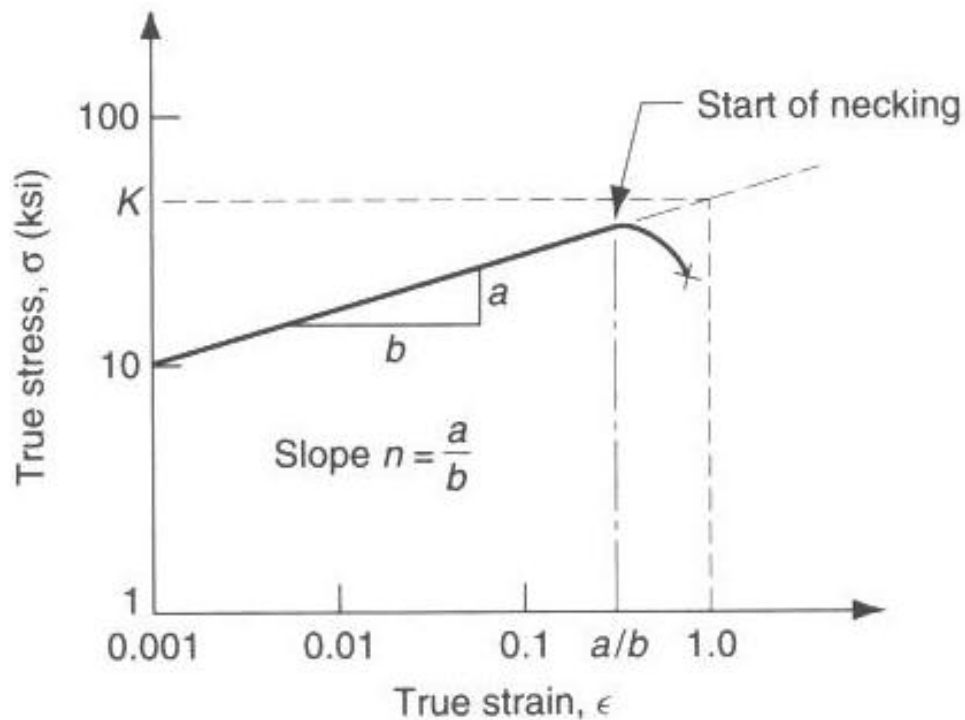
- Phenomenon – In the plastic region, the true stress increases continuously. This implies that the metal is becoming stronger as the strain increases.
- The relationship between true stress  $\sigma$  and true strain  $\varepsilon$  i.e. the flow curve can be expressed using the power law:

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

where  $K$  is called the strength coefficient and  $n$  the strain hardening exponent.

# Strain Hardening

Strain Hardening:



- The plastic portion of the true stress-strain curve (or flow stress curve) plotted on a log-log scale gives the  $n$  value as the slope and the  $K$  value as the value of true stress at true strain of one.

$$\log(\sigma) = \log(K) + n \log(\epsilon)$$

- For materials following the power law, the true strain at the UTS is equal to  $n$ .

# Strain Hardening

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## Effect of Strain Hardening –

- The influence of work/strain hardening on the load vs. elongation during the tensile test can be demonstrated using finite element (FE) analysis.
- Consider two materials with the following flow stress data:
  - Stainless Steel:  $K = 188$  ksi;  $n = 0.33$
  - Aluminum Alloy:  $K = 80$  ksi ;  $n = 0.10$ .
- The tensile test simulations for these two materials show the effect of strain hardening on the load required for deformation and the uniform elongation prior to the onset of necking.

# Strain-hardening Coefficient

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- The response of different metals to plastic deformation depends on their crystal structure.
- The shape of the stress-strain curve shows how much increase in strength can be gained by strain hardening. For this purpose, the true-stress vs. true-strain curve is more useful than the conventional engineering stress-strain diagram. The expression defines the strain hardening coefficient  $n$ .

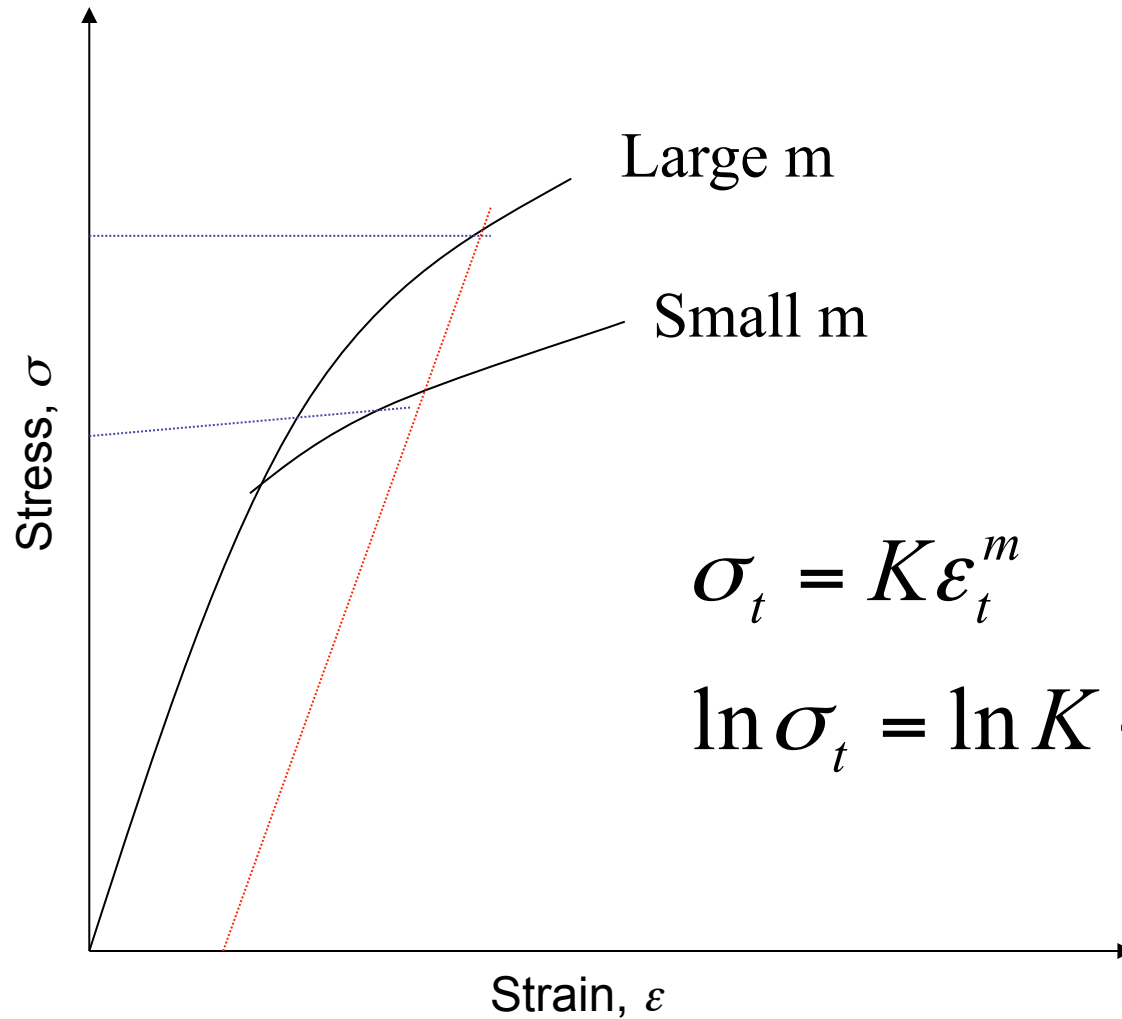


# Strain-hardening Coefficient

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- The true-stress vs. true-strain curve is a plot of the stress in the sample at its minimum diameter, after necking has begun, vs the local elongation.
- This more accurately reflects the physical processes happening in the material, but is much more difficult to measure than the engineering stress and strain, which divide the applied load by the original cross-sectional area, and the total elongation by the original length.

