# Mechanical Properties

## 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

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

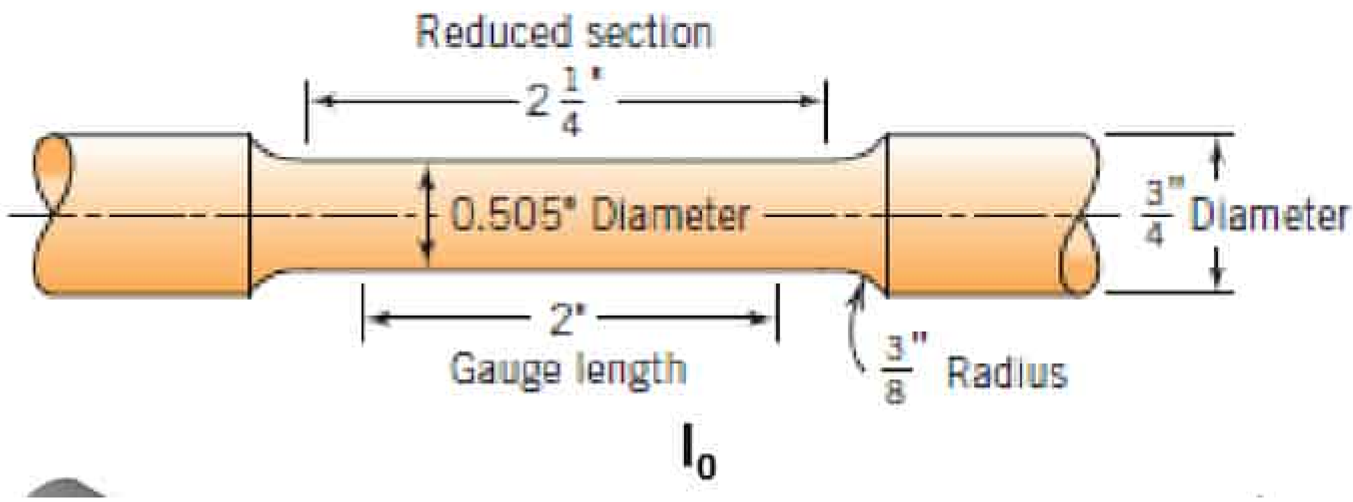
### True strain

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

# Tensile Test

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

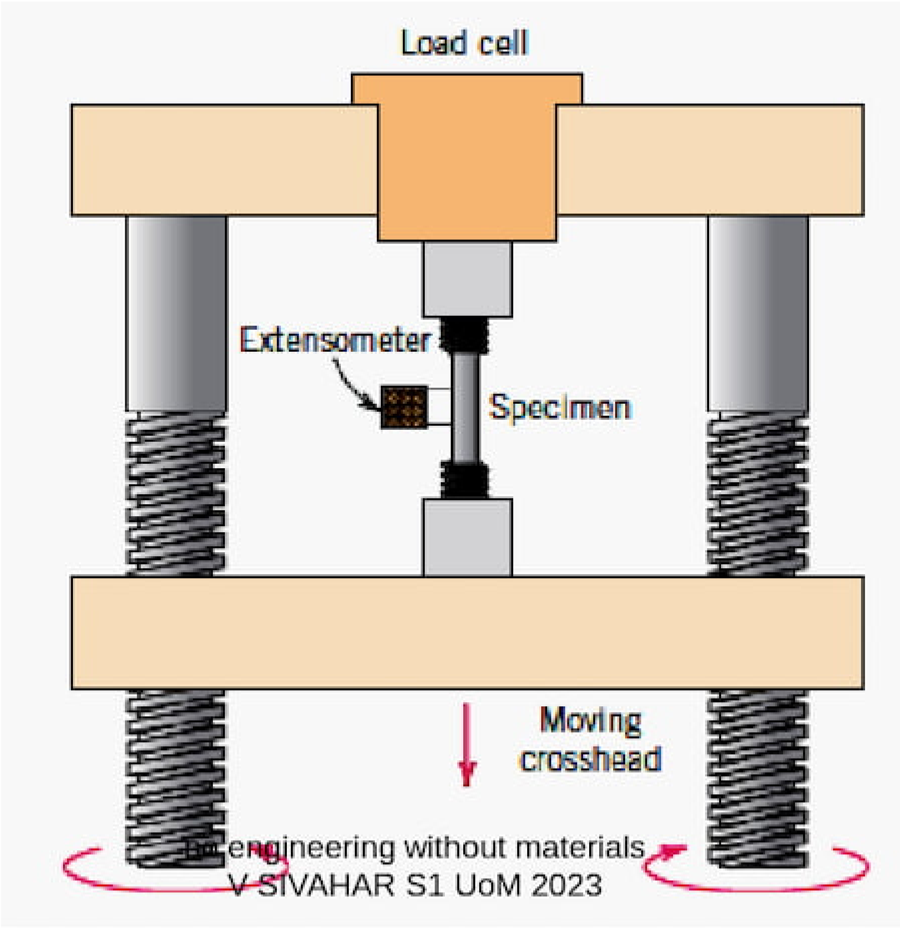
The specimen:




