Department of Mechanical and Production Engineering
Ahsanullah University of Science and Technology (AUST)

ME 2202: Mechanics of materials
Credit Hour: 1.5

General Guidelines:

1. Students shall not be allowed to perform any experiment without apron and shoes.
2. Students must be prepared for the experiment prior to the class.
3. Report of an experiment must be submitted in the next class.
4. Viva for each experiment will be taken on the next day with the report.
5. The report should include the following:
    - Top sheet with necessary information
    - Main objectives
    - Work material/machine/tool/equipment used (with their specifications)
    - Experimental procedures
    - Experimental results and discussions (Experimental setup, Experimental conditions, Data, Graph, calculation etc.)
    - Conclusions
    - Acknowledgements
    - References
6. A quiz will be taken on the experiments at the end of the semester.
7. Marks distribution:

Total Marks		
Report	Attendance and Viva	Quiz
30	30	40

Experiment No. 01

Tension test of mild steel specimen

OBJECTIVES

a. To test a mild steel specimen till failure under tensile load
b. To draw stress-strain diagram
c. To determine:
    I. Proportional limit
    II. Modulus of elasticity
    III. Yield limit
    IV. Ultimate strength
    V. Breaking strength
    VI. Percentage elongation
    VII. Percentage reduction in cross-sectional area
    VIII. Modulus of resilience

THEORY

When a specimen is subjected to the action of a force it is deformed, no matter how small the force is. If the specimen is elongated due to the application of the force, the specimen is said to be in tension and the force may be termed as tensile force. In 1678, Hooke showed that, up to a certain limit, a piece of material will extend in proportion to the load that produces the extension.

Tension test: Tension test, also known as tensile test, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. This test is performed to determine various fundamental mechanical properties of the specimen material. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. The most common testing machine used in tensile testing is the *Universal Testing Machine (UTM).*

Stress: When an external force is applied on the specimen an internal force is developed in order to resist the external force. The internal force per unit area at any section is called stress. Stress is denoted by $\boldsymbol{\sigma}$.

Therefore, $\sigma = \frac{F}{A}$ N/mm^2 (MPa)

Where, F is applied load; A is the original cross-section of the specimen.

Strain: When the force is applied on the specimen, it is deformed. For the tensile force the specimen is elongated. The elongation per unit length is called strain. Strain is denoted by $\boldsymbol{\varepsilon}$.

$$\text{Therefore, } \mathcal{E} = \frac{\delta}{L} \text{ N/mm}^2 \text{ (MPa)}$$

Where, δ is the deformation over the length L.

Stress-strain diagram:

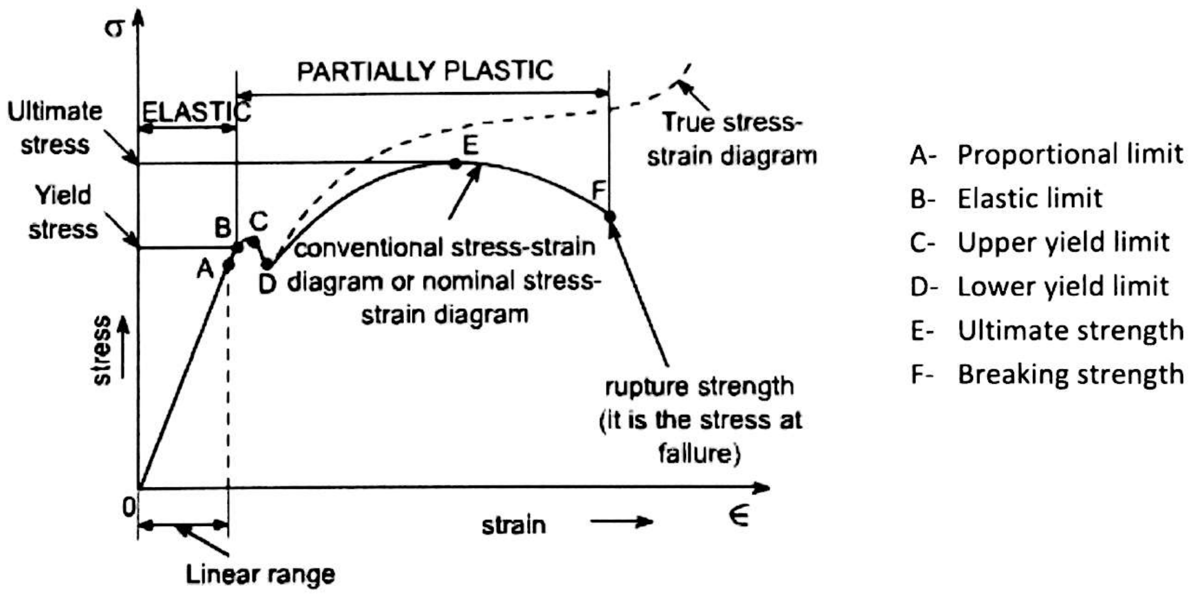


Figure: typical stress-strain diagram for mild steel specimen.

Proportional limit: The point in the stress-strain diagram up to which the stress is proportional to strain is called the proportional limit.

Elastic limit: The point in the stress-strain diagram up to which the specimen remains elastic is known as elastic limit.

Yield limit: The point in the stress-strain diagram at which there is an increase in strain with no further increase in stress is called the yield point. In the case of mild steel there are two yield points, upper and lower.

