DEPARTMENT OF CIVIL ENGINEERING

STRENGTH OF MATERIALS

LABORATORY MANUAL

Compiled by

Mr. K. S. Vivek
Asst. Professor (CE)

Mr. N.V. Mohan Krishna
Asst. Professor (CE)

KHIT

KALLAM HARANDHAREDDY INSTITUTE OF TECHNOLOGY

Approved by AICTE, New Delhi & Affiliated to JNTUK, Kakinada

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1. TENSION TEST ON STEEL BAR

Objective: To study the stress-strain behavior and find out young's modulus of steel bar by conducting tension test using universal testing machine (UTM).

EQUIPMENT: Universal testing machine, micrometer, metre rule, steel specimen confirming to IS 1608-1972 and vernier calipers.

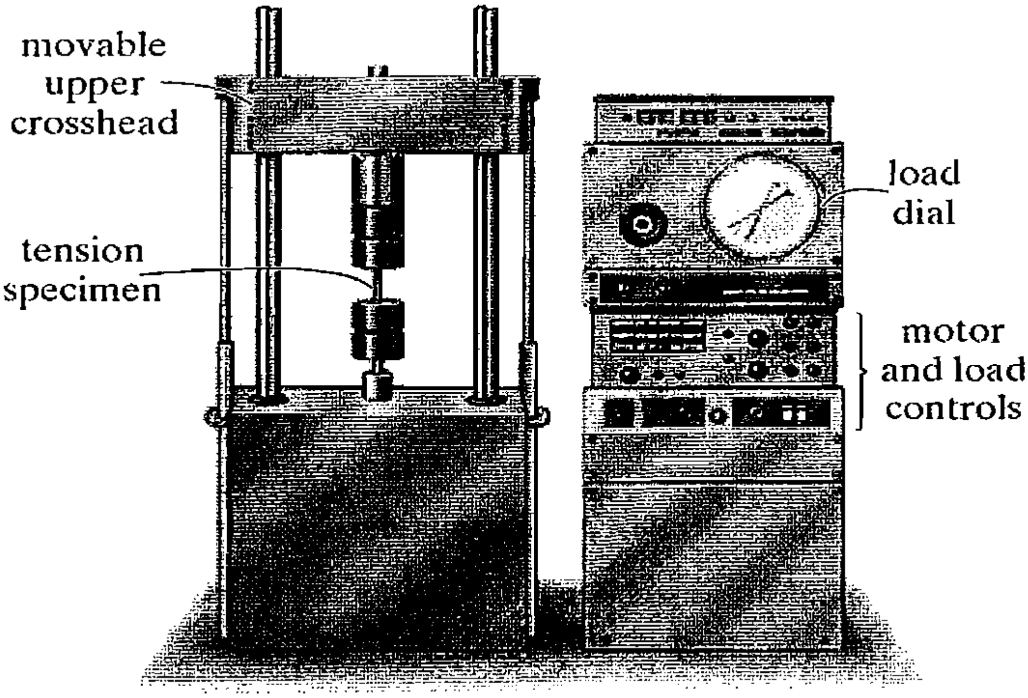


Figure 1: Universal Testing Machine

The UTM can be screw-gear type and hydraulic type. Mostly hydraulic UTM is used. An electric motor rotates a hydraulic pump that forces the oil into the cylinder where by the rigid assembly of lower and upper cross head is lifted up. During this movement a tensile load will act upon the specimen held between upper and middle cross head and a compressive force will act on the specimen placed on the lower cross head. The hydraulic pressure on the bottom of the hydraulic cylinder is transmitted to a hydraulic capsule which is connected to a bourdon tube gauge which can be calibrated to read the force directly. The schematic sketch of hydraulic UTM is shown in Figure 2.

