OPENCOURSEWARE

SOLID MECHANICS
BETM 2303
MECHANICAL PROPERTIES OF MATERIAL

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LESSON OUTCOME

1. To differentiate between elastic and plastic deformation of material.
2. To understand how to measure the stress and strain through experiments.
3. To correlate the properties of some engineering materials to the stress-strain diagram.

Strength of Materials

- Strength of material is the tendency of material to withstand applied load with no any deformation.
- Many materials when in service, are subjected to forces or load
- The properties of a material reflect the relationship between the deformation of the material to an applied load or force

Elastic Deformation

- Elastic deformation: is a deformation in which the material return back to its initial/original position after the load acting on the material is removed.
- Elastic deformation is temporary
- Elastic deformation is reversible

Plastic Deformation

- Plastic deformation: is a deformation in which the material cannot return back to its initial/original position after the load acting on the material is removed.
- Plastic deformation is permanent
- Plastic deformation is irreversible

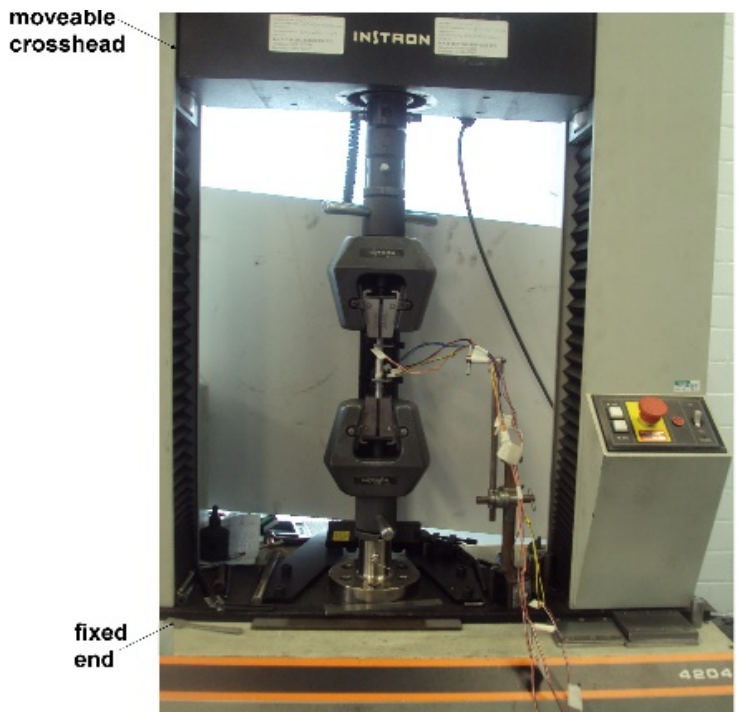
The Tension-Compression Test

- One of the most important test to perform in order to check the tendency of a material to withstand the applied load with no any deformation is known as tension or compression test.

The Tension-Compression Test

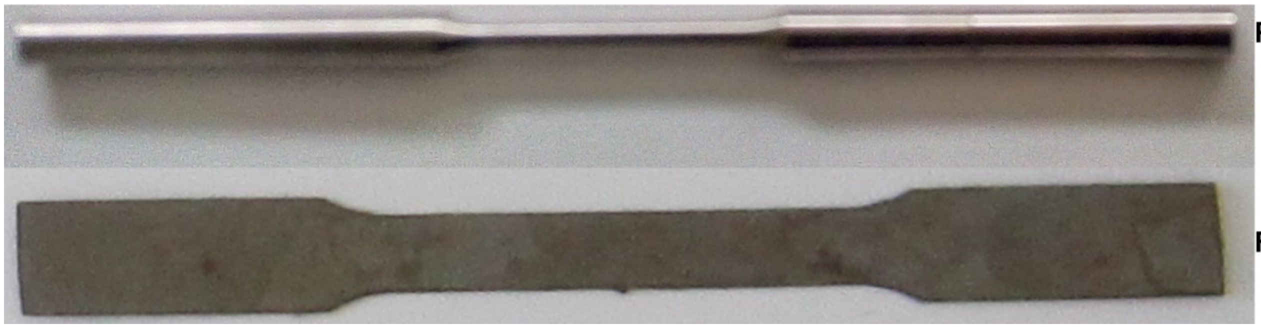
Tension-compression machine vary from one brands or manufacturer to the other. And also vary in the capacity of the load cell, i.e., 50 kN, 250 kN etc.

A typical tension-compression instron machine is shown in the figure below.



Procedure for Tension-Compression Test

1. The specimen must be machined into standard size and shape using the recommended standard (such as ASTM, BS EN 10002-1). The specimen can be a flat specimen or a round coupon.



Round specimen

Flat specimen

2. Mark the gage length (L_o), i.e., distance between two mark on the sample. The gage length is taken as the initial length of the sample for strain calculations.