# Strain-hardening Coefficient

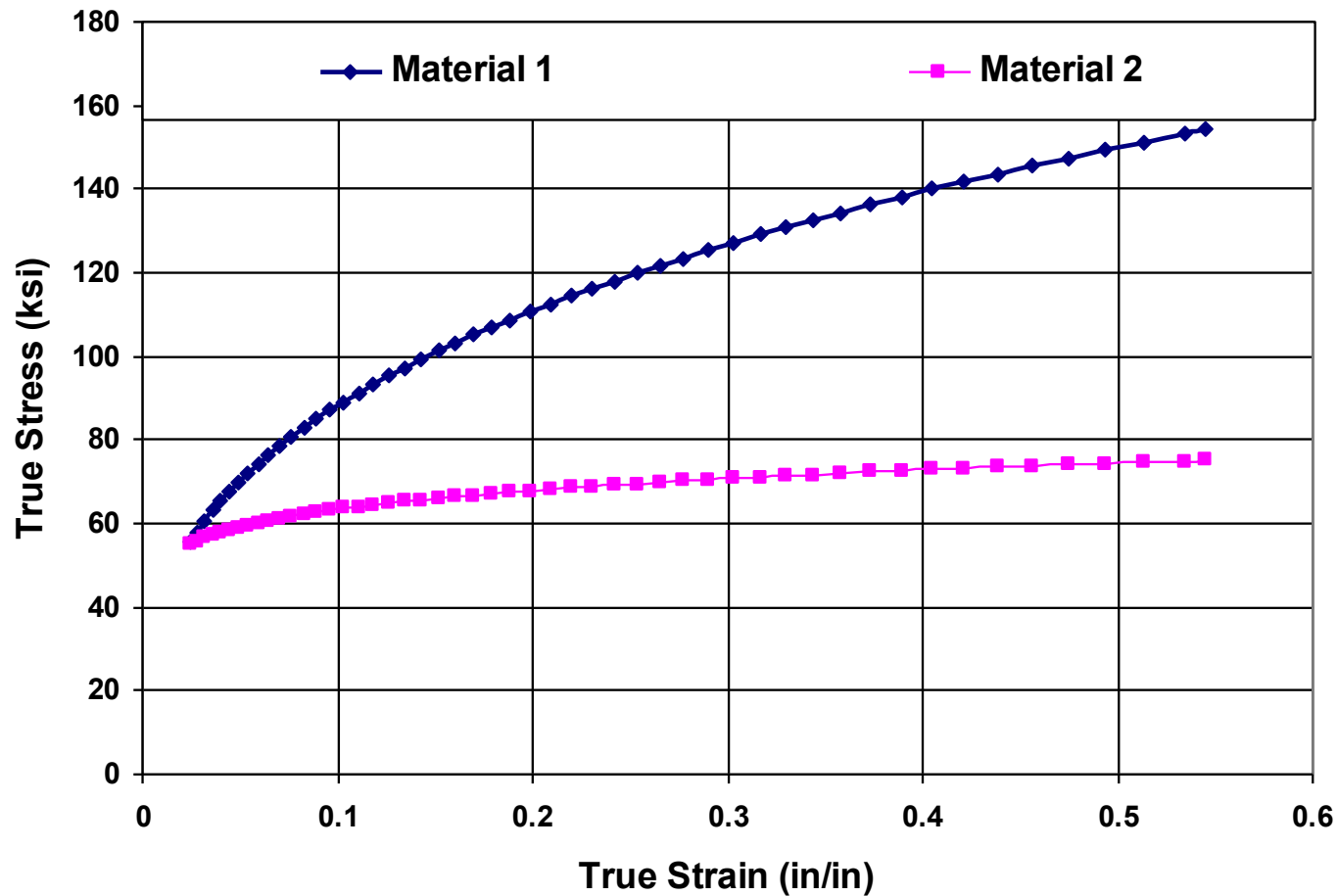


# Strain Hardening

- Effect of Strain Hardening:

**Stainless Steel**  $K=188$   
 $n=0.33$

**Aluminum**  $K=80$   
 $n=0.10$



# Strain Hardening

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Note: when you plot the log-log plot, use datapoints after the yield point (to avoid elastic points) and before instability (necking).

- A material that does not show any strain-hardening ( $n=0$ ) is designated as **perfectly plastic**. Such a material would show a constant flow stress irrespective of strain.
- $K$  can be found from the y-intercept or by substituting  $n$  and a datapoint (from the plastic region) in the power law.

# Tensile Test Example

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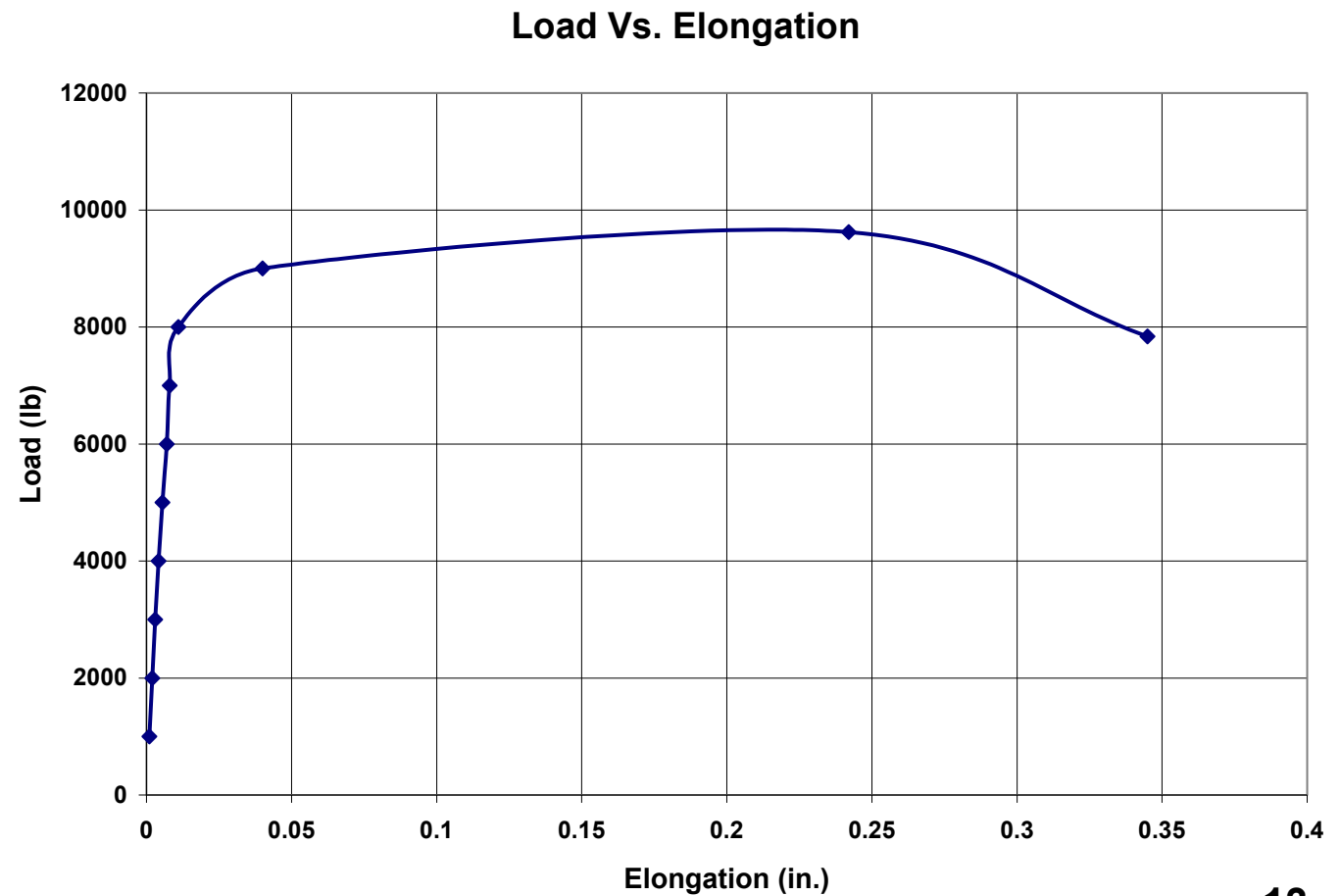
Load vs. Elongation (*Data obtained from the tensile test*):

*Material Data:*

Al 6061

Y = 40 ksi

TS = 49 ksi



# Tensile Test Example

Engineering Stress vs. Strain (*calculated from Load vs. Elongation data*):