Ultimate strength: The maximum stress in the stress-strain diagram is called the ultimate strength or tensile strength.

Breaking strength: the stress at which the specimen breaks away is called the breaking strength.

Percentage elongation: The difference between the length after rupture and the initial length divided by the length after rupture and multiplied by 100 is termed as the percentage elongation.

$$\text{Percentage elongation} = \frac{L_f - L_i}{L_i} \times 100\ \%$$

Where,

L_i is the initial gauge length
L_f is the final gauge length

Percentage reduction in area: The difference between the original cross-sectional area and the cross-sectional area at the neck (when the rupture takes place) divided by the original area and multiplied by 100 is termed as the percentage reduction in area.

$$\text{Percentage reduction in area} = \frac{A - a}{A} \times 100\ \%$$

Where,

A is the original cross-sectional area
a is the cross-sectional area at the neck

Modulus of elasticity: Below the proportional limit, stress is proportional to strain and the constant of proportionality is called the modulus of elasticity. This is denoted by ***E***.

Therefore, $E = \frac{\sigma}{\varepsilon}$ N/mm^2 (MPa)

Modulus of elasticity is a measure of material stiffness.

Modulus of resilience: The modulus of resilience is defined as the ability of a material to absorb energy within its proportional limit. This may be calculated as the area under the stress-strain curve from the origin up to the proportional limit. Modulus of resilience is denoted by U_p.

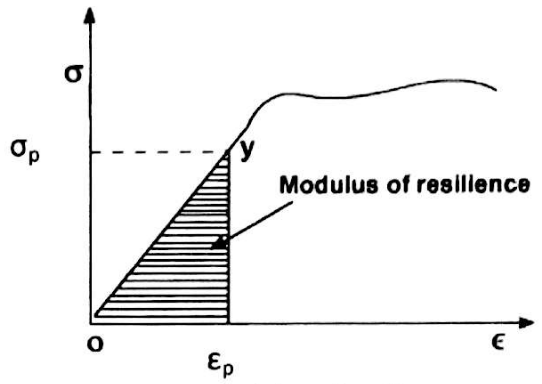


Figure: Modulus of resilience

Therefore, $U_p = \frac{1}{2}\sigma_p \varepsilon_p$ mJ/mm^3

Where, σ_p is the proportional limit.

Modulus of toughness: Toughness is the ability of a material to absorb energy and plastically deform before it fractures. Toughness is calculated by evaluating the area under the stress-strain curve. It is denoted by $\boldsymbol{U_T}$.

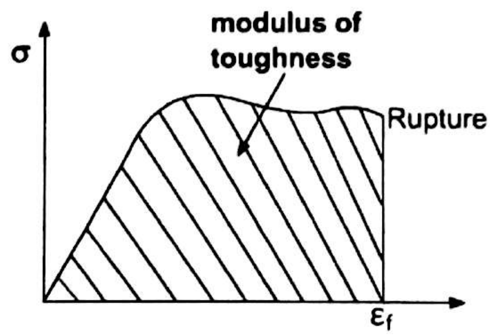


Figure: Modulus of toughness

$$U_T = \int_0^{\varepsilon_f} \sigma d\varepsilon$$

Where, ε_f is the strain at fracture. Modulus of toughness can also be calculated by using either of the following two simplified formulae.

1. $U_T = \sigma_u \varepsilon_f$
2. $U_T = \frac{\sigma_u + \sigma_y}{2} \varepsilon_f$

Where, σ_u is the ultimate strength and σ_y is the yield strength.