Procedure for Tension-Compression Test

3. Grip the specimen at the ends. And apply the tensile load (pulling the specimen away from the fixed end) or compressive load (pushing the specimen towards the fixed end).
4. At frequency interval, read the load and the elongation ($\Delta L = L - L_o$ between the mark on the specimen using extensiometer.

Procedure for Tension-Compression Test

5. Convert the load and deflection recorded to stress and strain.

$$\text{Stress, } \sigma = \frac{F}{A_o}$$

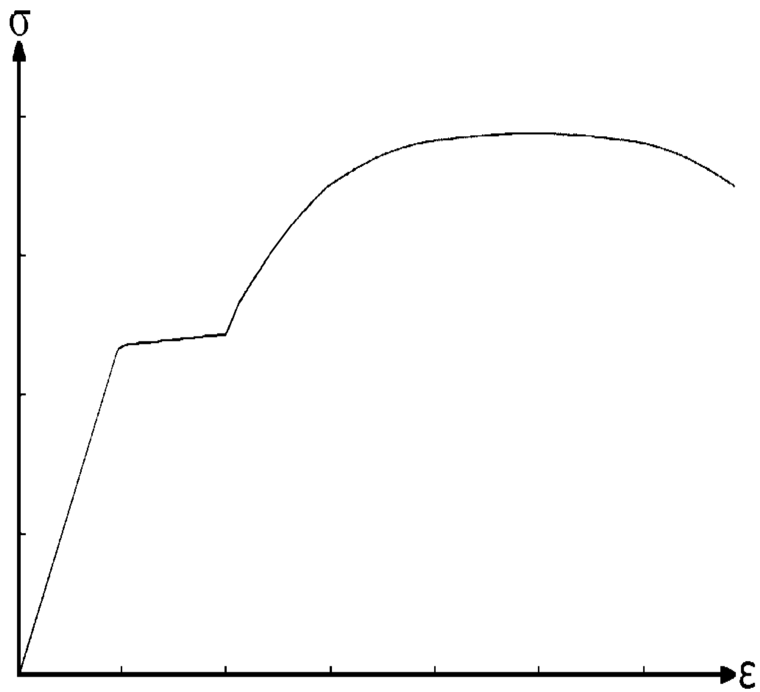
$$\text{Strain, } \quad \varepsilon = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o}$$

6. Plot the curve of stress versus strain which is called engineering stress-strain diagram.
7. From the $\sigma - \varepsilon$ curve, determine the mechanical properties of the material.

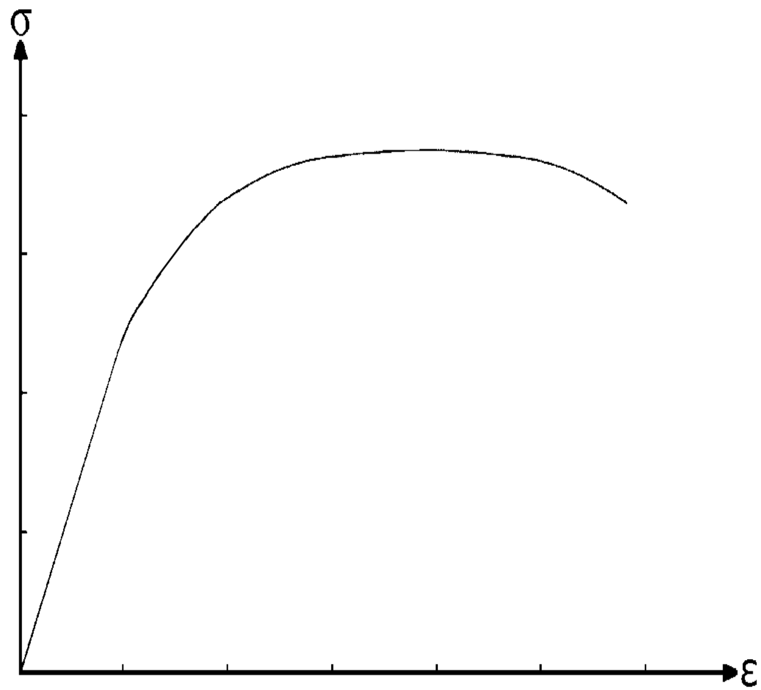
Stress-Strain Diagram

Understand carefully!

The shape and size of the σ – ε curve will depend on the material under consideration.



