Mechanical Properties

Introduction

Tensile Force

Pulls out of the cross-sectional area.

In the direction of force, length increases. Cross-sectional area decreases.

Compressive Force

Pushes into the cross-sectional area.

In the direction of force, length decreases. Cross-sectional area increases.

Stress

Force per unit area.

$$\text{Stress } \sigma = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

Engineering stress

$$\text{Engineering stress } \sigma = \frac{\text{Force}}{\text{Initial Area}} = \frac{F}{A_0}$$

True stress

$$\text{True stress } \sigma_T = \frac{\text{Force}}{\text{Instantaneous Area}} = \frac{F}{A_i}$$

Strain

Dimensional change with respect to the original dimensions.

Engineering strain

$$\text{Engineering strain } \epsilon = \frac{\text{Extension}}{\text{Initial Length}} = \frac{l - l_0}{l_0}$$

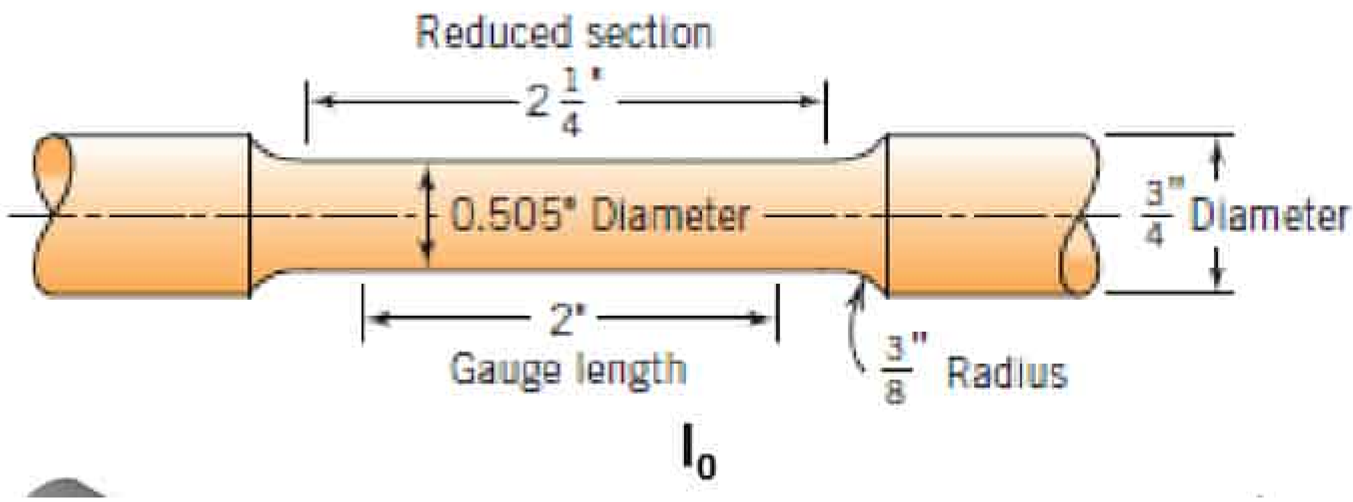
True strain

$$\text{True strain } \epsilon_T = ln\frac{l_i}{l_0}$$

Tensile Test

Follows ASTM Standards E 8 and E 8M. (American Society for Testing and Materials)