APPARATUS

1. UTM
2. Extensometer

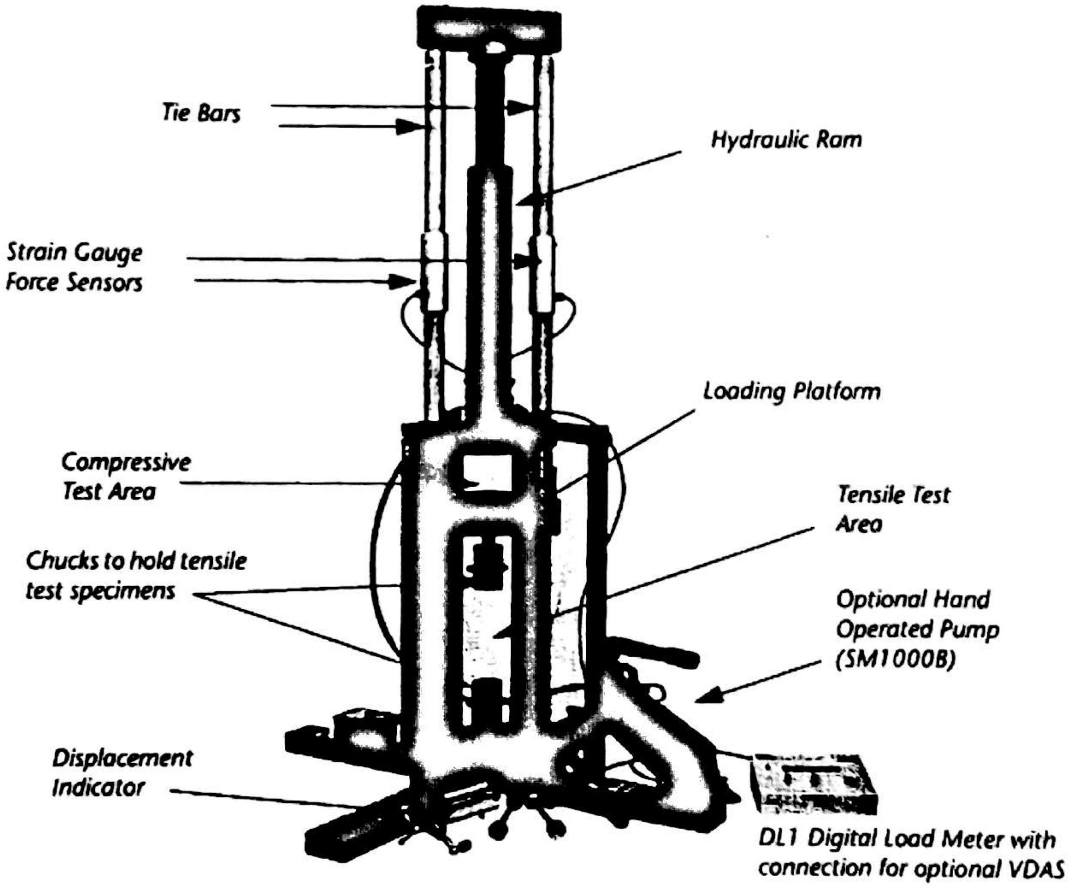


Figure 2 The 100kN Universal Testing Machine

SPECIMENS

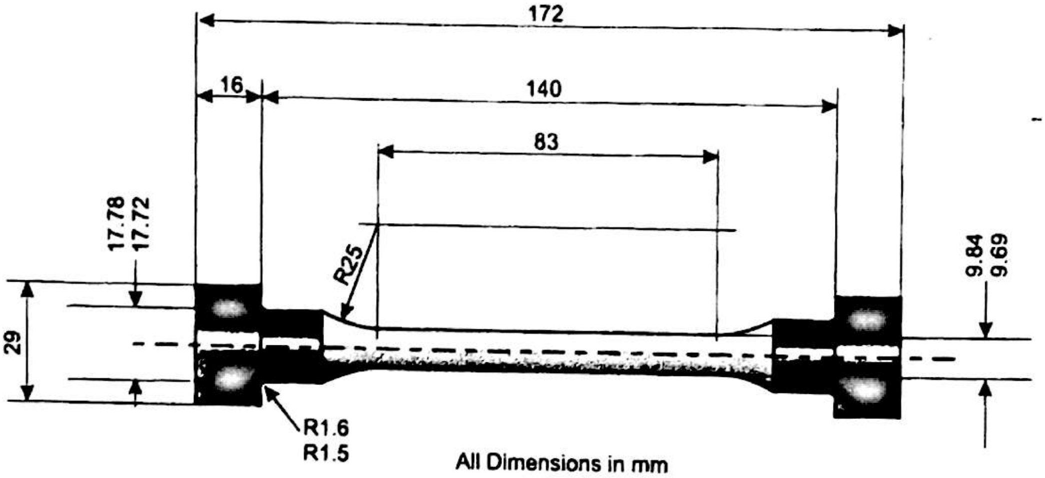


Figure : Dimensions of the Tensile Specimens (Included with the Universal Testing Machine)

DATA TABLE

Specimen type:

Initial gauge length, L_i =

Initial diameter of the specimen, d_i =

Initial cross-sectional area of the specimen, A_i =

Final diameter of the specimen, d_f =

Final cross-sectional area of the specimen A_f =

Final gauge length L_f =

Table: Data for the tension test of mild steel specimen

Obs. No.	*Force (KN)*	*Digital Displacement indicator reading (mm)*	*Extensometer reading (mm)*	*Strain, ε (mm/mm)*	*Stress, σ (MPa)*

Obs. No.	*Force (KN)*	*Digital Displacement indicator reading (mm)*	*Extensometer reading (mm)*	*Strain, ε (mm/mm)*	*Stress, σ (MPa)*

Obs. No.	*Force (KN)*	*Digital Displacement indicator reading (mm)*	*Extensometer reading (mm)*	*Strain, ε (mm/mm)*	*Stress, σ (MPa)*

Obs. No.	*Force (KN)*	*Digital Displacement indicator reading (mm)*	*Extensometer reading (mm)*	*Strain, ε (mm/mm)*	*Stress, σ (MPa)*

Obs. No.	*Force (KN)*	*Digital Displacement indicator reading (mm)*	*Extensometer reading (mm)*	*Strain, ε (mm/mm)*	*Stress, σ (MPa)*

Report Writing

Expt. No.: 01

Expt. Name: Tension test of mild steel specimen

1. **Objectives**
2. **Apparatus** (with specification)
3. **Experimental Setup:** Draw a schematic diagram of UTM
4. **Data table:** Photocopy the data table with the collected data. Then do the necessary calculation and fill up the whole data table individually.
5. **Sample calculation:** Show how displacement, stress and strain are calculated from the collected data using a sample data. The sample number should correspond to the last three digits of the student ID number of the student.
6. **Graph:** Draw load vs. deformation and stress vs. strain diagram using *MS Excel* and label it.
7. **Calculation from graph:** Calculate the following properties of the mild steel specimen from load vs. deformation and stress vs. strain curve:
   i. Proportional limit
   ii. Modulus of elasticity
   iii. Yield limit
   iv. Ultimate strength
   v. Breaking strength
   vi. Percentage elongation
   vii. Percentage reduction in cross-sectional area
   viii. Modulus of resilience
8. **Discussion:** Discuss the following points regarding the experiment:
   i. *Discuss the results and graph*
   ii. *Discuss about the failure mode and fracture surface*
9. **Reference**

Hardness Test

1. Objective

The primary objective of this experiment is to measure the Rockwell and Brinell hardness number using the correct indenter, loading, and scale. The tensile strength of the specimen material will also be calculated using the determined hardness number.