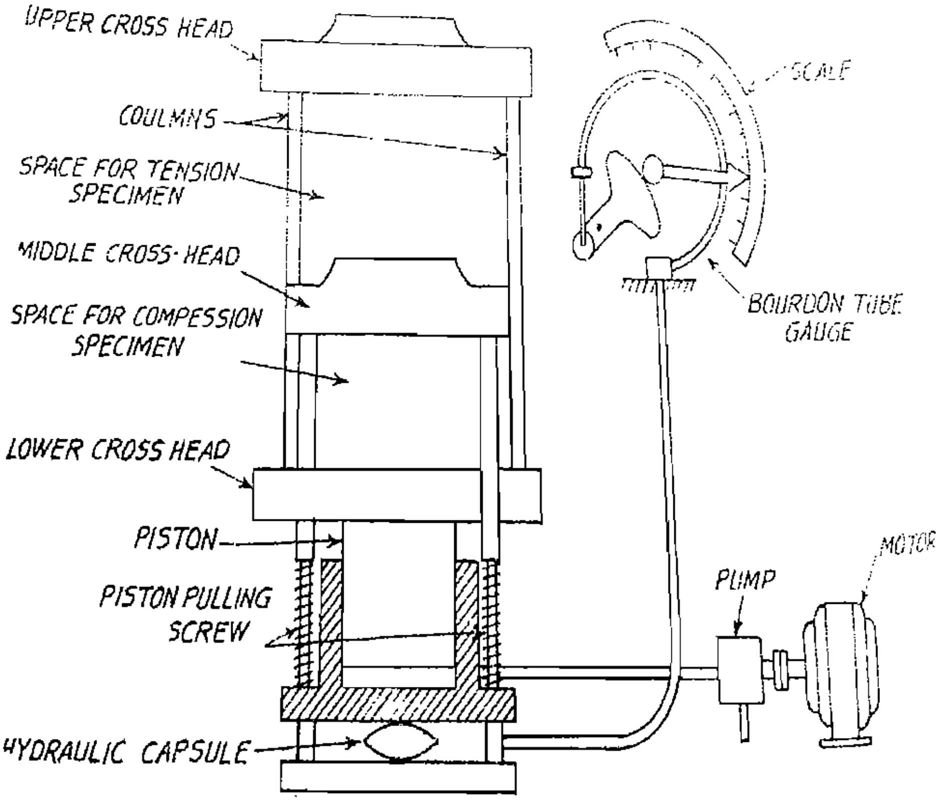


Figure 2: Schematic view of hydraulic UTM

Theory: Consider a bar subjected to gradually applied axial loads "P" as shown in Fig.3. Due to loads (external forces) P, internal resultant force N is produced which is perpendicular to cross-section. This internal resultant force per unit area of cross-section of the bar is called as "normal stress σ ". Let the bar is cut by a section and consider the equilibrium of the two parts of the bar. On the cut surface of the cross-section these will be distributed internal force N as shown in the fig. Therefore, normal stress is given by $\sigma = N/A$, where A is the area of cross-section of the bar. Since, for equilibrium N=P normal stress $\sigma = P/A$. When the bar is subjected to tension, length of the bar increases and this increase δ by original length L of the bar is referred to as "normal strain ε". The plot between stress (Y- axis) and strain (X- axis) is known as **Stress-Strain diagram**.

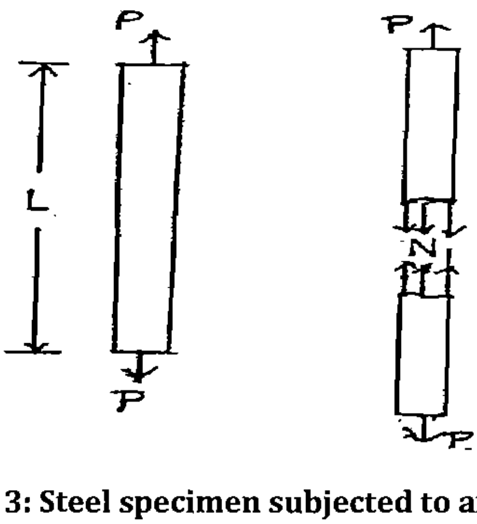


Figure 3: Steel specimen subjected to axial load

Steel bars can be classified as Mild Steel bars (M.S. bar) and Tor Steel bars (T.S. bar). The stress-strain curve for mild steel is shown in Figure 4. From this curve we can identify four different ways in which the material behaves, depending on the amount of strain induced in the material.