Typical conventional mild steel stress-strain profile

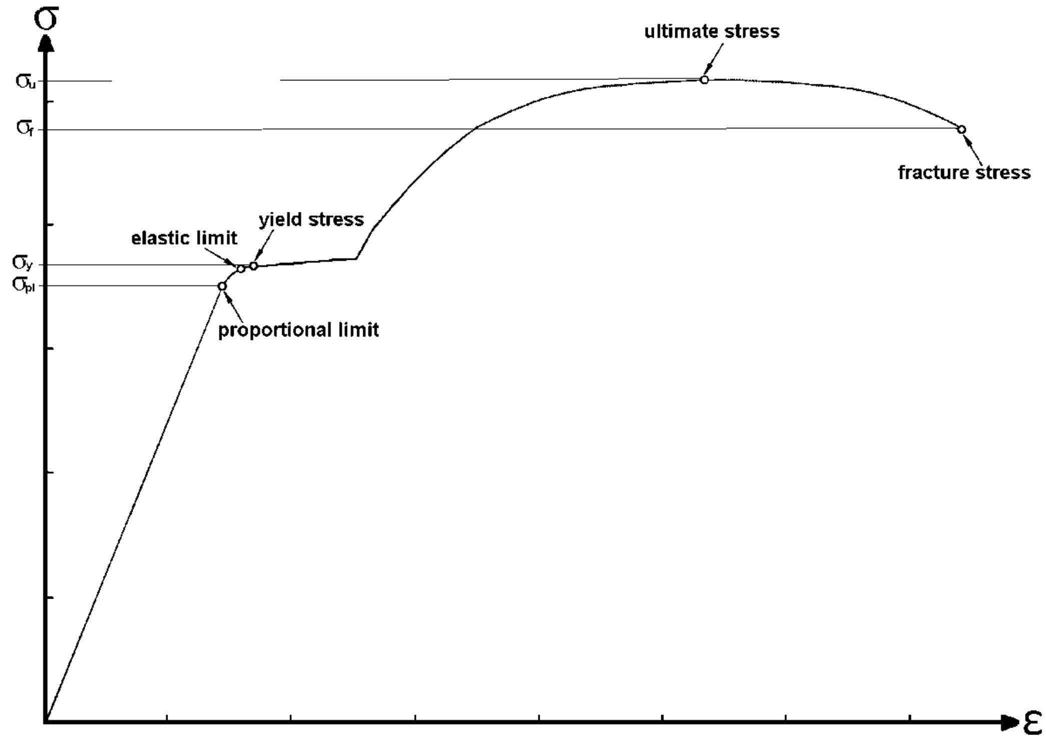


Typical conventional aluminium stress-strain profile

Stress-Strain Diagram

Understand carefully!

There are five (5) critical point on the stress-strain curve, they are:



i) Proportional limit: is maximum point on the graph where the curve is perfectly linear, i.e., the greatest stress at which the stress is directly proportional to strain.

Stress-Strain Diagram

Understand carefully!

ii) Elastic limit: is the maximum stress that the material can sustain with no any noticeable deformation on the material after removing the load. It is the greatest point of elastic deformation on the curve.

iii) Yield stress, σ_Y: is the stress that causes yielding of the material. It is the stress needed to produce a specific amount of deformation on the material. It is the minimum stress to produce plastic deformation of the material.