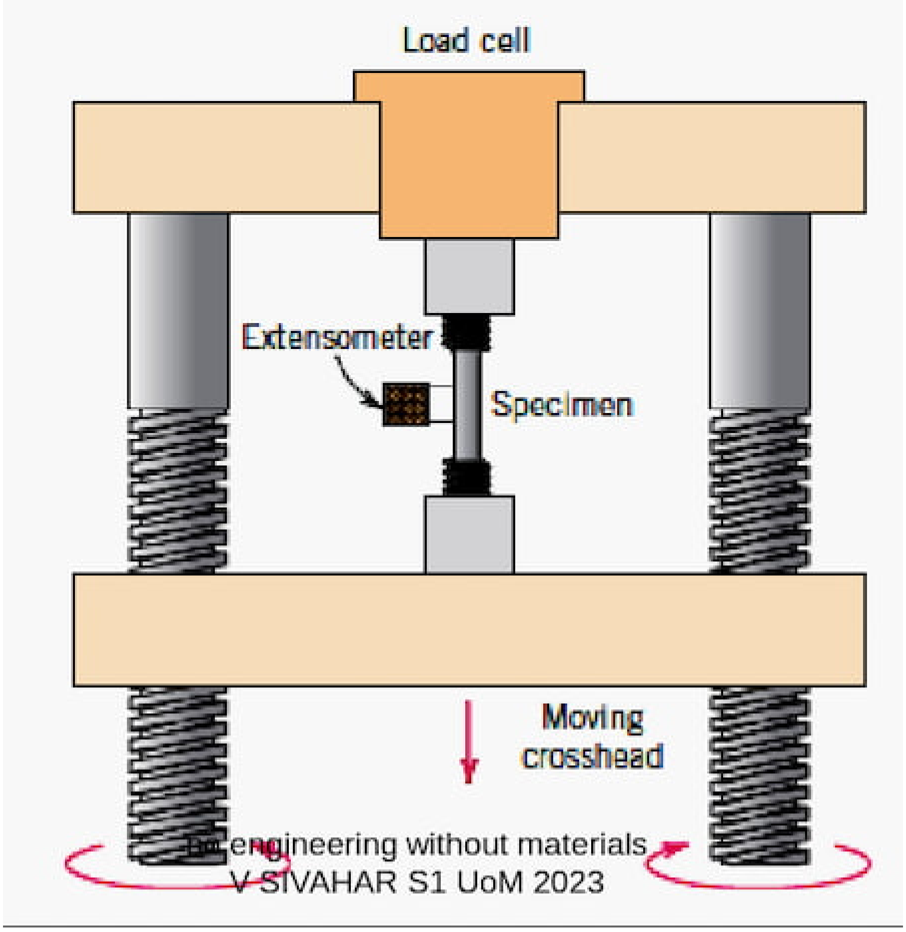
The specimen:



Here

- Gauge length l_0
- Initial diameter d_0
- Initial area $A_0 = \frac{\pi {d_0}^2}{4}$

The setup:



Test will be done until the specimen fractures. Results are converted to engineering stress and strain, and plotted.

Load cell

Measures the force applied to the specimen.

Extensometer

Used to measures the elongation (increase in length) in the specimen.

Tensile tests for brittle material

The σ-ε behavior of brittle materials cannot be assessed by a tensile test because:

- Difficult to prepare test specimens
- Difficult to grip brittle materials without fracturing them

> ⓘ **For brittle materials**

> Fracture strength is normally specified for engineering design purposes. Tensile strength is calculated from its **modulus of rupture (MOR)** or **flexural strength** value.
>
> $$\text{Tensile strength} \times 1.3 = \text{MOR}$$

Necking

All deformation up to the maximum point is uniform throughout the specimen.

At this maximum stress, a neck begins to form – known as necking. All subsequent deformation is confined to this neck.

Fracture

Fracture occurs at the neck.

Definitions

Elastic deformation (elasticity)

Deformation is temporary. Returns to its original shape when load is released.

Linear elastic materials

When elastic deformation portion in stress-strain diagram is straight line.

Young’s modulus (aka Elastic modulus)

$$\text{Young's modulus } E = \frac{\text{stress}}{\text{strain}} = \frac{\sigma}{\epsilon}$$

Can be thought of as **stiffness**.