2. Theory

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Hardness tests can be used for many engineering applications to achieve the basic requirement of mechanical property. For example:

- Surface treatments where surface hardness has been much improved.
- Powder metallurgy
- Fabricated parts: forgings, rolled plates, extrusions, machined parts.

The hardness test produces permanent deformation (or change of shape) of the material. The test is therefore destructive. Because deformation of the material is controlled by dislocation motion, it is not surprising the hardness can be correlated with both yield strength and tensile strength. Typically, hard material have high strength, soft material have low strength.

However, there are three general types of hardness measurements depending on the manner in which the test is conducted:

a) Scratch Hardness measurement: Scratch tests are the simplest form of hardness test. In this test, various materials are rated on their ability to scratch one another. Moh's hardness test is of this type. This test is used mainly in mineralogy.
b) Rebound Hardness measurement: In rebound hardness measurement, a standard body is usually dropped on to the material surface and the hardness is measured in terms of the height of its rebound. Shore Hardness is measured by this method.
c) Indentation Hardness measurement: Static Indentation tests are based on the relation of indentation of the specimen by a penetrator under a given

load. The relationship of total test force to the area or depth of indentation provides a measure of hardness. The Rockwell, Brinell, Knoop, Vickers and ultrasonic hardness tests are of this type. For engineering purposes, mostly static indentation tests are used.

2.1 Rockwell Hardness testing

This hardness test uses a direct reading instrument based on the principle of differential depth measurement.

Rockwell Hardness tests are conducted in four steps:

1. The minor load (usually 10 kg for Regular and 3 kg for Superficial) is applied. Use of minor load greatly increases the accuracy of this type of test, because it eliminates the effects of backlash in the system and causes the indenter to break through slight surface roughness.
2. The major load (usually 60, 100 or 150 kg for Regular and 15, 30 and 45 for Superficial) is applied. This causes the indenter to dent the material surface.
3. The major load is removed, leaving the minor load on. Doing this relaxes the elastic deformation, leaving the indenter resting in the plastically deformed dent.
4. The difference in indenter height between steps 1 and 3 is measured.

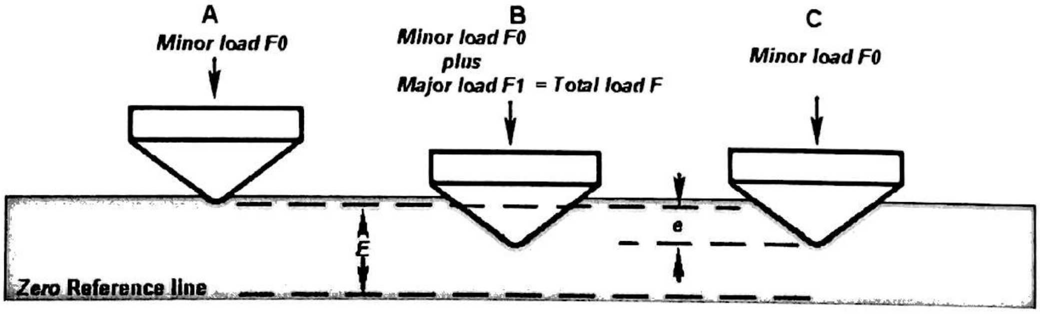


Fig. 1: Rockwell hardness test.

$$HR = E - e$$

Here,

F0 = preliminary minor load in kgf

F1 = additional major load in kgf
F = total load in kgf
e = permanent increase in depth of penetration due to major load F1
E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter
HR = Rockwell hardness number
D = diameter of steel ball

There are a large number of Rockwell Hardness scales. Each scale represents a specific combination of indenter and major load. The different scales make it possible to measure the Rockwell Hardness of a huge variety of materials. There are also "Regular" and "Superficial Rockwell Scales". The following discussion refers to the Regular Rockwell scales. Superficial scales are used for measuring thin and soft materials.

Rockwell Hardness values are expressed as HR (scale) (value). For example, very hard steel might read HRC 62. HRA 55 might be annealed mild steel.

2.2 Fields of application with different Rockwell scales

There is a considerable number of Rockwell scales and choosing the right one depends on the hardness of the material, and the thickness of the specimen or hardened surface (in case where there have been surface treatments such as carburization, nitriding, etc.). The hardness of the material determines the choice of the penetrator, diamond cone or ball.

There are usually two types of indenters. The conical diamond (Brale) indenter is used mainly for testing hard materials such as hardened steel and cemented carbides. It is recommendable for steel with solidity below 785 N/mm^2 (20 HRC, 230 HB/30).

Hardened steel ball indenters with diameters 1/16", 1/8", 1/4", 1/2" are used for testing softer materials such as fully annealed steels, softer grades of cast iron, and a wide variety of non-ferrous metals. The softer material, the larger should be the diameter of the ball and / or the smaller should be the total test load. For instance, the materials that can be tested with the HRB scale (ball 1/16" – total test load 980.7 N) are harder than the materials tested with the HRL scale (ball 1/4" – total test load 588.4 N).