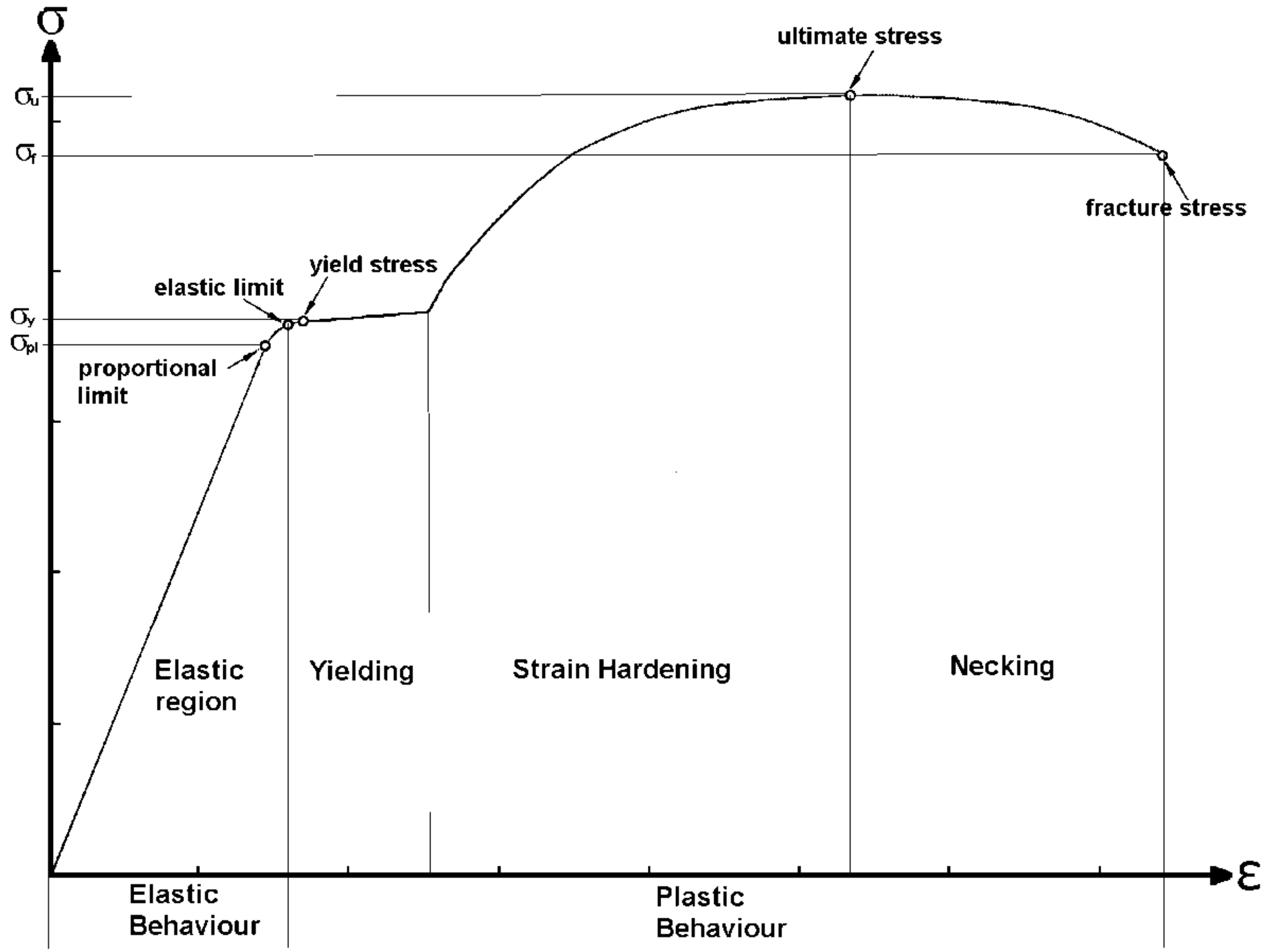
iii) Ultimate stress, σ_u: is the highest stress achieved on the $\sigma - \varepsilon$ curve. It is the highest point on the stress-strain curve

iv) Fracture stress, σ_f: is the stress at which the material fail. It is the last point on the $\sigma - \varepsilon$ curve.

Stress-Strain Diagram

Understand carefully!

On the stress-strain curve, there are four (4) regions, namely:



Stress-Strain Diagram

Understand carefully!

i) **Elastic region**: this is a region where the material will return back to its initial position when the load is removed. The deformation is temporary.

Mathematically, it means the material obeys Hooke's law.
Hooke's law, states that stress is directly proportional to strain.
i.e., $\sigma \propto \varepsilon$

$$\sigma = E\varepsilon$$

Where:
E = Modulus of Elasticity (Young's Modulus) = σ/ε

From the above equation, it implies that E can be determine from the ratio of any stress and its corresponding strain in the elastic region.

Therefore, E is the slope or gradient of the straight line in the elastic region.

Stress-Strain Diagram

Understand carefully!

ii) Yielding: Prior to yield stress, the material behave elastically and will return to initial shape when applied load is removed. After the yield stress, the material goes into plastic deformation where some fraction of the deformation will be permanent.

If the stress goes beyond the elastic limit, the material begins to deform permanently.

σ_Y = yield stress = transition from elastic region to plastic region

iii) Strain hardening: is the region where the material strengthen itself against the applied load. In plastic region, as the load increases, the material try to resist the load acting on it, thereby straining itself against the load.

Stress-Strain Diagram

Understand carefully!