Nonlinear elastic materials

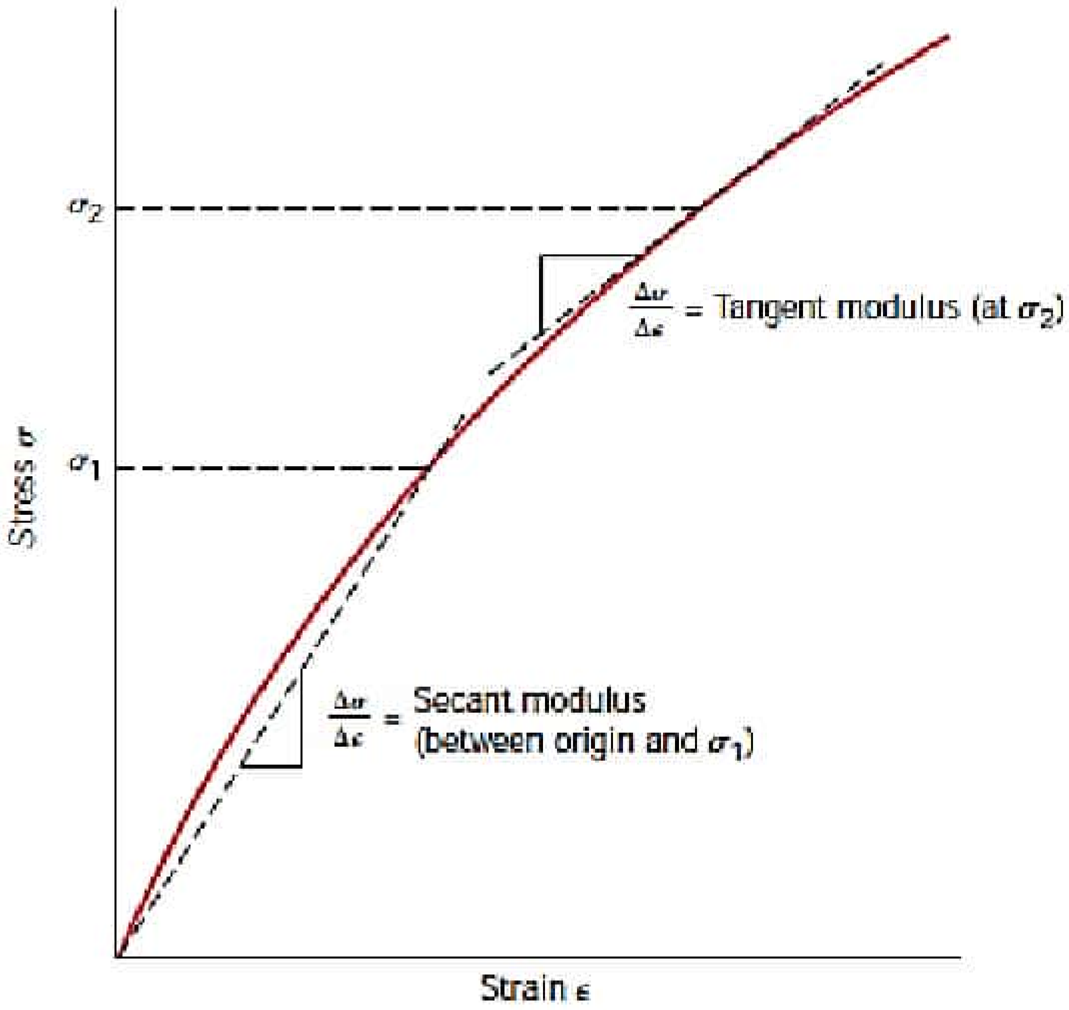
When elastic deformation portion in stress-strain diagram is not straight line.

Secant modulus

Equal to the tangent of the line connecting a point in the stress-strain diagram and the origin.

Tangent modulus

Equal to the instantaneous tangent on a point in the stress-strain diagram.



Poisson’s ratio

A tensile stress in a particular direction causes extension (say ϵ_z) in that direction and contraction in other two directions (ϵ_x and ϵ_y). For isotropic materials:

$$v = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

For metals (if not given) can be taken as $v = 0.34$. Rubber’s poisson’s ratio is 0.5 which is the maximum possible value, mathematically.

Isotropic materials

Homogenous materials. $\epsilon_x = \epsilon_y$.

Plastic deformation (plasticity)

When stress is not proportional to strain. Deformation is permanent or non-recoverable or **plastic**.

Yield strength

Stress at point P. Point P is where plastic deformation starts (in stress-strain diagram). Denoted by σ_y. Used when the strength of a metal is cited for design purposes.

Point P is very difficult to find practically. Therefore **strain offset method** is used to find the yield strength.

Strain offset method

A straight line is constructed parallel to the elastic portion of the stress-strain curve at some specified strain offset. The stress corresponding to the intersection of this line and the stress-strain curve is defined as the yield strength σ_y.

0.2% proof stress

Yield strength when 0.002 is used in strain offset method.