*Material Data:*

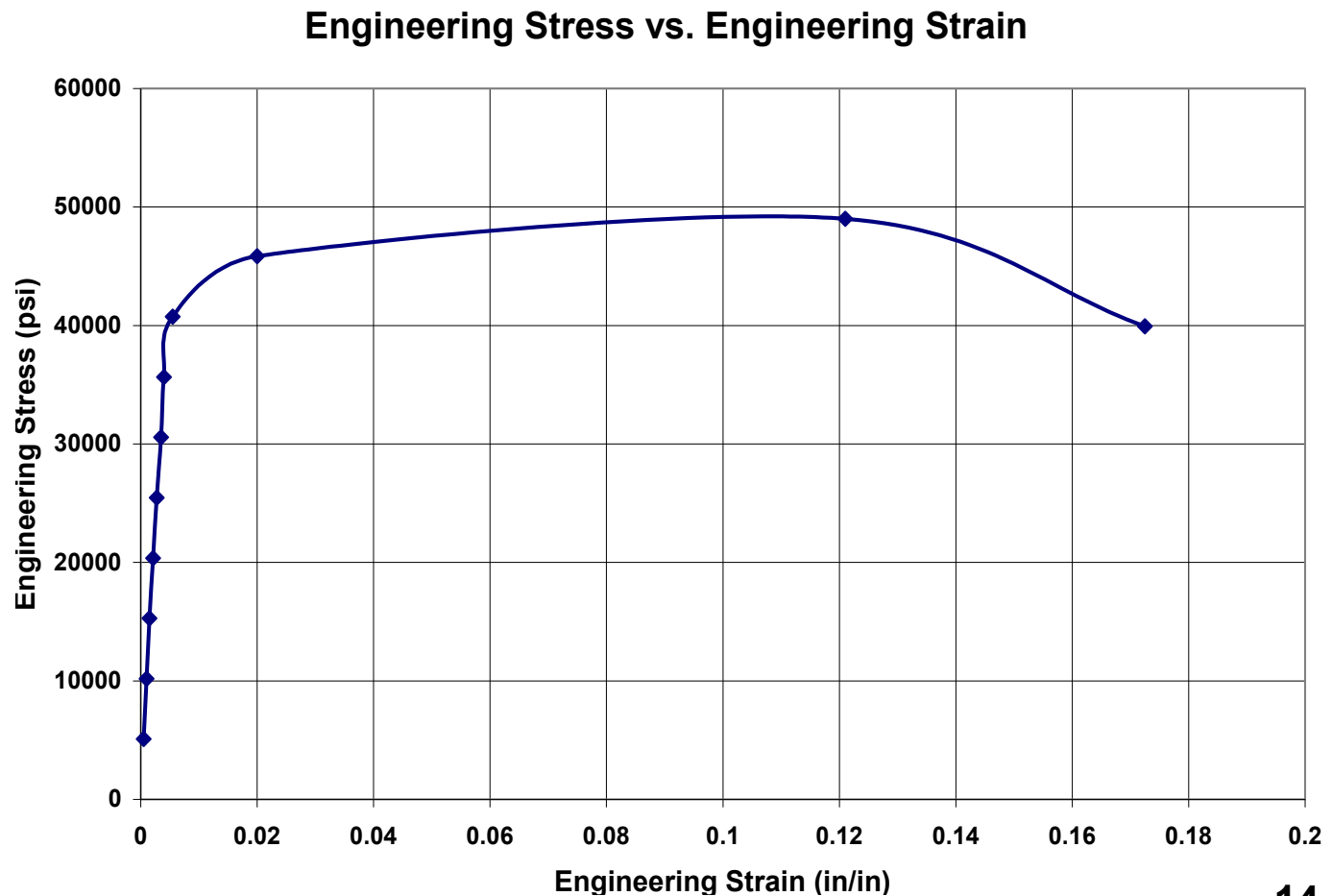
Al 6061

Y = 40 ksi

TS = 49 ksi

$$\sigma_e = \frac{F}{A_0}$$

$$e = \frac{L - L_0}{L_0}$$



# Tensile Test Example

True Stress vs. True Strain (*calculated from Engineering stress/strain data*):

*Material Data:*

Al 6061

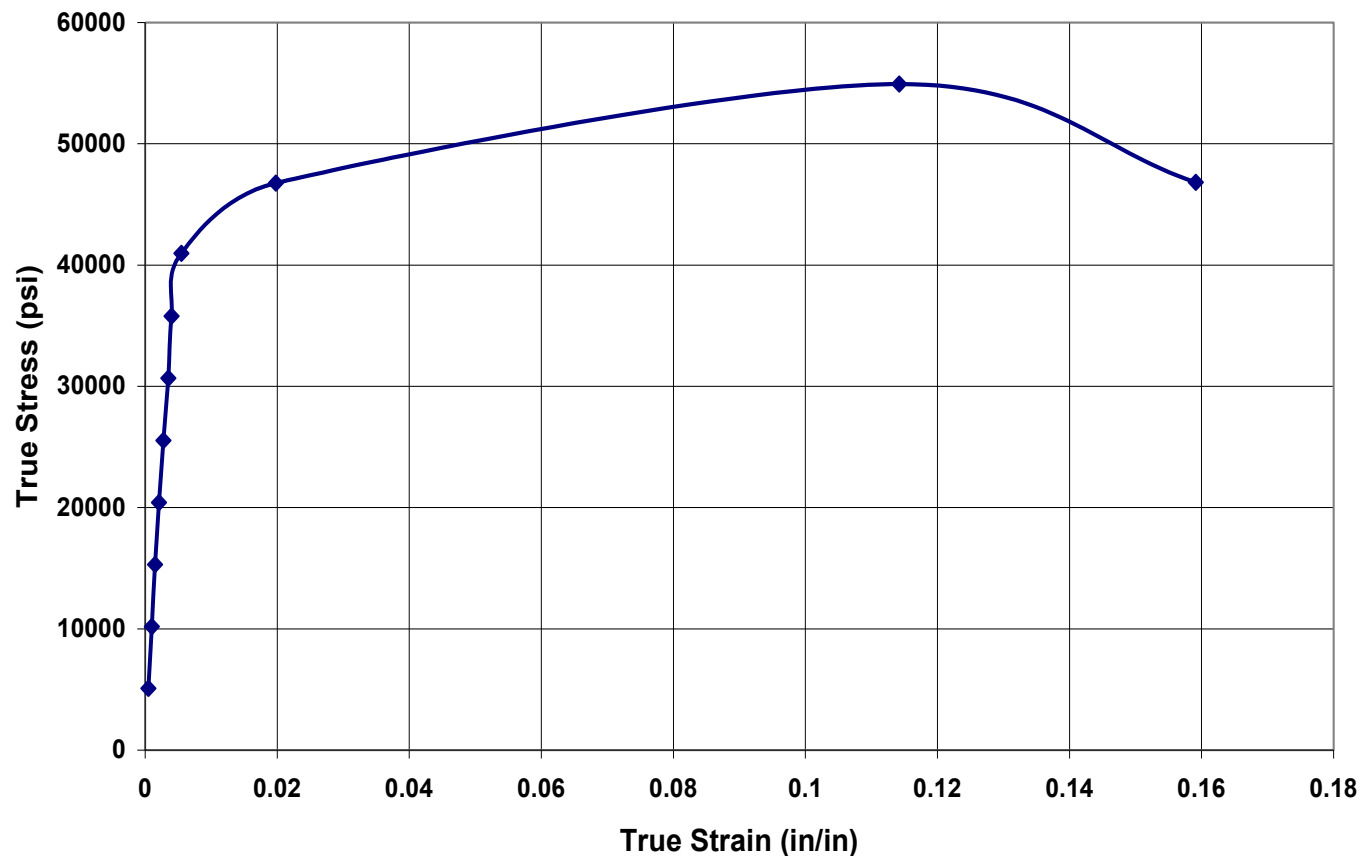
Y = 40 ksi

TS = 49 ksi

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

$$\varepsilon = \ln \frac{L}{L_0}$$

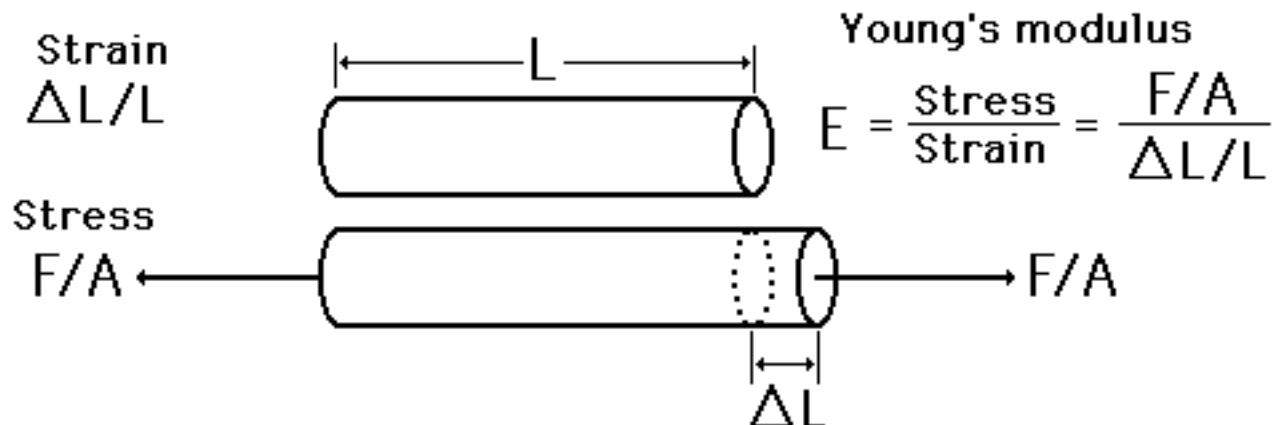
True Stress vs. True Strain



# Tensile Test

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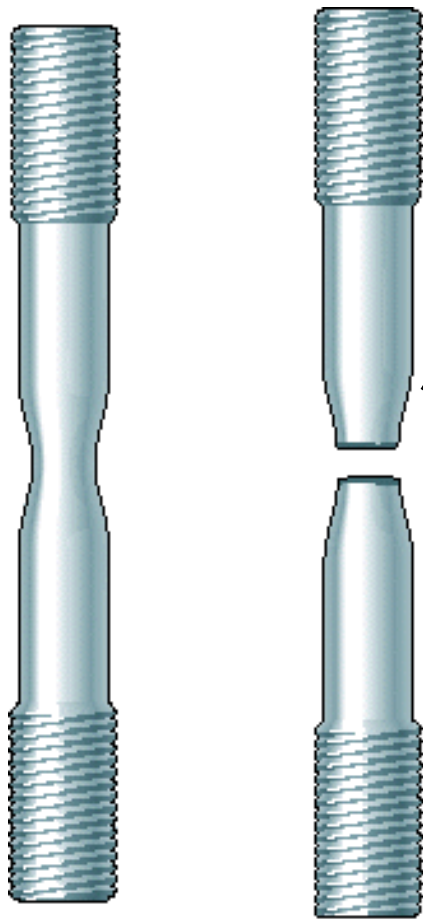
- The mechanical properties of a material are used to determine its suitability for a particular application.
- It is convenient to break the properties, and the tests that measure them, into several types
  - Slow application of stress, as in the [tensile test](#), allows dislocations time to move





# Ductile Tension Test Specimens

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(a)



(b)

Can you tell how we can elongate the bar without breaking in manufacturing process?

