# **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.

$$ext{Stress } \sigma = rac{ ext{Force}}{ ext{Area}} = rac{F}{A}$$

## **Engineering stress**

$$ext{Engineering stress } \sigma = rac{ ext{Force}}{ ext{Initial Area}} = rac{F}{A_0}$$

#### **True stress**

$$ext{True stress } \sigma_T = rac{ ext{Force}}{ ext{Instantaneous Area}} = rac{F}{A_i}$$

### 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** 

$$ext{True strain } \epsilon_T = lnrac{l_i}{l_0}$$

## **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  $45^{\circ}$

#### **Brittle fracture**

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

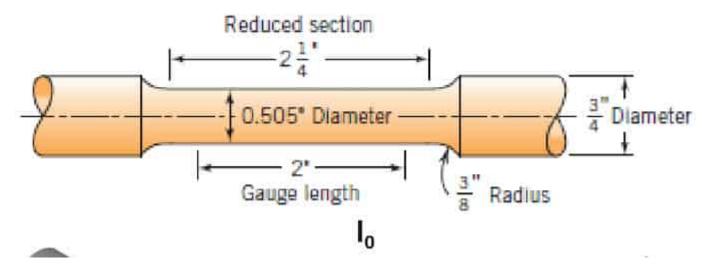
More dangerous than ductile fracture.

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

## **Tensile Test**

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

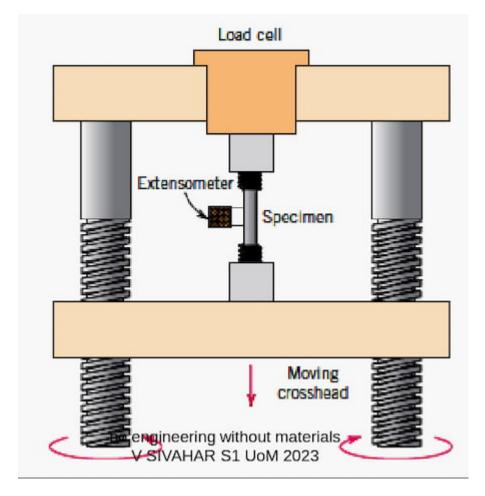
The specimen:



Here

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

#### 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  $\sigma$ - $\epsilon$  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

### (i) 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.

Tensile strength 
$$\times 1.3 = MOR$$

## **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.

## **Definitions**

**⚠** TODO

This page is not very well organized.

## **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)

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

Can be thought of as **stiffness**.

#### Nonlinear elastic materials

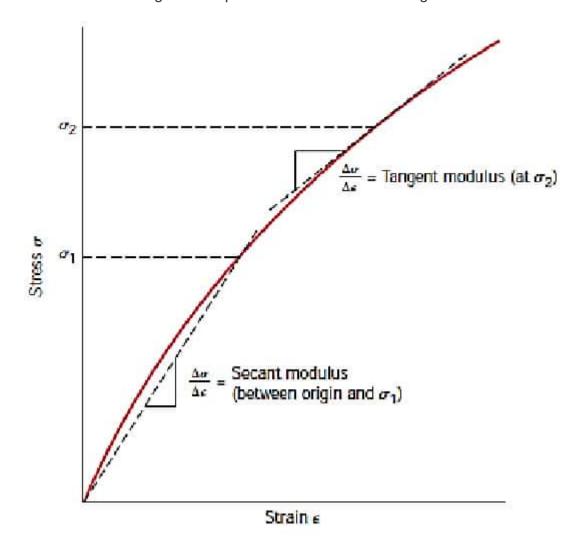
When elastic deformation portion in stress-strain diagram is not straight line.

#### **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:

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

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 stress point**

The point where plastic deformation starts in stress-strain diagram.

## **Yield strength**

Stress at yield stress point. Denoted by  $\sigma_y$ . Used when the strength of a metal is cited for design purposes.

True yield stress point is very difficult to find practically. Therefore **strain offset method** is used to find an approximate 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.

### (i) 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.

## **Ductility**

A measure of the degree of plastic deformation at fracture.

Most metals are ductile.

### **Percentage elongation**

$$rac{l_f - l_0}{l_0} imes 100$$

#### Percentage reduction in area

$$\frac{A_0-A_f}{A_0}\times 100$$

#### **Brittle**

A material that experiences very little or no plastic deformation.

## Malleability

Ability of a material to undergo plastic deformation under compression.



All ductile materials are malleable. Converse is **not** true.

## **Ductility & Brittleness**

Depends on:

- Composition of the material
- Temperature

## **Ductile-Brittle Transition**

Ductile materials show brittle behavior as the temperature is lowered. This is known as ductile-brittle transition.

Ductile-brittle transition behavior of materials is studied by performing impact test over a range of temperatures.

The transition behavior is:

- Sudden in BCC metals
- Gradual in FCC metals

## **Ductile-Brittle Transition Temperature**

The temperature which a material is:

- brittle below the temperature
- ductile above the temperature

Many steels exhibit this behaviour.



Titanic sunk because of this transition.

## **Work Hardening**

Strength and hardness of a metal increases as a result of plastic deformation. This process is called work hardening.