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

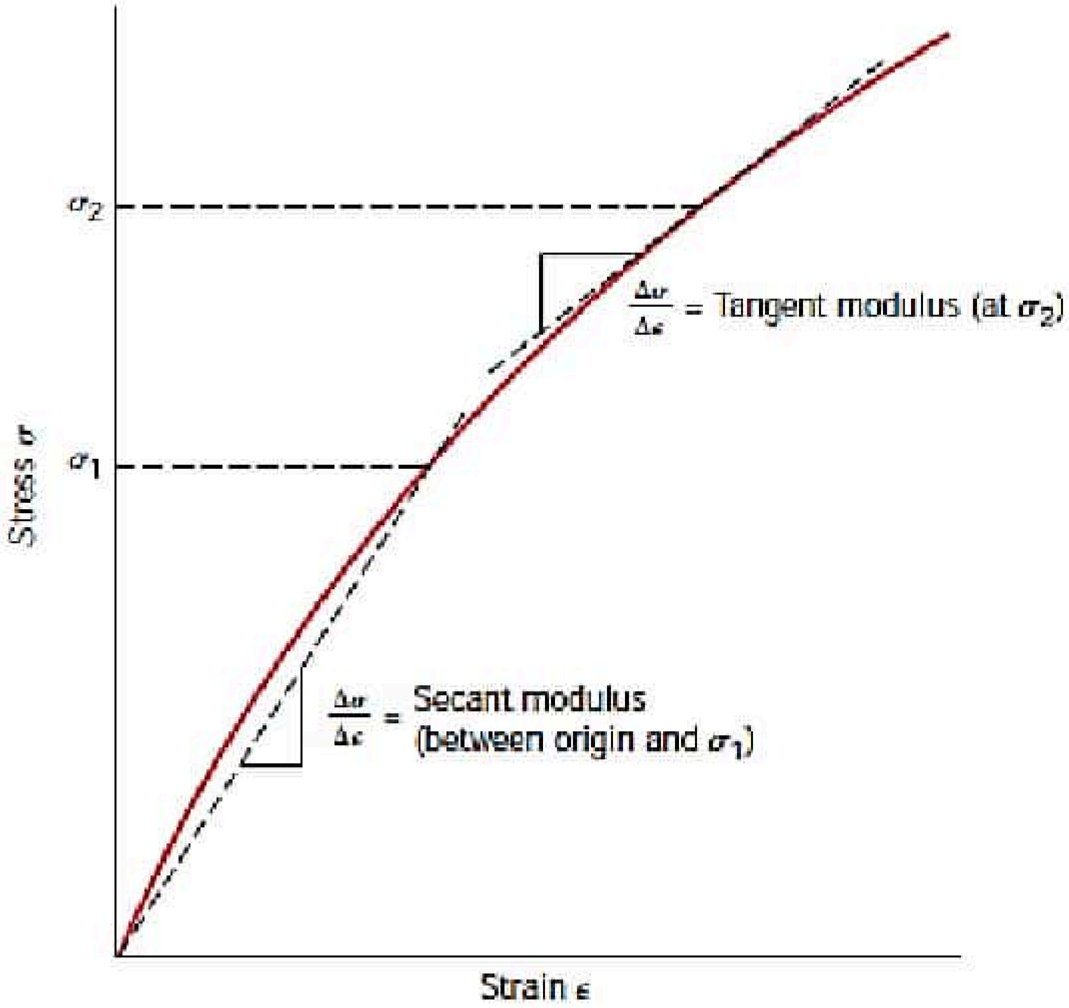
When elastic deformation portion in stress-strain diagram is not straight line.