The most frequent Rockwell Scales are given below:

1. HRC (diamond cone – 150 kgf)

It is used for steel, hardened steel, case hardened steel, pearlitic cast iron, titanium.

2. HRA (diamond cone - 60 kgf)
   For thinner or more brittle specimens of the RC families: cemented carbides, thin case hardened parts, thin gauge steels.
3. HRB (steel ball of 1/6" diameter - 100 kgf)
   In Europe, this scale is usually used for copper alloys (brass, bronze etc.). In the US, it is also used for steel up to approx. 686 N/mm^2.

2.3 Brinell hardness Scale:

The test is achieved by applying a known load to the surface of the tested material through a hardened steel ball of known diameter. The typical test uses a 10 millimeters diameter steel ball as an indenter with a 3000 kgf force. For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball.

Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings. Brinell testing often use a very high test load (3000 kgf) and a 10mm wide indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The Brinell method applies a predetermined test load (F) to a carbide/steel ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters - usually at right angles to each other and these result averaged (d). The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula.

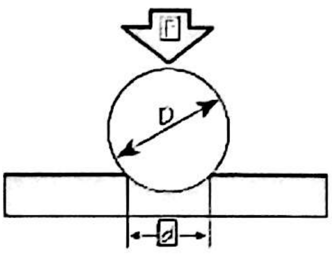


Fig. 2: Brinell hardness test.

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

D = ball diameter
d = impression diameter
F = load
HB = Brinell hardness

3. Experimental Procedure

- First examine the Rockwell hardness tester insuring that the operating lever is in the position closest to the operator and that the correct major load is in a position to be applied.
- Insert the proper indenter into the testing machine and place the test specimen on the anvil.
- Next, turn the elevating screw, raising the specimen into contact with the indenter. Continue to elevate the specimen until the initial load (10 kg) is fully applied, determined by the pointer.
- The machine will automatically apply the major load
- Finally, record the result of the test in the proper scale.

3.1 Precautions

1. Thickness of the specimen should not be less than 8 times the depth of indentation to avoid the deformation to be extended to the opposite surface of a specimen.
2. Indentation should not be made nearer to the edge of a specimen to avoid unnecessary concentration of stresses. In such cases, distance from the edge to the center of indentation should be greater than 2.5 times diameter of indentation.
3. Rapid rate of applying load should b avoided. Load applied on the ball may rise a little because of its sudden action. Also rapidly applied load will restrict plastic flow of a material, which produces effect on size of indentation.

4. Calculation

- Rockwell hardness number will be directly given by the hardness testing machine.
- Brinell hardness will be calculated by the formula given in the theory section.
- Tensile strength will be determined by the following formula.

$$TS = 3.55\ HB\ (HB \leq 175)$$

$$3.38\ HB\ (HB > 175)$$

5. Result

Students will fill up this section with their individual outcome/results about the test.

6. Discussion

Students should fill up this section with their individual findings and shortcomings/improvements regarding the test.

Experiment No.: 05
IMPACT TEST

Objectives:

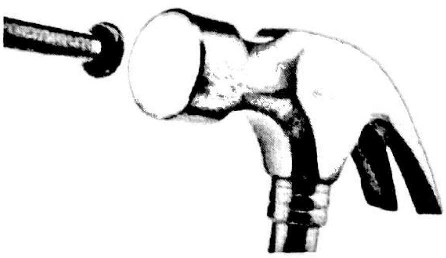
1. To study the impact testing machine
2. To determine the energy absorbed in fracturing the given specimens
3. To observe the appearance of the fracture of the specimens

Theory:

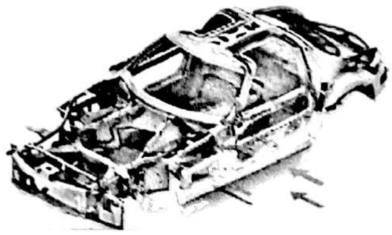
The impact test is done to measure the impact strength of materials. The impact strength indicates the amount of energy required to fracture the materials under dynamic or impact loading.

Toughness:

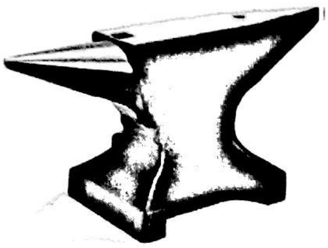
Toughness is the property of a material that it does not break under a sudden shock. It is simply expressed as the ability of a material to withstand shock loading. Toughness property is required in many parts such as: car chassis, hammer head, connecting rod, and anvils to do the job they intended to do properly.



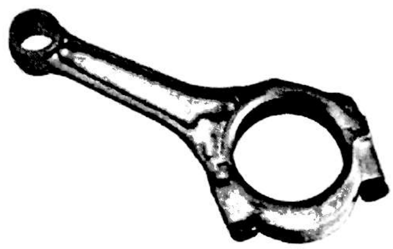
(a)



(b)



(c)

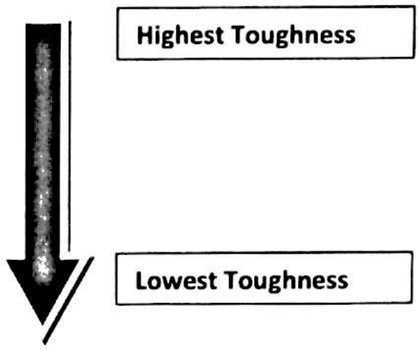


(d)

Fig.5.1: (a) Hammer (b) Car chassis (c) Anvil (d) Connecting rod.