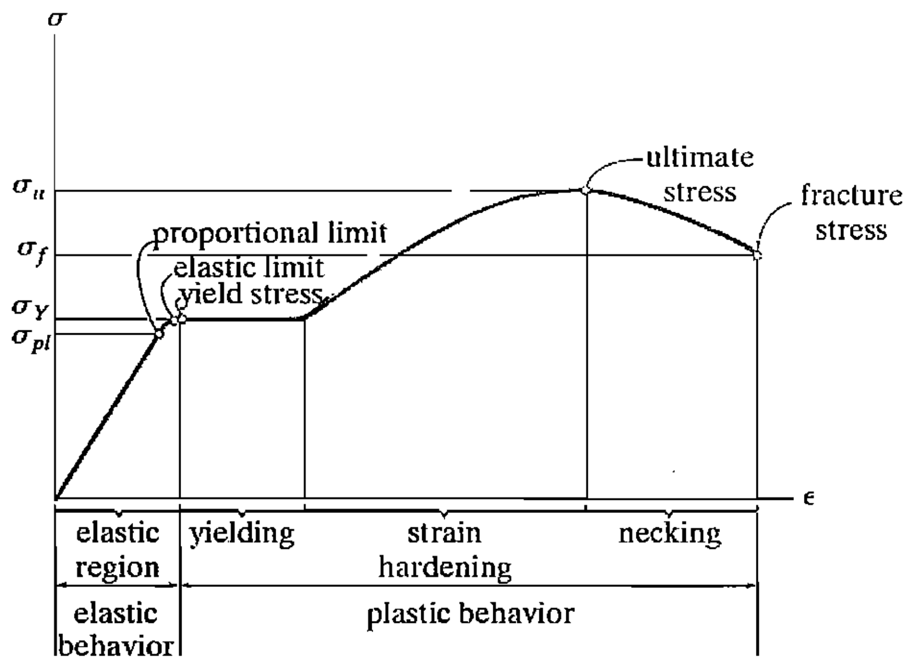


Figure 4: Conventional Stress-strain curve for mild steel

1) Elasticity (Elastic behavior): The material property of regaining its original shape and size after removal of load.
2) Plasticity (Plastic behavior): The material property of not regaining its original shape and size after removal of load.
3) Elastic limit: The point on stress-strain curve up to which the member posses elastic behavior.
4) Proportionality limit: Within elastic limit up to at a certain point, the stress varies linearly with respect to strain i.e., stress- strain curve varies linearly (Straight line). Up to this point the behavior of the material is Linearly – Elastic. Within proportionality limit (linear elastic behavior) Hooke's law is obeyed. Hooke's law states that "Within linear-elastic region, stress is directly proportional to strain".

Mathematically

$$\sigma \approx \varepsilon$$

$$\Rightarrow \sigma = E\ \varepsilon$$

Where E is young's modulus or modulus of elasticity. The slope linear stress strain curve gives modulus of elasticity. The stress at this point is called as Proportionality Stress .

5) Non-linear Elastic: Within proportionality limit and elastic limit the curve is not linear though the material behaves elastically. Such region is called as Non-linear elastic. Hooke's law cannot be applied.

6) Yield point or limit: The point at which the stress reaches the material's yield stress, is called as yield point. Yield stress is the stress at which the fibres of the bar start yielding (Strain increases but stress does not change). Yielding of the specimen is the onset of failure of the specimen.

7) Strain hardening: After yielding, the material posses extra energy and ability to carry further increase in load. In strain hardening region, stress increases rapidly but strain does not increase rapidly. This phenomenon of less increase in strain is called strain hardening.