#### 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 $\epsilon_z$) in that direction and contraction in other two directions ($\epsilon_x$ and $\epsilon_y$). 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 $\sigma_y$. 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 $\sigma_y$.

### 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

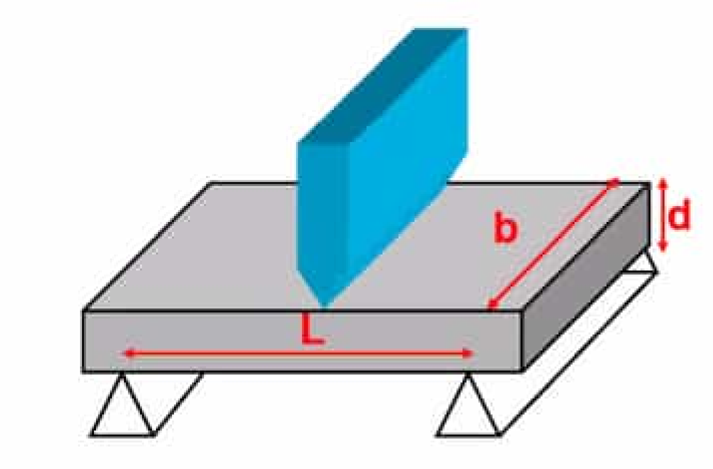
## Ductile to Brittle Transition Temperature

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.