Ductile material from a standard tensile test apparatus. (a) Necking; (b) failure.

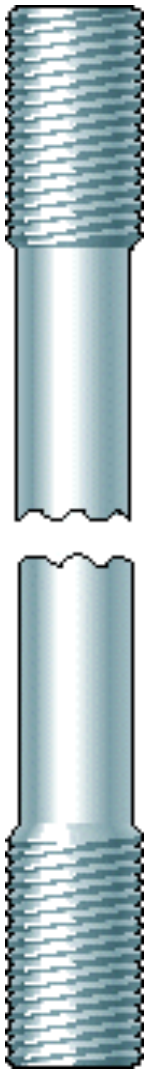
# Ductile Materials

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- $\%EL = (l_f - l_0) / l_0 * 100\%$
- Ductile material  $\rightarrow \%EL > 5\%$ 
  - Low carbon 37%
  - Medium carbon 30%
  - High carbon 25%
- Ductile material can be brittle under dynamic load.

# Brittle Tension Test Specimen

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Failure of a brittle material from a standard tensile test apparatus.

# Stress-Strain Diagram/Curve

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- Plotting the applied stress versus the strain or elongation of the specimen shows the initial **elastic** response of the material, followed by **yielding**, **plastic** deformation and finally **necking** and **failure**
- Several measurements are taken from the plot, called the Engineering Stress-Strain Diagram/Curve.

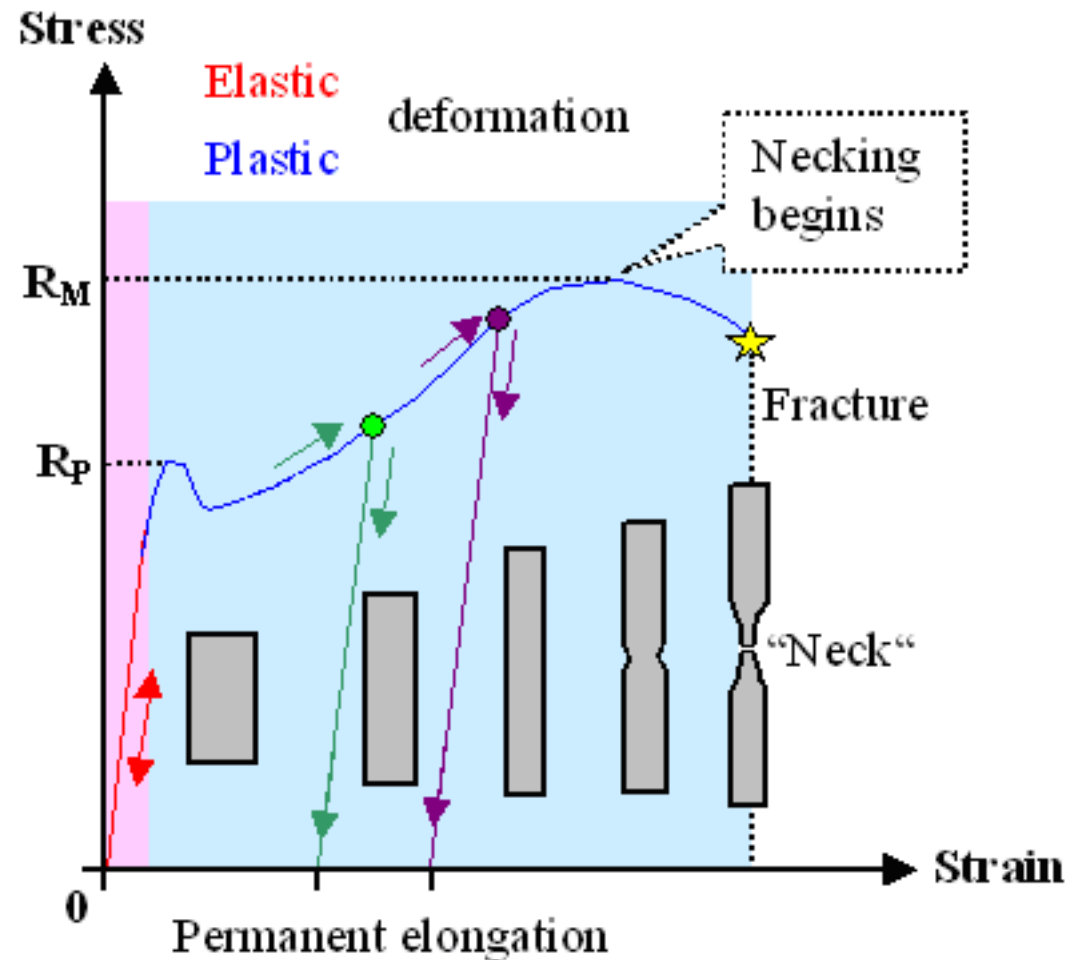
# Definitions

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- Students are sometimes confused by the elastic contraction that occurs when the applied stress is released, either by reversing the test machine or when the specimen breaks. The **contraction** follows the same slope as the linear elastic portion of the stress-strain curve, defined by the **modulus of elasticity** of the specimen. It is the result of the atoms moving back to their equilibrium separation distance. Hence it is shown on the diagram as **a line parallel to the elastic portion of the curve**. Any net strain remaining after the stress is released is **plastic deformation**.

# Necking

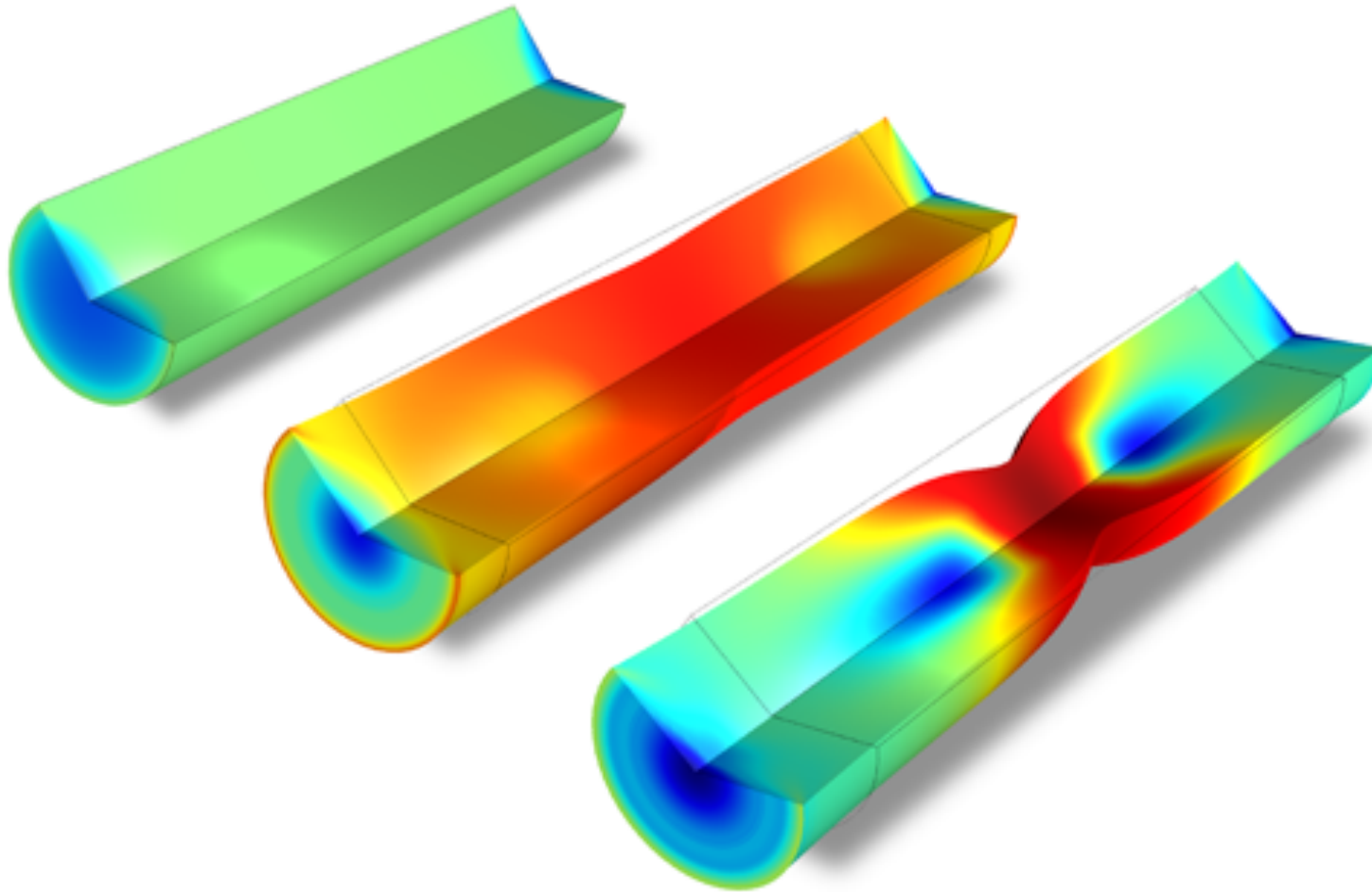
- The **engineering stress-strain curve** of a ductile material usually drops past the tensile strength point. This is because the cross-sectional area of the material decreases because of **slip** along atom planes that are oriented at an angle to the applied force (since the slip occurs by **dislocation** motion). This local deformation is called a necking.