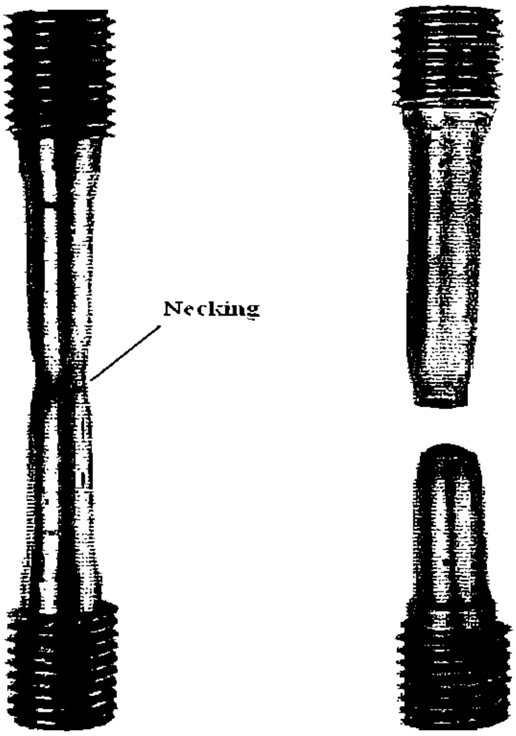
8) Ultimate stress: The maximum stress which the material can sustain is called ultimate stress. Ultimate stress is the ratio of ultimate load to area of cross section of the specimen. The point at which the ultimate stress reaches is known as ultimate stress point.

9) Necking: Upon reaching the ultimate stress, necking of the bar (reduction in area of cross section) occurs as shown in Figure 5(a).

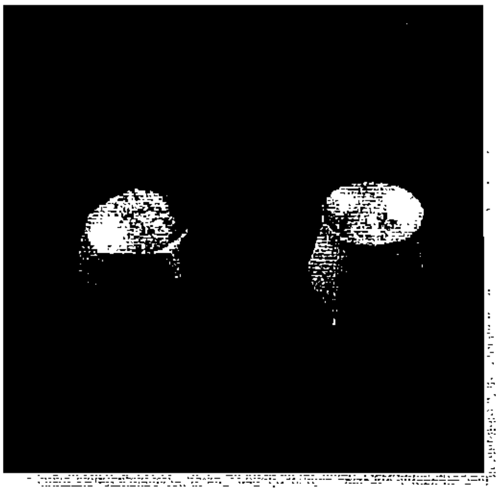
10) Fracture stress: The material after reaching ultimate stress looses the ability to carry load and fails.

NOTE: For mild steel the proportionality limit point, elastic limit point and yield point coincide.

The failure of mild steel is ductile failure as mild steel is ductile material. A material which undergoes large plastic deformation before failure is called ductile material. The failure of mild steel occurs as cup-cone failure (diagonal failure due to maximum shear stresses on inclined plane at 45^0) as shown in Figure 5(b) and is called as ductile failure. It is a gradual failure. Ductile materials are weak in resisting shear stress.



(a) (b)



This steel specimen clearly shows the necking that occurred just before the specimen failed. This resulted in the formation of a "cup-cone" shape at the fracture location, which is characteristic of ductile materials.

Figure 5: Cup cone failure of mild steel

Tor steel is high strength steel and is a brittle material. The stress-strain curve of brittle material is shown in Figure 6. No specific yield point can be noticed and stress corresponding to 0.2% offset of strain is considered as Yield stress. Failure occurs due to tensile stress on plane perpendicular to the line of action of load at 90°. The failure occurs suddenly and is called as brittle failure. Brittle materials are weak in resisting tensile stress.