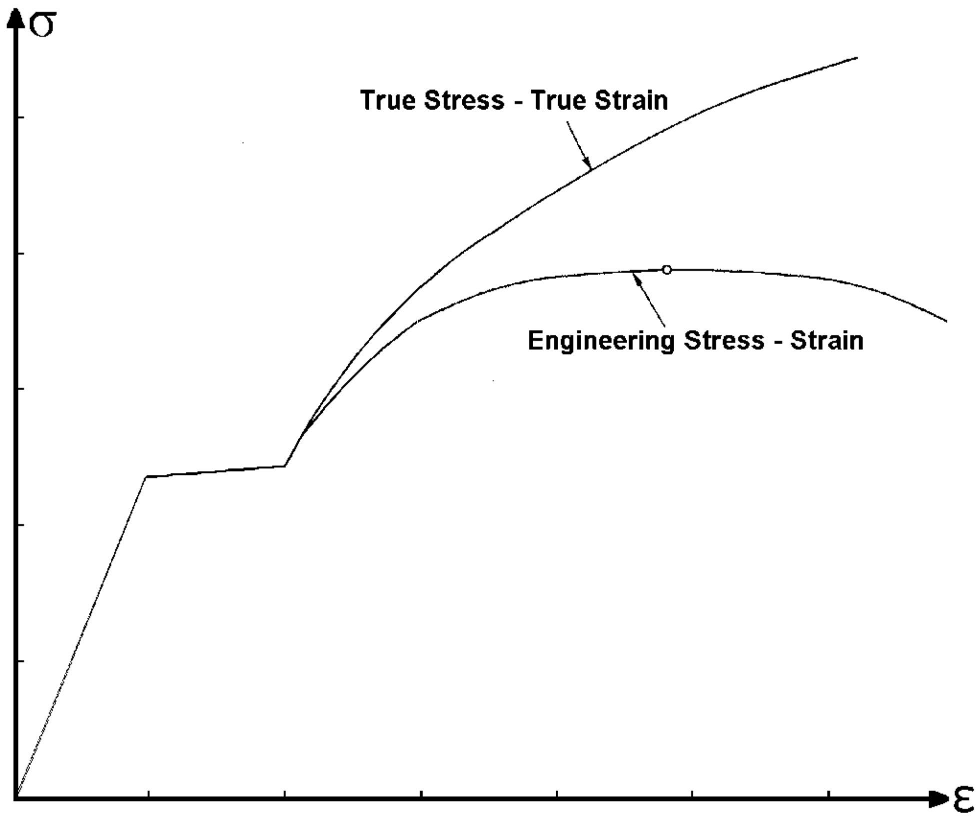
iv) Necking: This region exist just after the ultimate tensile strength. Necking results when reduction in specimen cross-sectional area at a point greater than the load arising from strain hardening. At the point of maximum load (when σ reached σ_{ut}) constriction (cross section area begin to decrease in a localized region) begins to form.
As necking begin, the stress will be concentrated at the necked region, and eventually, the material will fail at this region.

Necking

Stress-Strain Diagram

Understand carefully!

There is a difference between conventional (engineering) stress-strain curve and the true stress true strain curve.



True Stress & Strain

Conventional S-S Diagram:

• Using original cross sectional area and original length of specimen to calculate stress, σ and strain, ε.

True S-S Diagram

• Using actual cross sectional area (instantaneous area) and instantaneous length of specimen at the instant load to calculate stress σ and strain ε.

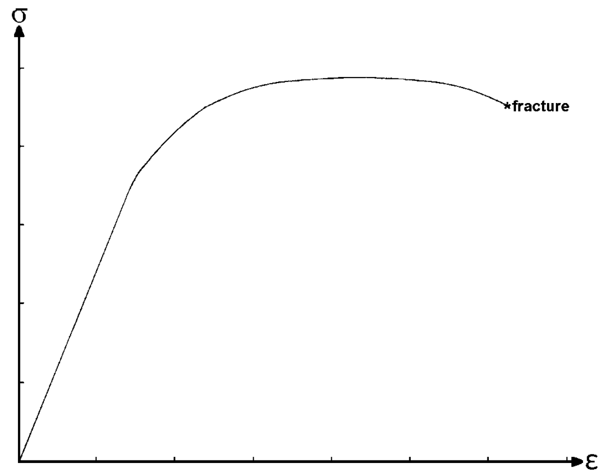
- True stress $\sigma_T = F/A_i$
- True strain $\varepsilon_T = \ln(\ell_i/\ell_o)$

$$\sigma_T = \sigma(1+\varepsilon)$$
$$\varepsilon_T = \ln(1+\varepsilon)$$

Stress-Strain Behavior

Ductile Materials

- Material subjected to large strains before fractures.
- Eg: mild steel, aluminum alloy, brass, molybdenum, zinc, wood
- Aluminum's yield not occur beyond elastic range.

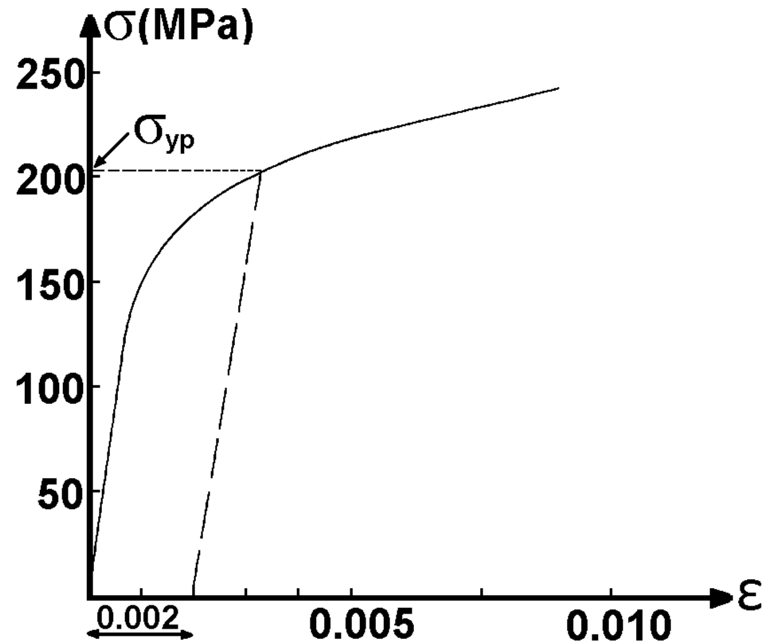


Stress-Strain Behavior

Offset Yield Strength (σ_y):

Some metals do not have a well defined yield point. 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 specific strain. Normally a 0.2% strain, (e = 0.002) is used.

$$s_o = \frac{P_{(strainoffset=0.002)}}{A_o}$$



Stress-Strain Behavior

Fracture stress (σ_f):

The final point on the curve, fracture happens in the neck region.