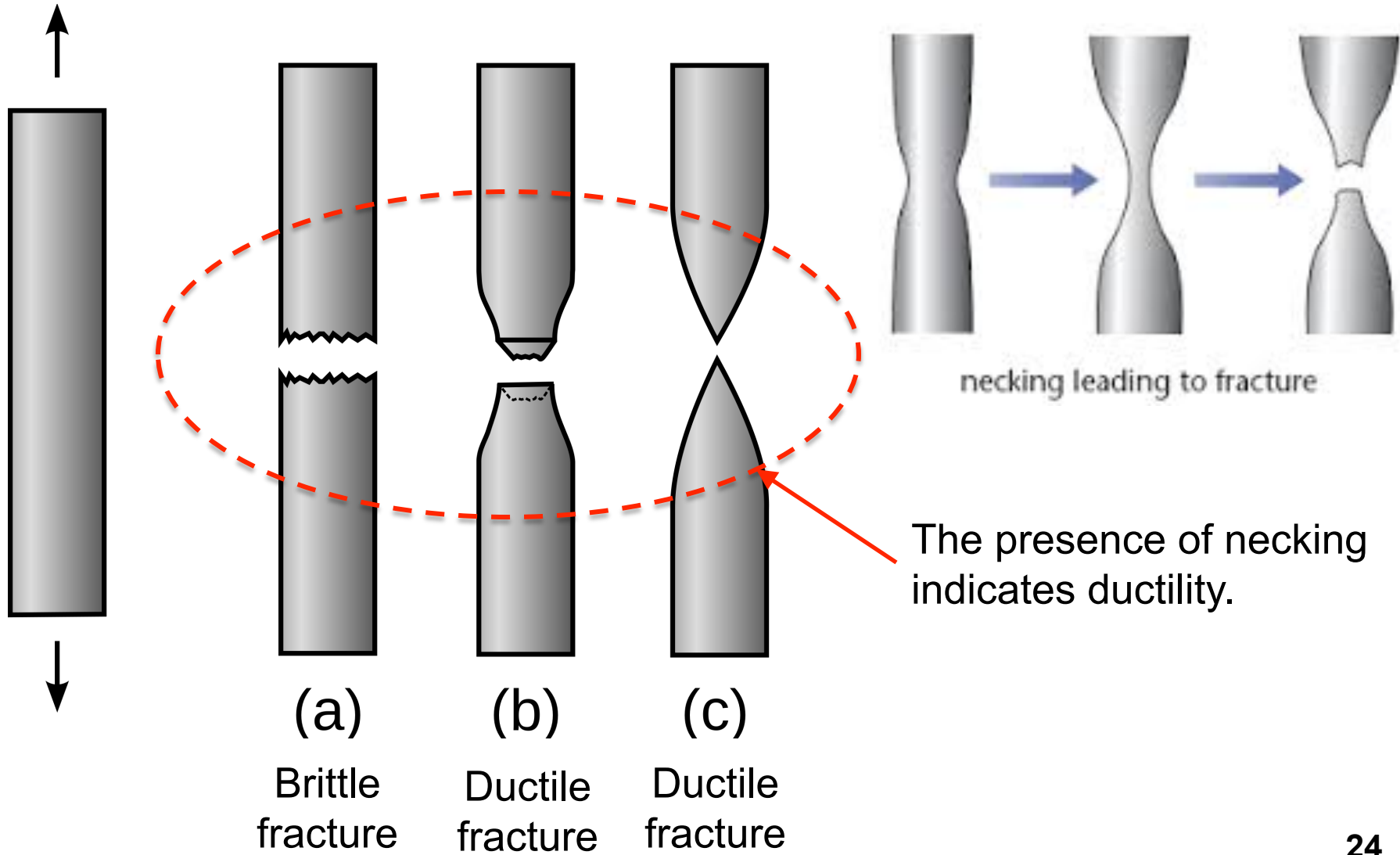
# Necking

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- Internal stress distribution of necking:



