# **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.

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

#### **Engineering stress**

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

**True stress** 

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

#### Strain

Dimensional change with respect to the original dimensions.

**Engineering strain** 

$$ext{Engineering strain } \epsilon = rac{ ext{Extension}}{ ext{Initial Length}} = rac{l-l_0}{l_0}$$

True strain

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

# **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  $A_0=rac{\pi {d_0}^2}{4}$

#### 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.

# 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)

Young's modulus 
$$E = rac{ ext{stress}}{ ext{strain}} = rac{\sigma}{\epsilon}$$

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.

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

#### **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.

## **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.

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

Here

- L length
- *b* width
- d depth

# **Charpy Impact Test**

# Tester



# Specimen

According to ASTM-E 23.



#### Loaded state



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