Ductility: Measure of ability to deform plastically without fracture.

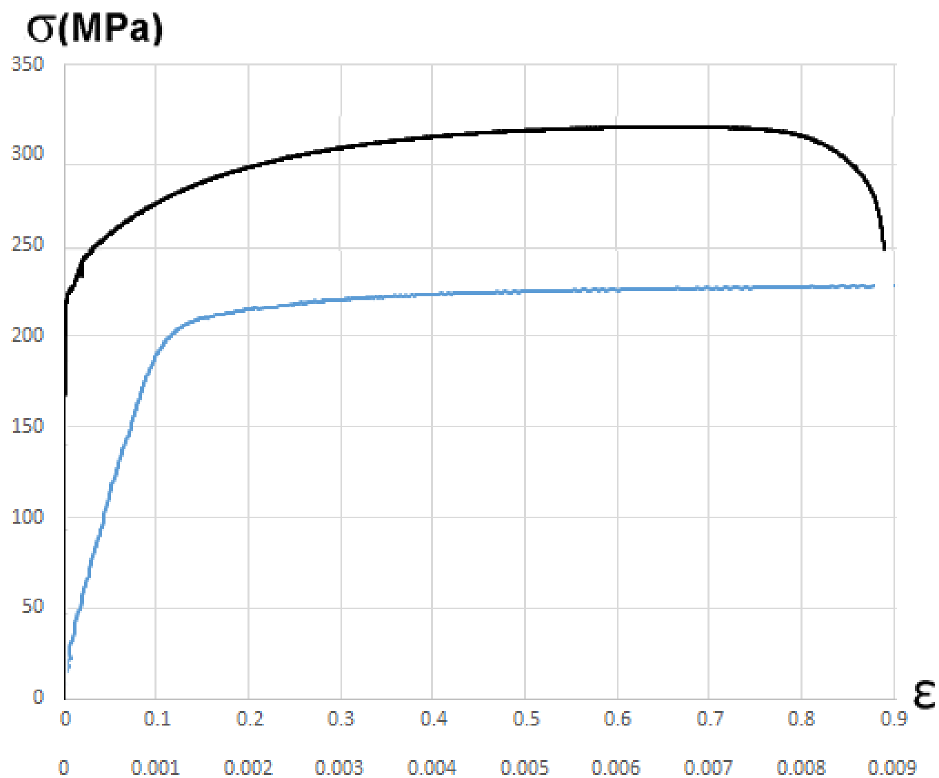
The maximum strain before rupture, materials that can be subjected to large strains is called a ductile material.

$$\%\text{Elongation} = \frac{(L_f - L_o)}{L_o} \times 100$$

$$\%\text{ Area Reduction} = \frac{A_o - A_f}{A_o} \times 100$$

Example 1

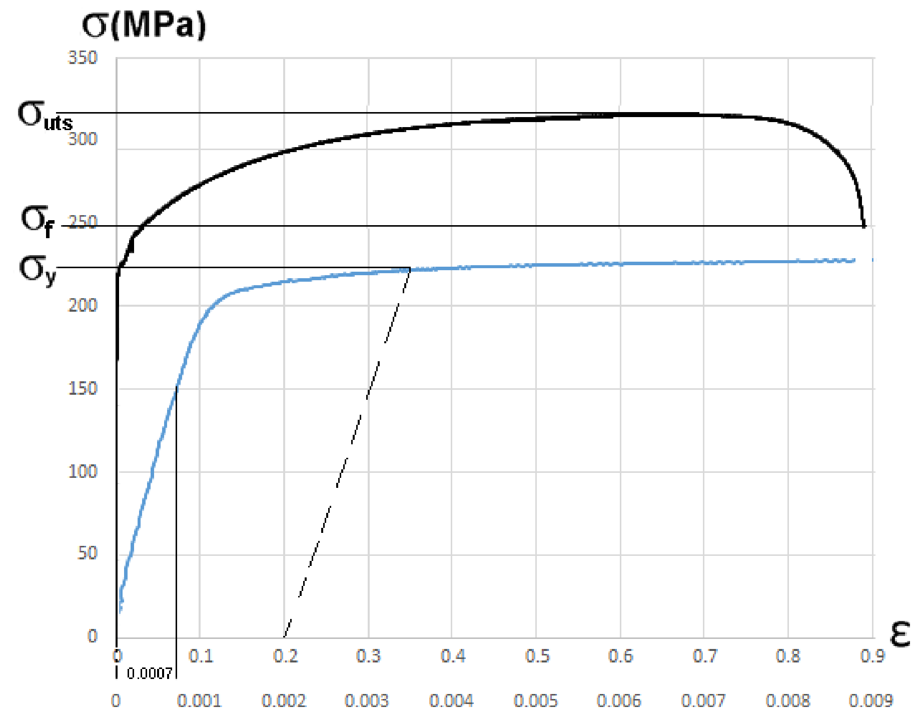
A tensile test for mild steel was carried out on a flat tensile specimen, the resulting stress-strain diagram is presented in the Figure below. Determine: (i) modulus of elasticity, (ii) 0.2% offset yield stress, (iii) the ultimate stress and (iv) the fracture stress.