# Fracture





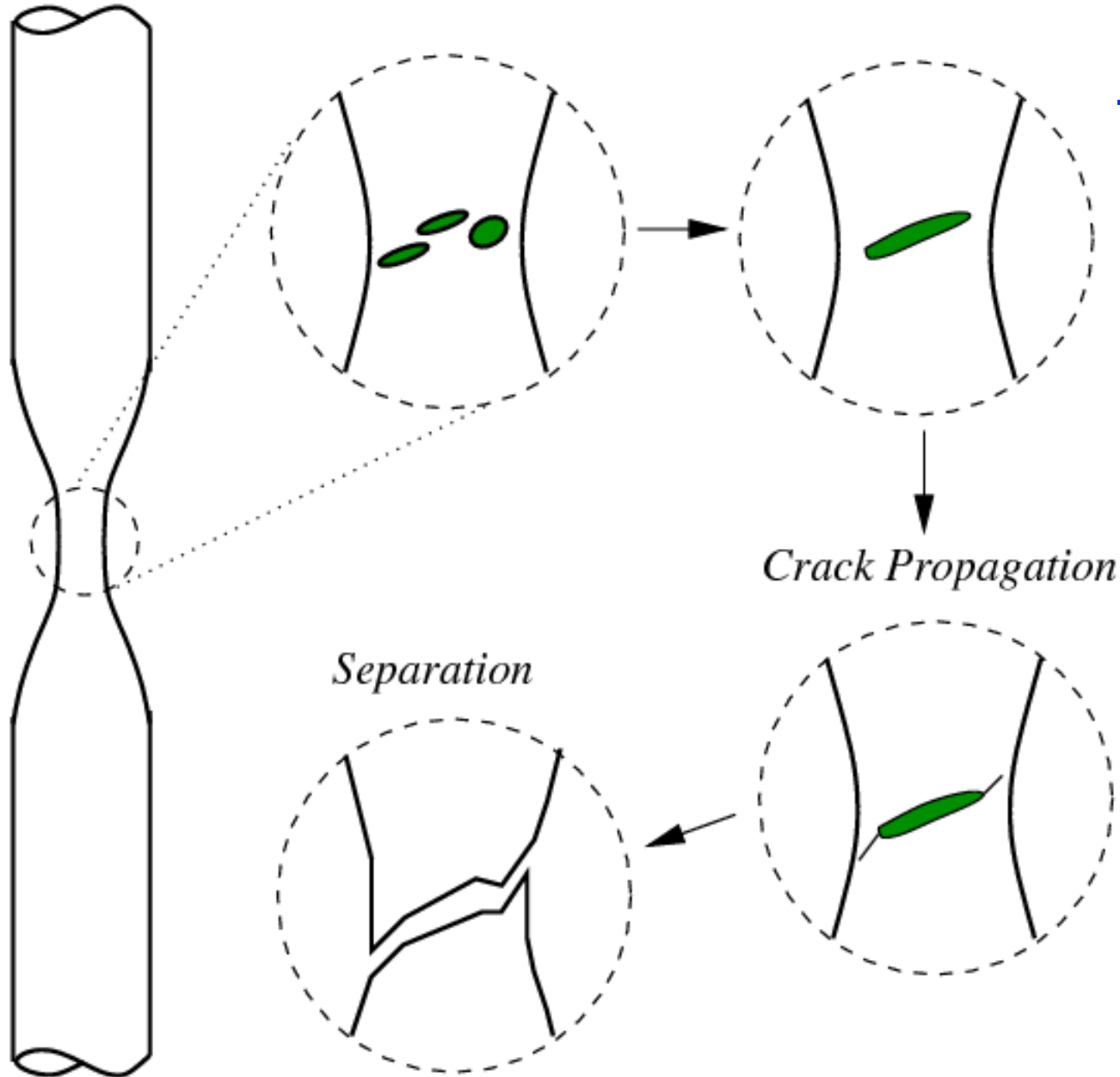
*Necking*

*Void Nucleation*

*Void Coalescence*

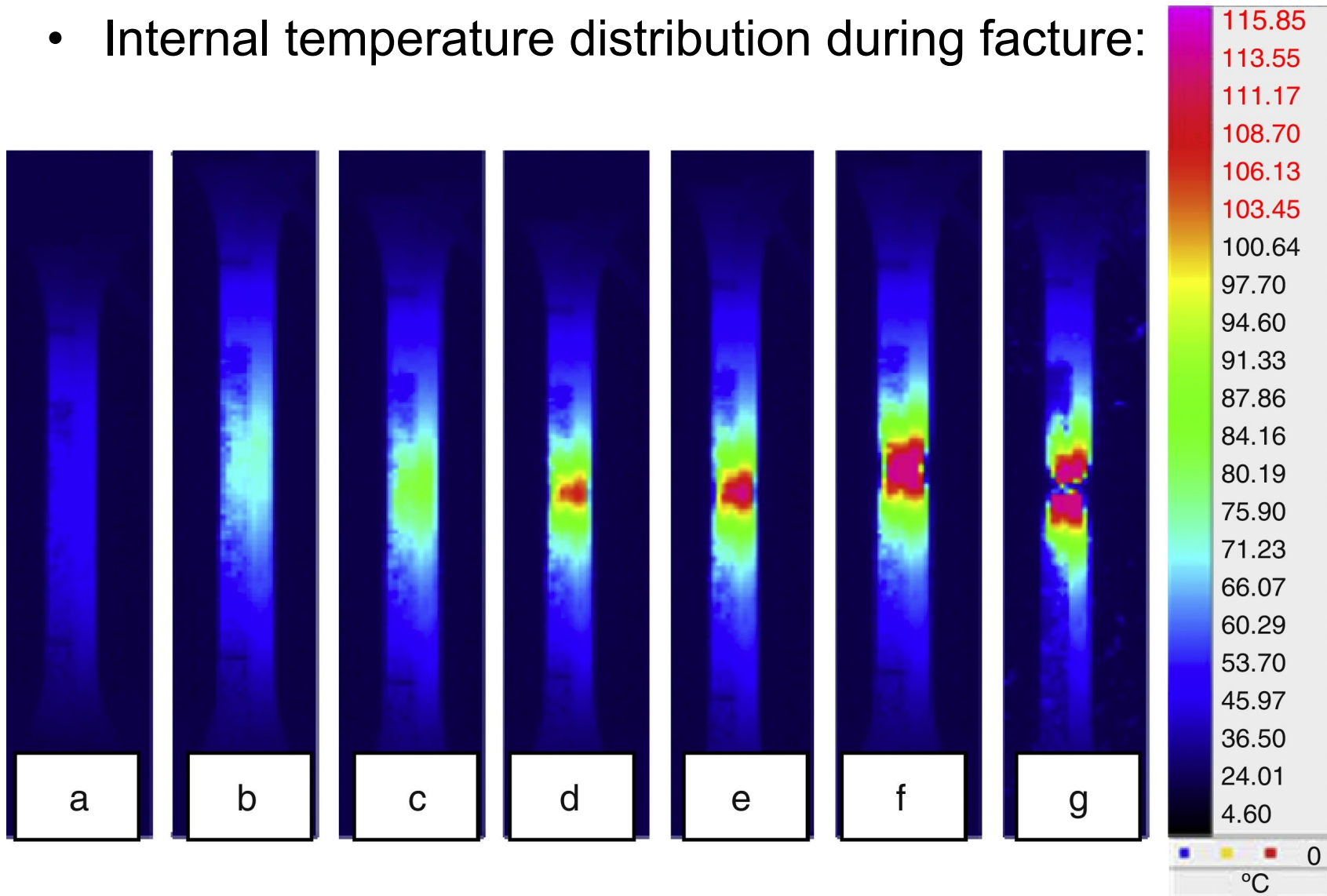
**Fracture**

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# Fracture

- Internal temperature distribution during fracture:



# Facture

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# Fracture Toughness

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- Stress intensification factor

$$k = f\sigma\sqrt{\pi a}$$

- Critical stress intensity factor (fracture toughness)  $K_c$
- If  $k$  becomes  $K_c$ , then crack propagate
- $K_{ic}$ : plane strain (large thickness case) fracture toughness; normally reported as material property

# Fracture Toughness

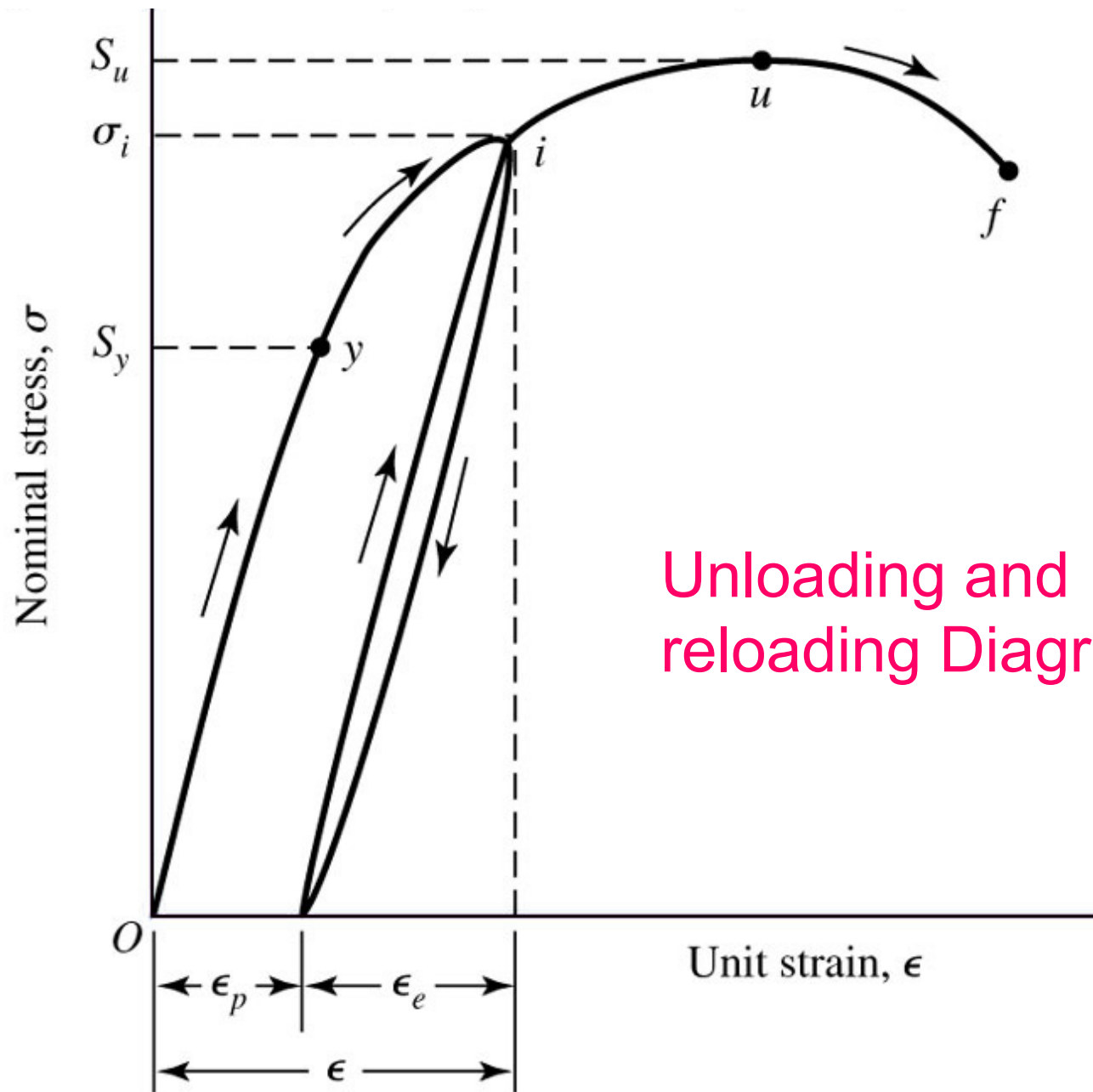
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- The geometry factor  $f$  is 1.0 for the case of a small surface crack in a very thick plate.
- The  $K_{Ic}$  value is a material constant, the same as other mechanical properties. It includes both strength and ductility characteristics of the material. The  $f$  and  $a$  values on the right side of the equation are the failure stress and the crack depth (or half the crack length for an internal crack), and it is their interrelationship that is important.