Examples of toughness of materials arranged in a descending order:

1. Copper
2. Nickel
3. Iron
4. Aluminum
5. Lead
6. Tin
7. Cobalt



How to compare toughness of different metals?

One way to compare toughness of different materials is by comparing the areas under the stress strain curves from the tensile tests of these materials as shown in Fig. 5.2. This value is simply called "material toughness" and it has units of energy per volume.

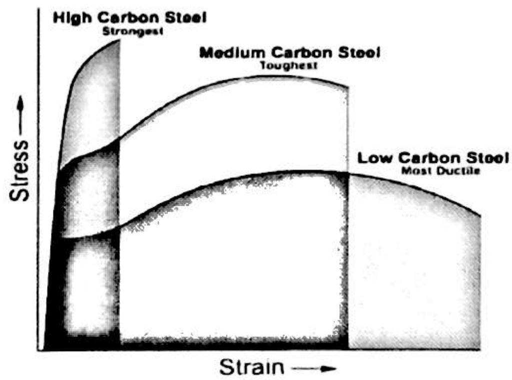


Fig. 5.2: The stress strain curve for different materials.

Toughness and Impact Tests:

There are basically three types of impact tests for evaluating the toughness of materials:

• The Pendulum test.

• The Drop Weight test.

• The Instrumented test

In this experiment, we shall only study the most commonly used impact which is the "**Pendulum Test**".

The pendulum impact test

The pendulum impact test measures the kinetic energy absorbed by a material specimen of specific dimensions as it fractures by the impact of a known energy value of a special hammer mounted in a pendulum. See Fig.7.3.

The kinetic energy of the hammer at the time of impact equals to the potential energy of the hammer before its release.

The potential energy of the hammer (PE) can be calculated using the following formula:

$$PE = m*g*h$$

Where:

PE = the potential energy.

m = the mass of the hammer in Kilograms (Kg).

g = the gravity acceleration in m/s^2.

h = the vertical height in meters (m).

The mass of the hammer and the height of fall (h_F) determine the energy In the elevated position, the pendulum possesses a definite potential energy which is converted to kinetic energy during its downward swing. The pendulum achieves maximum kinetic energy at the lowest swing position just before it strikes the specimen.

The impact energy absorbed by the specimen during rupture is measured as the difference between the height of the drop before fracture (h_F) and the height of rise after fracture of the test specimen (h_R) and is directly read on the dial scale which is calibrated to give the reading directly in joules.

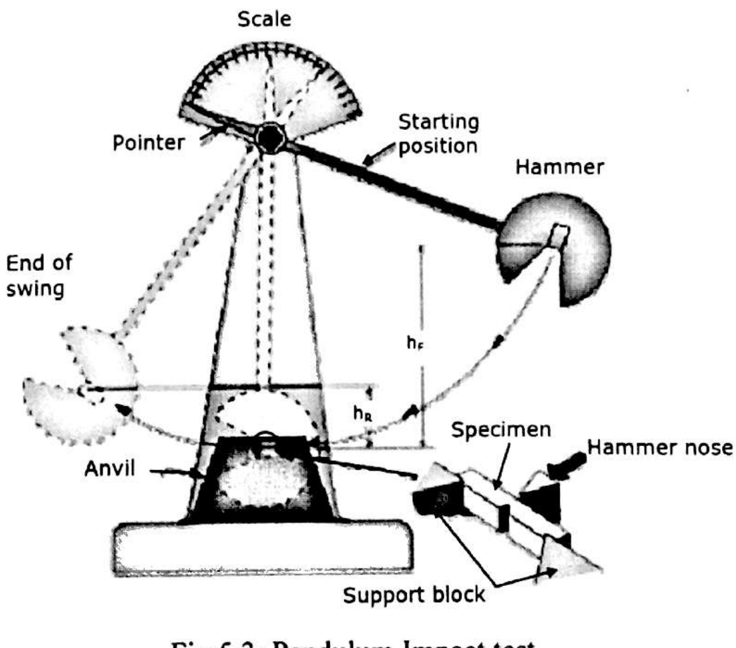


Fig.5.3: Pendulum Impact test

Impact strength = $mg(h_F - h_R)$

$$= mgR(Cos\theta_R - Cos\theta_F) \quad \text{Joule}$$

The testing machine which is used here is of the pendulum type. Mostly used types of the test are 1) Charpy and 2) Izod.

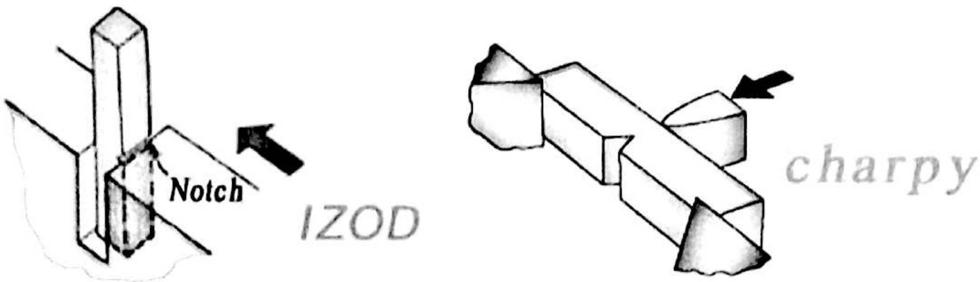


Figure 5.4: Difference between Charpy and Izod impact test.