Example 1 (SOLUTION)

(i) Modulus of Elasticity: The modulus of elasticity is the slope of the straight-line region of the graph

$$E = \frac{150MPa - 0MPa}{0.0007 - 0} = 214.3GPa$$



(ii) Yield Stress: For 0.2% offset,

Start at strain of 0.002 (dashed line).

σ_y = 221 MPa

(iii) Ultimate Stress: The maximum point on the stress-strain diagram

σ_{uts} = 322.12 MPa

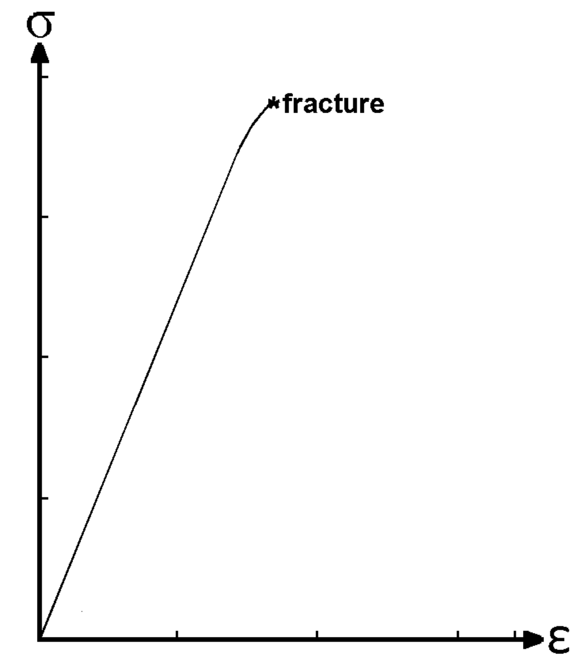
(iv) Fracture Stress: The final point on the stress-strain diagram

σ_f = 250 MPa

Stress-Strain Behavior

Brittle Materials

- Material exhibit little or no yielding before failure.
- Eg: gray cast iron, concrete
- Don’t have well defined tensile fracture test due to random appearance of initial crack of the material
- High resistance against axial compression.



Self-review Questions

1. In solid mechanics, plastic deformation can be defined as deformation in which:

(a) the material return back to its original position after load is removed

(b) the matrial undergoes a temporary change

(c) the materieal undergoes a reversible process

(d) the material cannot return back to its original position after load is removed