> ⓘ **For steel**
>
> Yield strength is taken as the average stress at the lower yield point. Strain offset method is not required. Upper yield point occurs because of C atoms, and is specific to steel.

Tensile strength

After yielding, the stress necessary to continue plastic deformation increases to a maximum, and then decreases.

Ultimate tensile strength (UTS)

The maximum stress that can be sustained by a material in tension.

Toughness

The strain energy absorbed by a material before fracture.

Fracture

Separation of a solid into more than 1 parts under load or stress.

Based on the type of load:

- Tensile fracture
- Compressive fracture
- Shear fracture
- Fatigue fracture
- Creep fracture

Characterized into 2:

- Ductile fracture
- Brittle fracture

Ductile fracture

Materials show significant amount of plastic deformation prior to fracture. Fracture surface gives cup & cone appearance. Aka. cup-and-cone fracture.

Steps:

1. Specimen forms a neck
2. Cavities start to form within the neck
3. Cavities join with each other and form a crack
4. Crack propagates towards surface perpendicular to stress
5. Direction of crack changes to 45°

Brittle fracture

Little or no plastic deformation prior to fracture. Fracture surface is smooth.

More dangerous than ductile fracture.

- No warning sign
- Crack propagates at very high speeds
- No need for extra stress during crack propagation.

Ductility & Brittleness

Depends on:

- Composition of the material
- Temperature

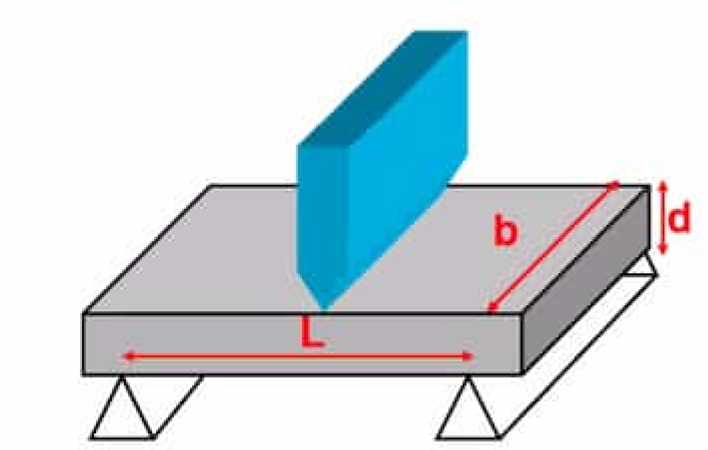
Ductile to Brittle Transition Temperature

The temperature which a material is:

- brittle below the temperature
- ductile above the temperature

Many steels exhibit this behaviour.

Flexural Test



Support the material at 2 ends. Apply pressure perpendicular to the material until the material fractures.