Apparatus Used:

Specimen Used:

Experimental Setup:

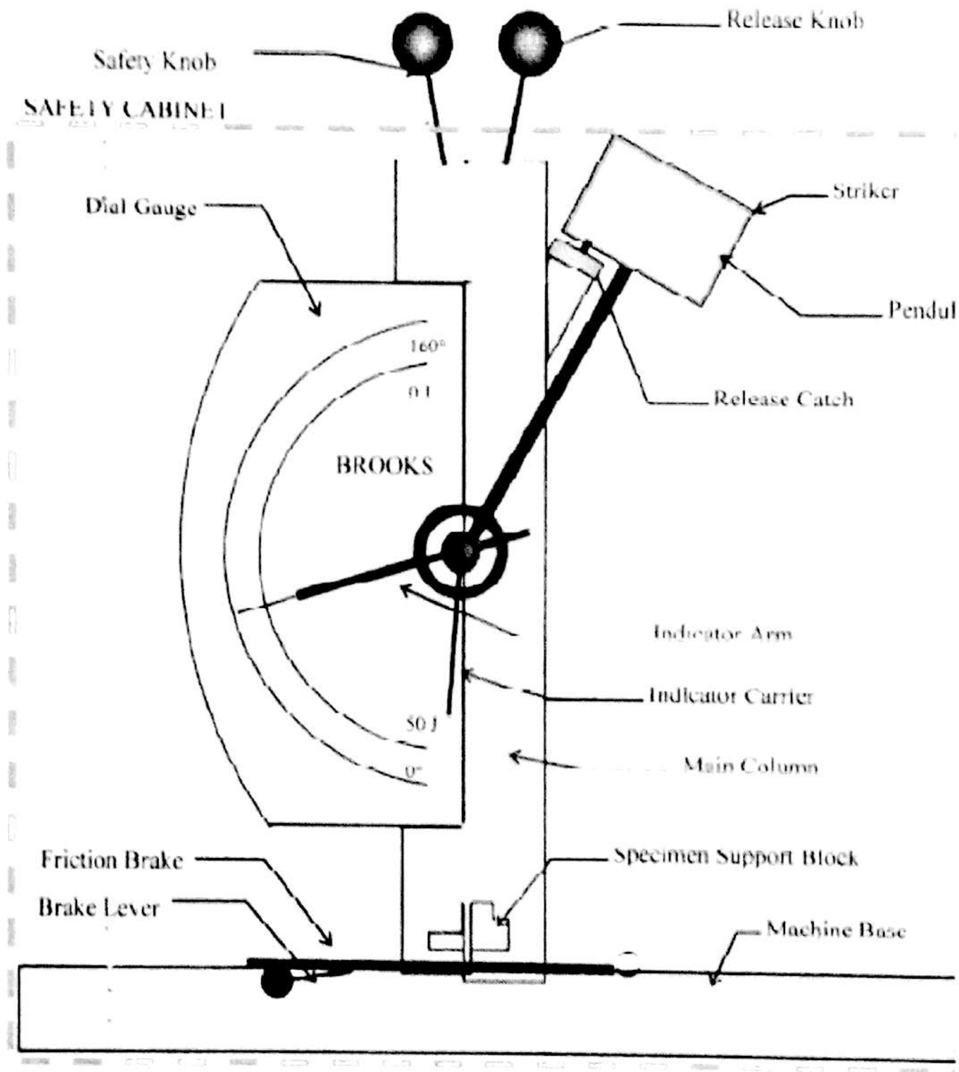


Fig. 5.5: Experimental setup

Standard Test Specimen Dimensions:

The specimens used in this apparatus can be made of a low carbon steels as well as plastic materials and must be of the dimensions shown in Fig.5.6.