(e) none of the above

Self-review Questions

2. Which of the following is not one of the critical points for strength specification on the stress-strain diagram:

(a) Yield stress

(b) Proportional limit

(c) Necking

(d) Elastic limit

(e) Fracture stress

Self-review Questions

3. From the figure below, determine the ultimate stress of the material in (Mpa)

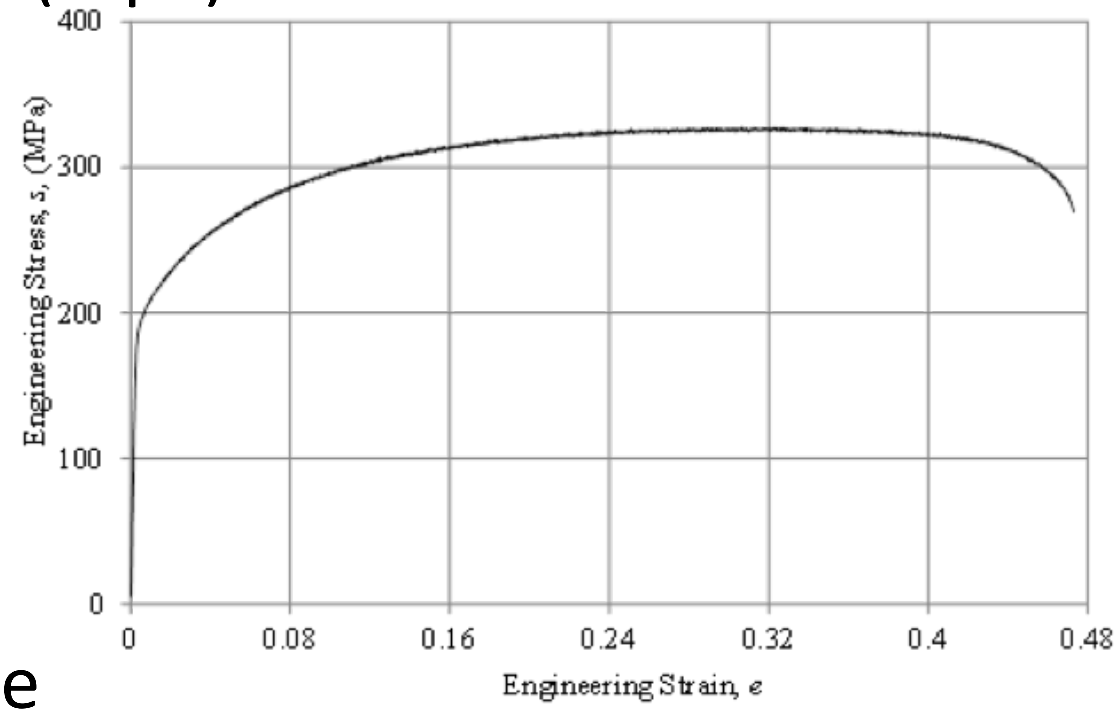
(a) 325.7

(b) 269.5

(c) 300.0

(d) 200.0

(e) All of the above



Self-review Questions

4. From the figure below, determine the fracture stress of the material in (MPa)

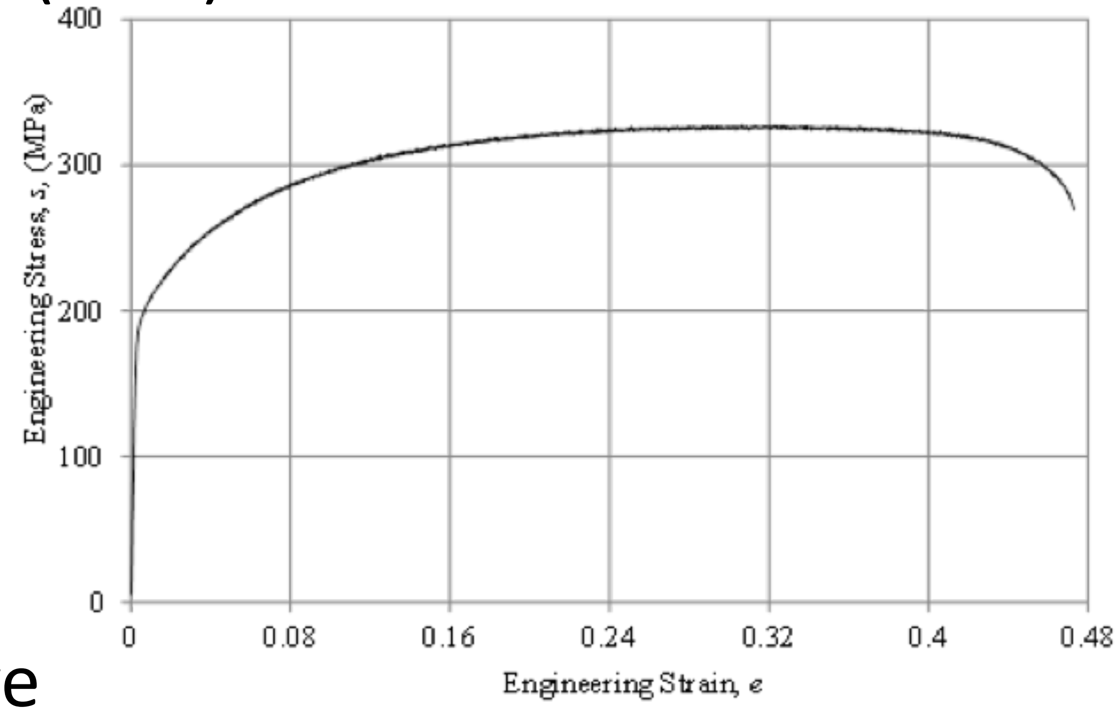
(a) 325.7

(b) 269.5

(c) 300.0

(d) 200.0

(e) All of the above



Self-review Questions

5. On the stress-strain curve, there are four regions. Which is the following is not a region on the stress-strain curve:

(a) Necking

(b) Yielding

(c) Elastic region

(d) Strain hardening

(e) Ultimate stress

Self-review Answers

1. d

2. c

3. a

4. b

5. e

Summary

- Introduction
  - Strength of material
  - Elastic deformation
  - Plastic deformation
- Tension and Compression test
- The Stress-strain diagram
- Stress strain behavior of ductile and brittle material