#### Increases:

- strength
- hardness

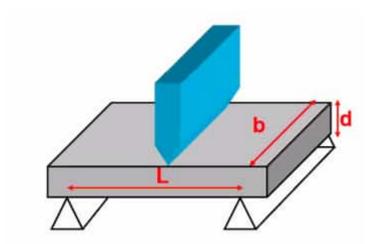
#### Decreases:

- ductility
- toughness

## **Steps**

- Specimen is loaded onto a tensile test apparatus
- Test is stopped after the specimen has gone under plastic deformation
- Specimen is unloaded and reloaded
- New  $\sigma \epsilon$  diagram will have a increased yield strength

## **Flexural Test**



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

\_ -

$$ext{MOR} = rac{3PL}{2bd^2}$$

Here

- $oldsymbol{\cdot}$   $oldsymbol{L}$  length
- $oldsymbol{b}$  width
- ullet d depth

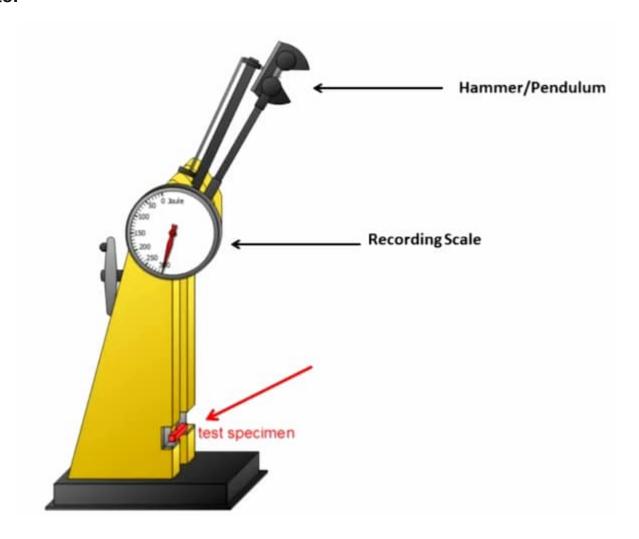
## **Toughness**

Maximum strain energy, a material can absorb upto fracture. Area under the  $\sigma-\epsilon$  graph is a measure of toughness. Can be measured by impact test.

Generally ductile materials have a high toughness compared to brittle materials.

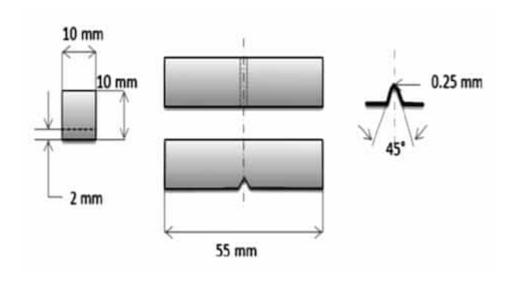
# **Charpy Impact Test**

## Tester

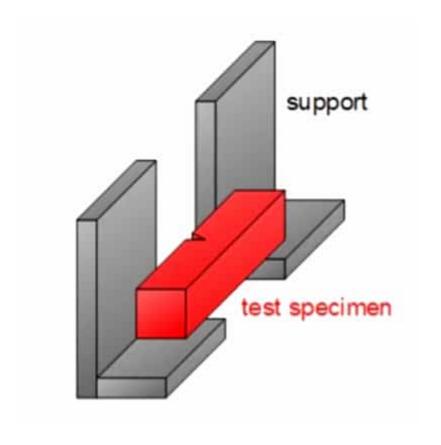


## Specimen

According to ASTM-E 23.



#### Loaded state



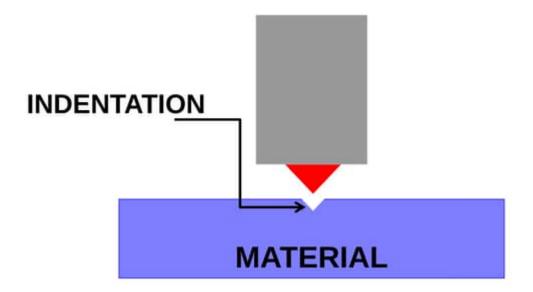
## **Hardness**

Hardness of metals is defined as resistance to indentation. Can be measured by  $\underline{\text{indentation test}}$ ..

When 2 surfaces are rubbing against each other, hardness is important. Materials with less hardness will be worn off quickly.

## **Indentation Test**

Metal is subjected to indentation with a hard indenter. Depth of the indent is a measure of hardness.



Hardness units differ with the type of indenter used and the load applied.

### **Units**

### **Brinell (HB)**

- 10 mm diameter steel / WC ball indenter
- Any load can be applied
- Diameter of the indentation is measured instead of the depth

$$HB=rac{2F}{\pi D(D-\sqrt{D^2-d^2})}$$

#### Here:

- F applied load
- D diameter of the indenter (  $10 \, mm$  )
- d diameter of the indentation
- h depth of the indentation

## Vickers (HV)

- Pyramid shaped indenter made of diamond
- Any load can be applied
- ullet Diagonal lengths d1 and d2 of the diamond-shape indentation are measured
- ullet Average  $oldsymbol{d}$  is used in the calculation

## (i) Note

Angle between the diamond faces is 136 degrees.

$$HV=rac{1.854\,F}{d^2}$$

## Rockwell (HR)

Not accurate enough to be used in academic level (or where accuracy is important). Industrially preferred because of ease of measurement.

| Туре | Load  | Indenter  |
|------|-------|---|
| HRA  | 60kg  | Cone-shaped indenter. Made of diamond.            |
| HRD  | 100kg | Cone-shaped indenter. Made of diamond.            |
| HRC  | 150kg | Cone-shaped indenter. Made of diamond.            |
| HRF  | 60kg  | 1/16" diameter (1.5mm approx.) ball made of steel |
| HRB  | 100kg | 1/16" diameter (1.5mm approx.) ball made of steel |
| HRG  | 150kg | 1/16" diameter (1.5mm approx.) ball made of steel |
| HRE  | 100kg | 1/8" diameter (3mm approx.) ball                  |



Only 3 load options. No need to remember the above data.

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