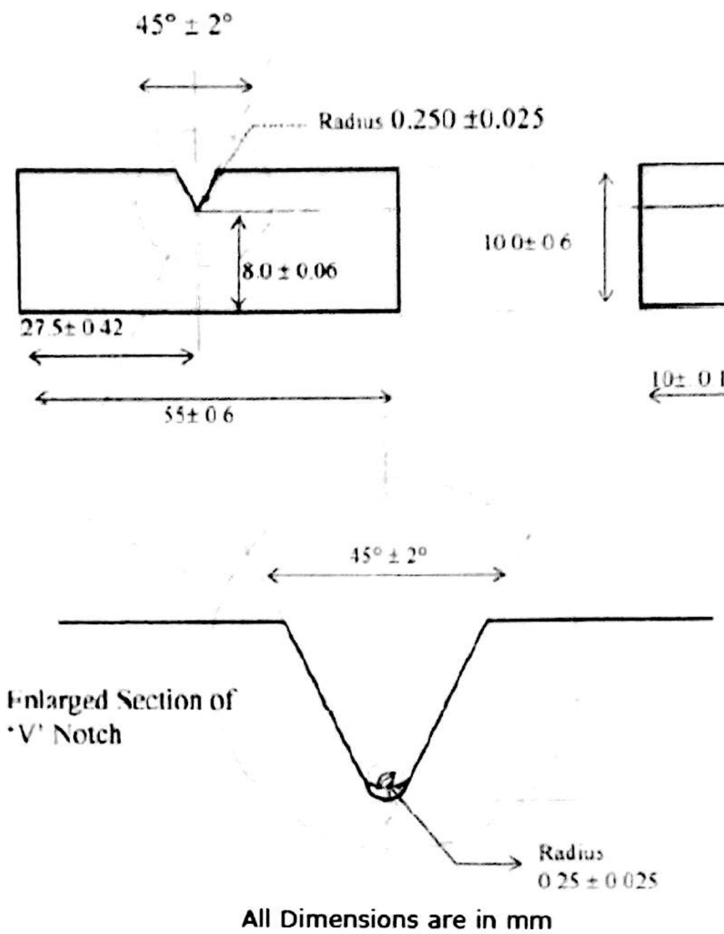


Fig. 5.6: Impact test specimen dimension

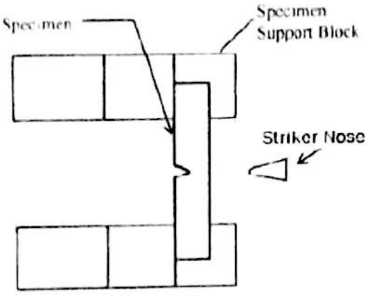
Procedure:

1. Open the safety cabinet and raise the pendulum till it engages with the release catch as shown in Fig.5.7.

Fig. 5.7: engaging the pendulum with the release catch.

2. Place the prepared specimen on the support block and ensure that its notch is facing the opposite side of the hammer as shown in Fig.5.8a.

N.B: When inserting the test piece into the support, the pendulum must be supported by the safety support pin shown in Fig.5.8b.



(a)

(b)

Fig. 5.8: (a) specimen orientation on the support block. (b) Safety Release catch Safety pin

3. Adjust the indicator with its carrier to the "zero" position (set to zero or 50 joules) as shown in Fig.5.9.

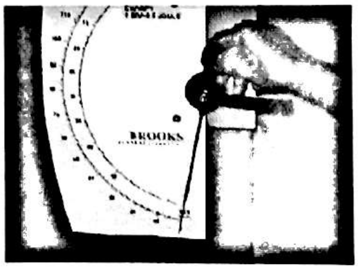


Fig.5.9: setting the indicator to zero.

4. Check for safety fall and close the safety cabinet.

N.B: When operating the equipment, the access door should be firmly closed and remains secured until the pendulum stop. See in Fig.5.9.

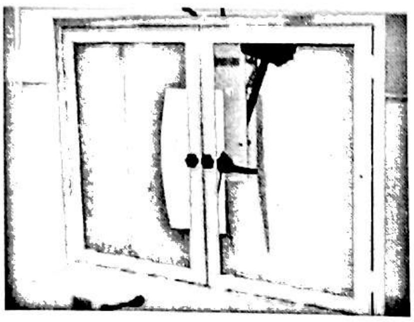


Fig.5.9: The access door is firmly closed.

5. Release the pendulum latching device by operating the two knobs in sequence (safety knob first and then the release knob) as shown in Fig.5.11.

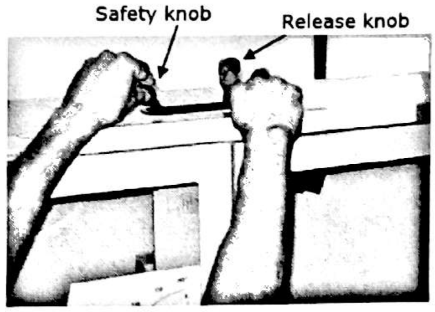


Fig.5.11: Starting the test.

6. After the specimen breaks and the pendulum complete its initial swing, apply the friction brake to stop the pendulum and open the cabinet as shown in Fig.5.12.

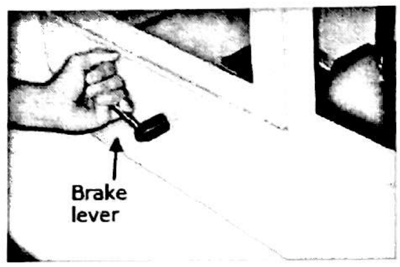


Fig.5.12: Using the brake lever to stop the pendulum.

7. Read the energy absorbed by the broken specimen from the pointer on the dial See Fig.5.13.

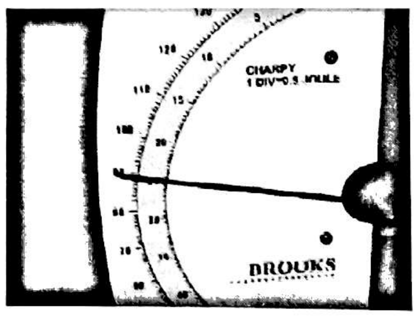


Fig.5.13: read the dial

EXPERIMENT NO. 05

IMPACT TEST

DATA SHEET

Course no.:
Group no.:

Student ID no.:
Date:

Particulars of Specimen:

Weight of the hammer, W = 6.6 kg

No. of observation	Type of Specimen	Area under the notch (mm^2)	Notch Impact Strength (Nm/mm^2)

Signature of the teacher