# Fracture Toughness

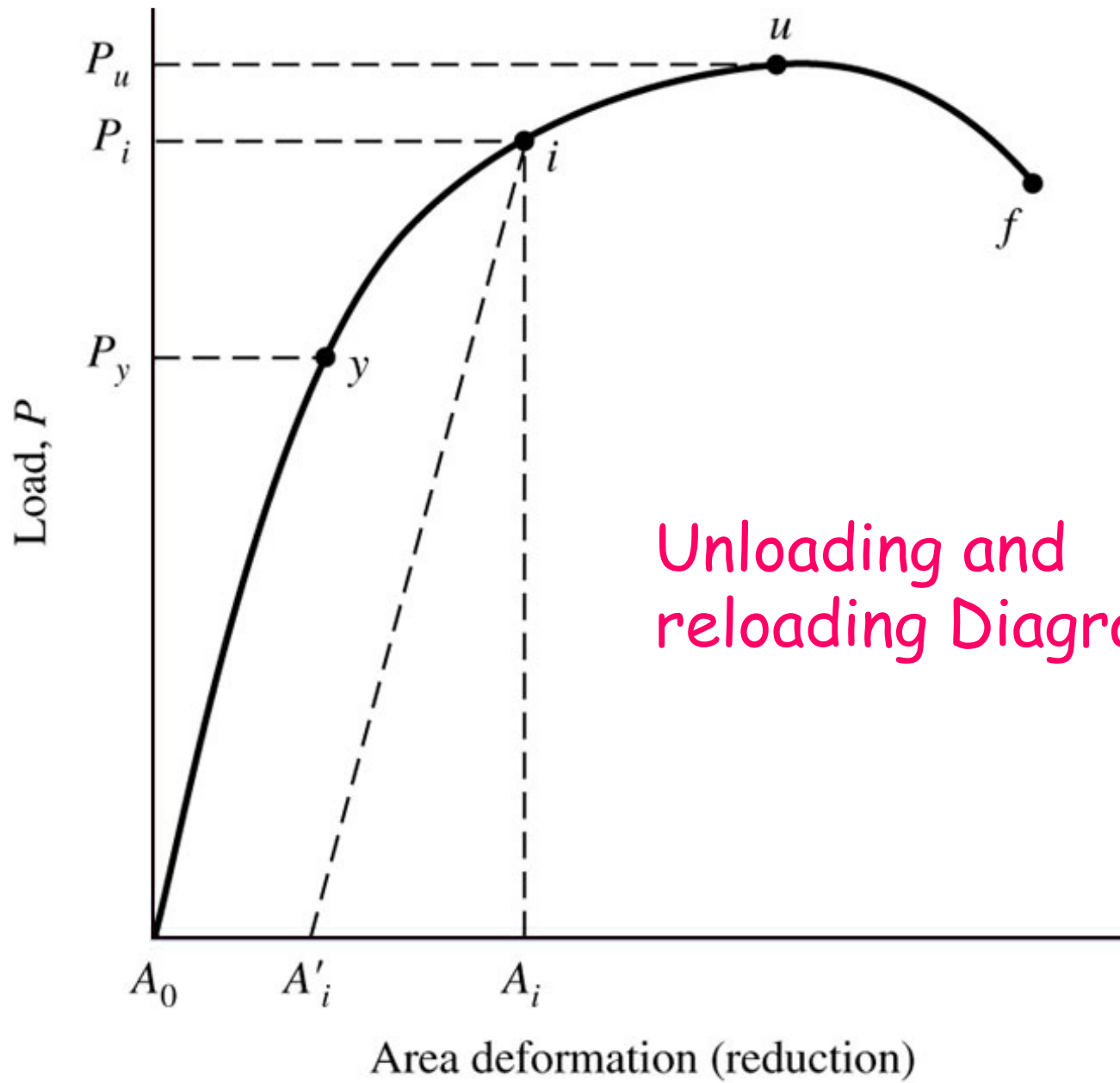
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- As the crack size increases the failure stress drops.
- To achieve a design failure stress, it must be possible to detect and prevent any cracks larger than a certain size.
- In addition to surface cracks that are present accidentally in materials, any hole or notch acts as a stress concentrator. Rivet holes in the aluminum skin of airplanes may act to start fractures.
- There is a direct relationship between the energy absorbed in impact and the toughness measured as the area under the stress strain curve. Materials with a high toughness value absorb more energy in fracture, which may provide a margin of safety in real structures in the event of failure.



Unloading and reloading Diagram

(a)



Unloading and reloading Diagram

(b)



# Statistical Significance

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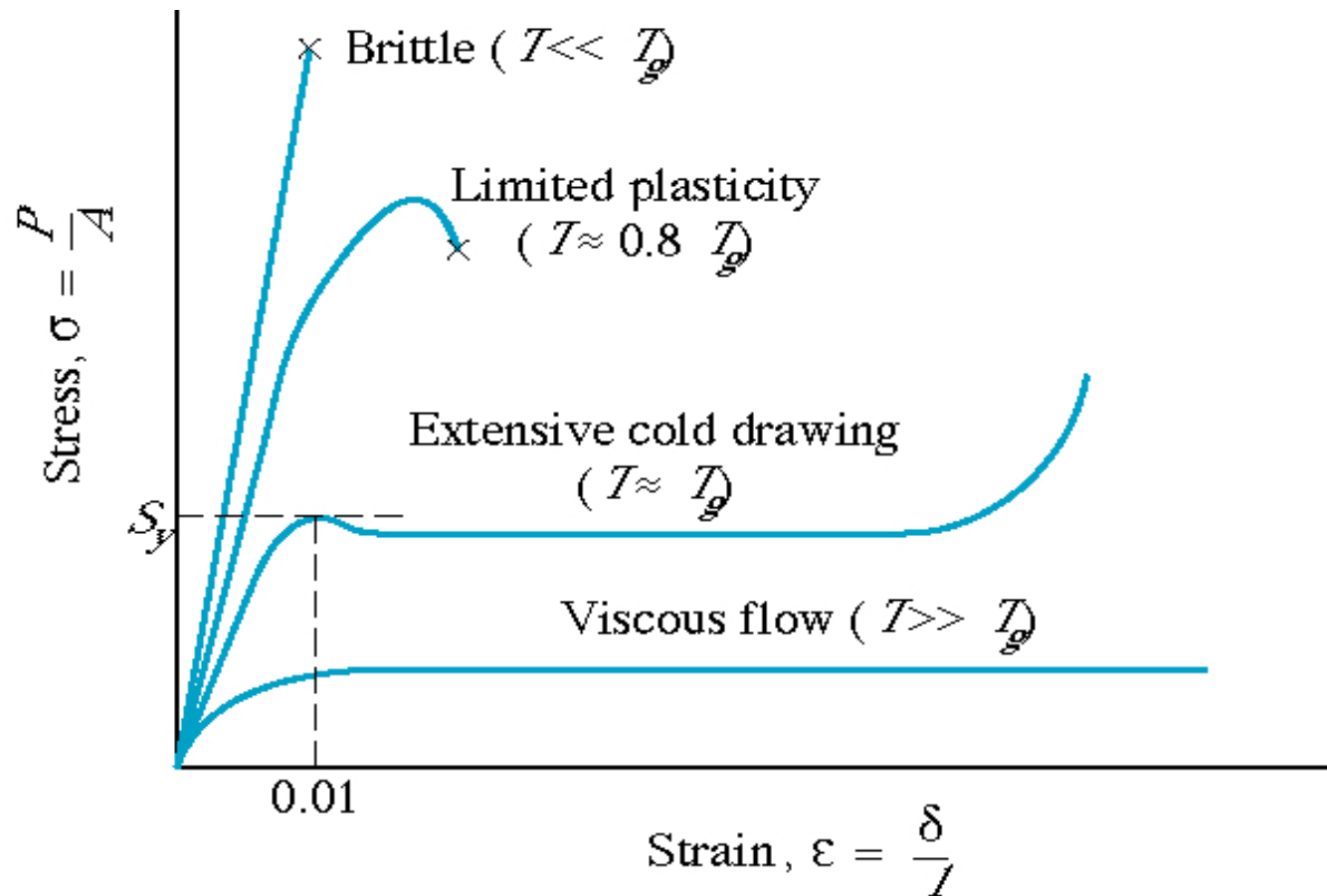
- If we test more specimens, we will find different strength measurements during tensile tests. → *Specimens are not perfectly homogeneous and not made of identical material (or materials of identical quality).*
- Statistical (stochastic) interpretation is necessary.
- Probability density function of the normal distribution –

$$f(x) = \frac{e^{-\frac{1}{2}z^2}}{\hat{\sigma}_x \sqrt{2\pi}} \quad z = (x - \mu) / \hat{\sigma}_x$$