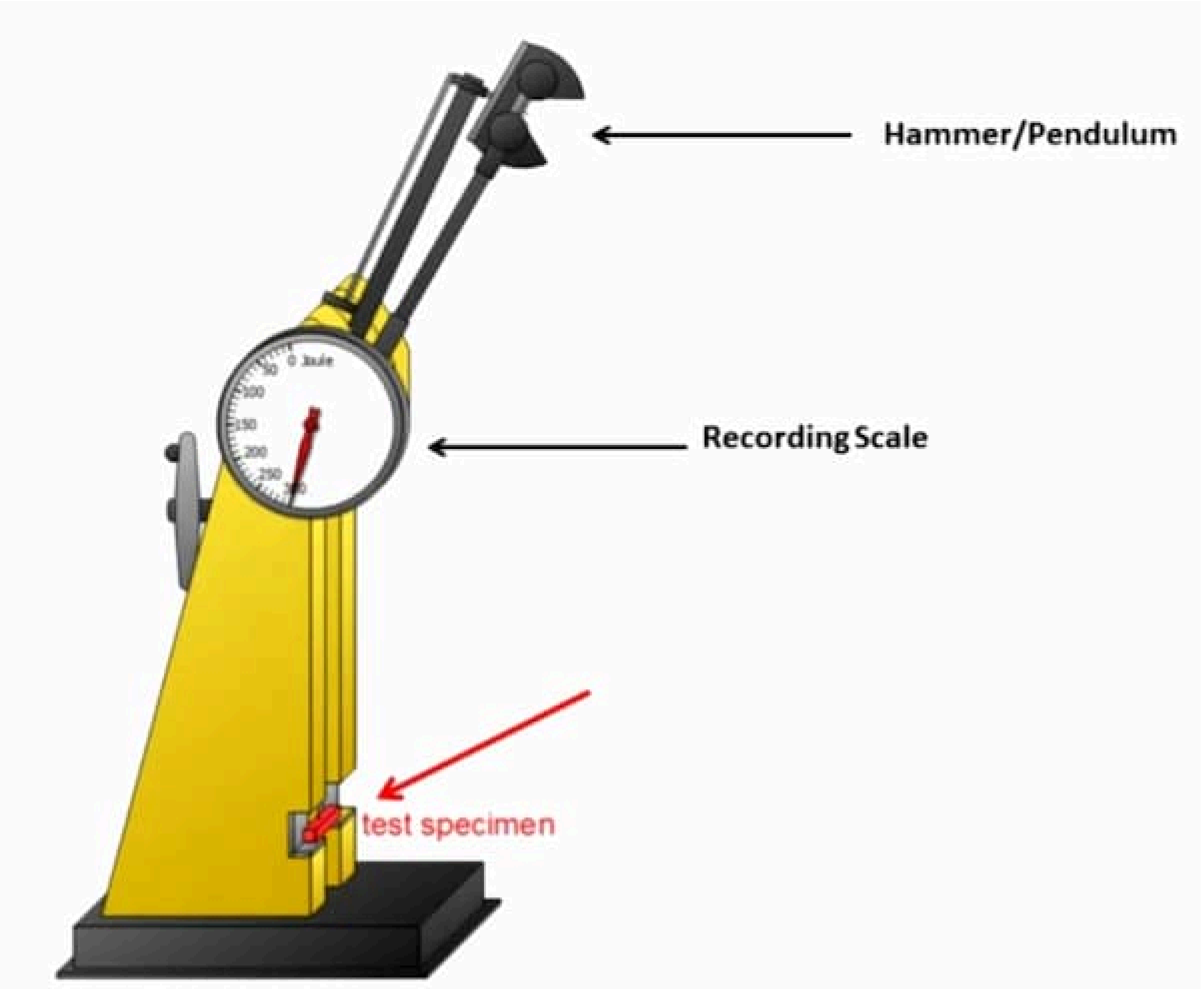
$$\mathrm{MOR} = \frac{3PL}{2bd^2}$$

Here

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

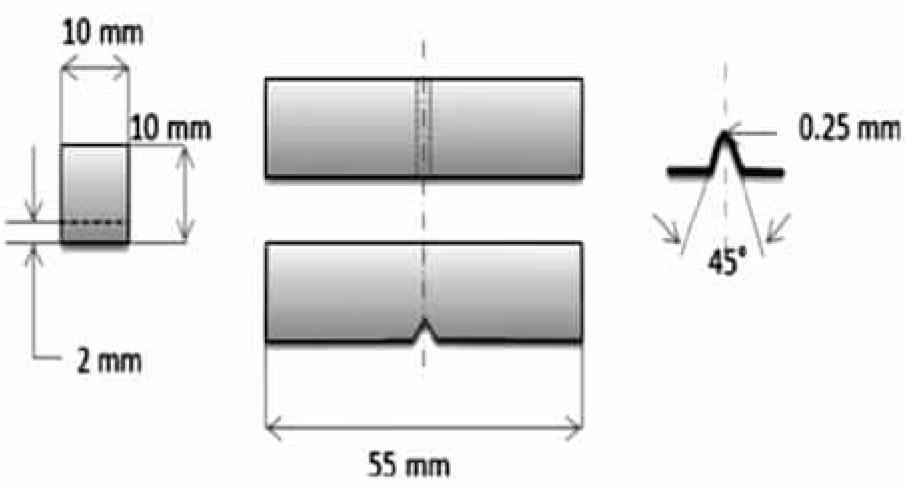
# Charpy Impact Test

## Tester

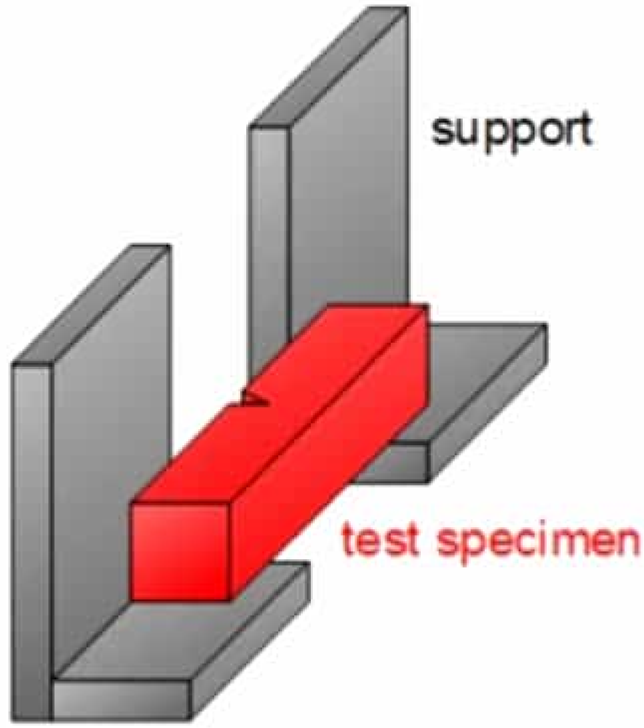



## Specimen

According to ASTM-E 23.




### Loaded state


support
test specimen