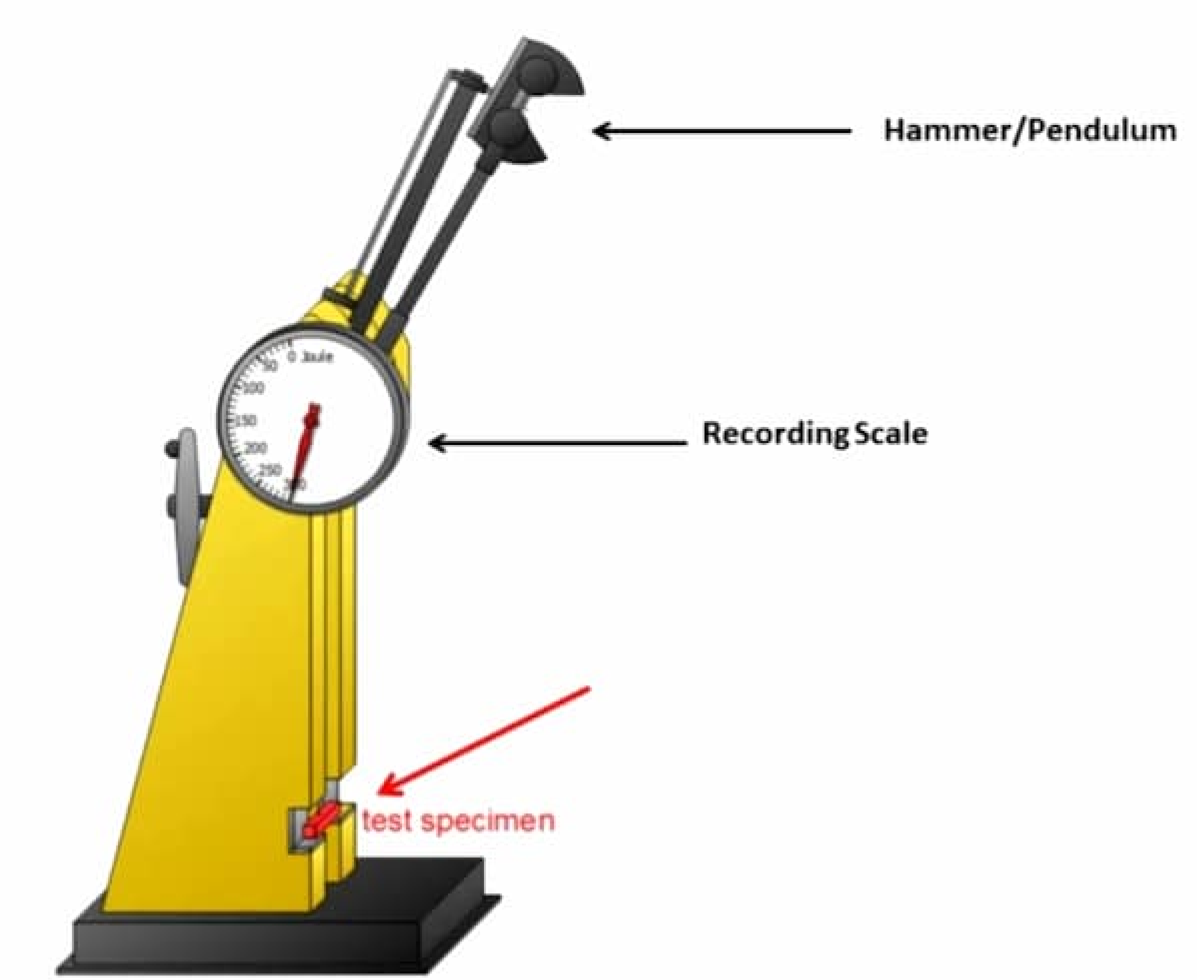
$$\mathrm{MOR} = \frac{3PL}{2bd^2}$$

Here

- L - length
- b - width
- d - depth

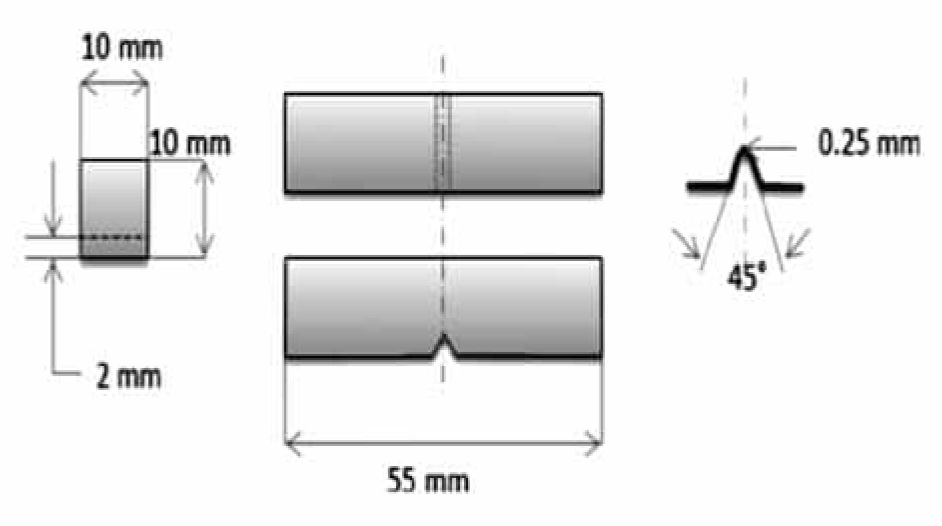
Charpy Impact Test

Tester



Specimen

According to ASTM-E 23.



Loaded state