$\hat{\sigma}_x$  = standard deviation = (variance)<sup>1/2</sup>

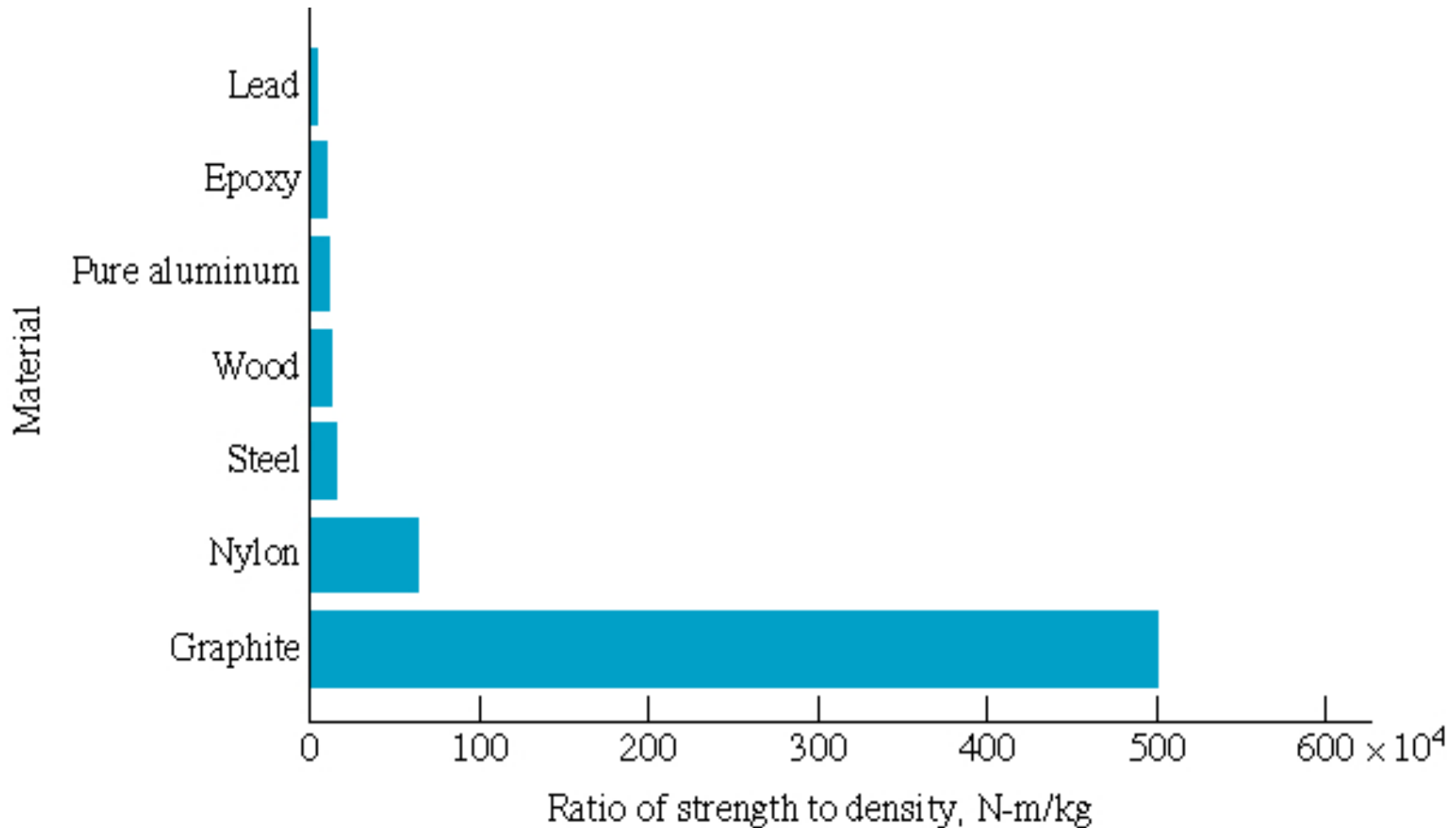
$\mu$  = mean/expectation

# Stress-Strain Diagram for Polymers



Stress-strain diagram for polymer below, at, and above its glass transition temperature  $T_g$ .

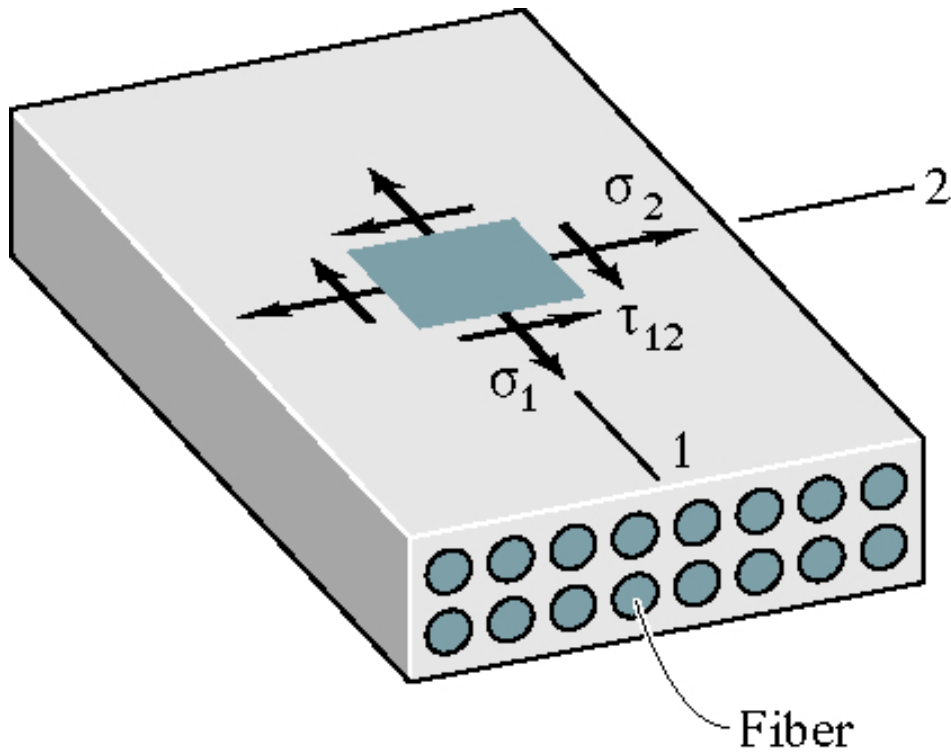
# Strength/Density Comparison



Strength/density for various materials.

# Fiber Reinforced Composite

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Cross section of fiber reinforced composite material.

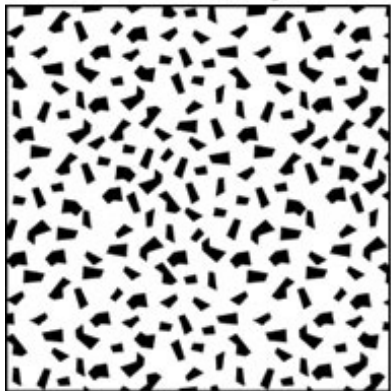
# Composite

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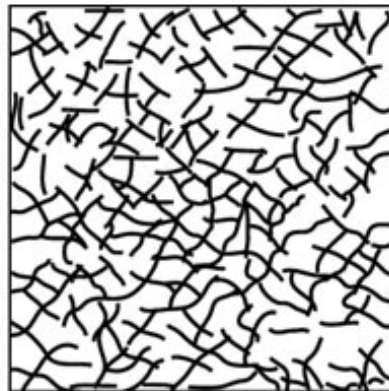
- The smaller the diameter, the more stronger.
- Fibers are very small in diameter
- Fibers are brittle; the matrix provides toughness
  - Lightweight
  - you can tailor to the need; strengthen to various angles
  - Corrosion resistance

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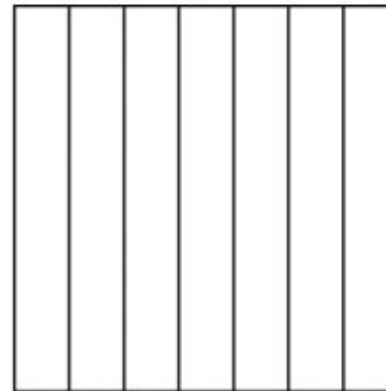
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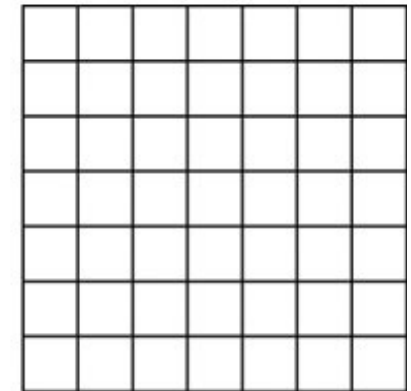
Particulate composite



Randomly oriented short fiber composite



Unidirectional continuous fiber composite



Woven fabric composite