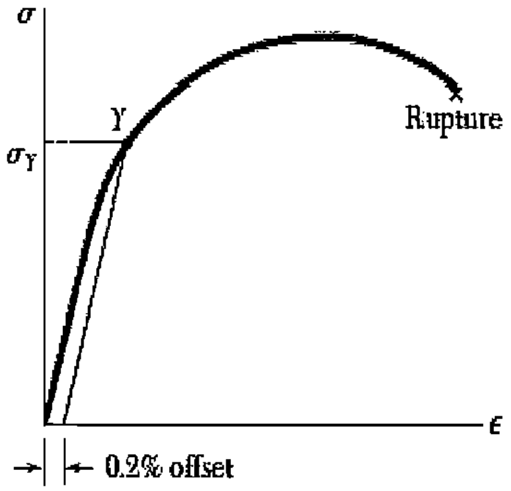


Figure 6: Stress-strain curve for tor steel

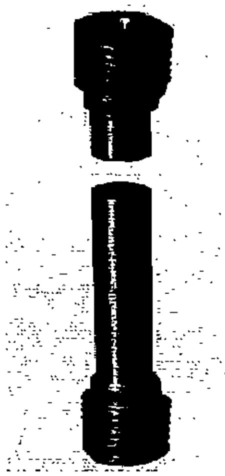


Figure 6: Failure of tor steel

Ductility is usually measured as percentage of elongation or percentage reduction in area of cross-section. These measures of ductility are obtained after fracture, by keeping together the two broken pieces of the specimen, and measuring the gauge length at fracture, and of cross-section at fracture.

Percentage of elongation = $(L_f - L_0)/L_0 \times 100$

Percentage reduction in area of cross-section = $(A_0 - A_f)/A_0 \times 100$

where L_0 and A_0 are initial gauge length and initial area of cross-section respectively; L_f and A_f are measured gauge length at fracture and area of cross-section at fracture respectively.

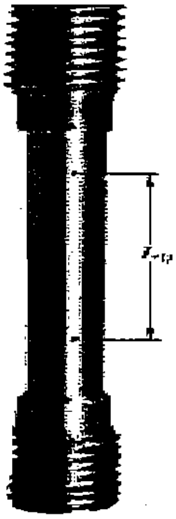


Figure 7: Gauge length

For measurement of strain and for calculation of percentage of elongation, proper gauge length has to be selected. It is important to note that longer the gauge length used, smaller will be the % of elongation. To keep % of elongation reasonably constant over a wide range of cross-section shape, gauge length must be selected proportional to cross-sectional dimensions. Further, gauge length must be sufficient enough to include necked region. Generally, gauge length is taken as 5 times the diameter of a specimen for ductile material or $5.65\sqrt{A_0}$ for brittle materials, where A_0 is the original cross-sectional area of the specimen.

PROCEDURE FOR MILD STEEL SPECIMEN

1) Measure the diameter of the specimen at two or three sections and calculate mean diameter "d". Obtain the gauge length of the specimen i.e. 5 x d.
2) Mark the clear length of the specimen in between the grips at each 1 cm. This is required so as to obtain the increase in gauge length of the specimen near the necking portion. Measure the clear length of the specimen in between the grips.
3) Fix the specimen firmly to the jaws of the universal testing machine.
4) Adjust the graph paper and the pen of the plotter so that it is ready for drawing graph between force applied and elongation produced. Load pointer should initially read zero.
5) Start the universal testing machine after closing both the left and right valves of the control panel. Release the right valve to the required level of rate of loading. Note the load at

1mm,2mm,3mm.....10mm,12mm,14mm,16mm,18mm,20mm,25mm,30mm,40mm..

6) After the specimen fractures, remove the specimen pieces from the loading frame. Also, cut the graph from the graph roll.
7) From the force vs elongation graph, note down the elongation at different levels of force applied and calculate corresponding stresses and strains.
8) Draw a graph between stress and strain. Mark the yield point and obtain the yield strength of the material.
9) Keep the broken pieces of the specimen together so as to resemble the original specimen and measure the gauge length near the necking of the specimen. Also, measure the minimum diameter of the specimen at the necking.
10) Calculate percentage of elongation and percentage reduction in area of cross-section.

OBSERVATIONS AND CALCULATIONS

Vernier scale reading = Main scale reading + (Least count * Vernier coincidence)
VSR = MSR + (LC * VC)
L = Clear length of the specimen between the grips =
Initial mean diameter "d"=
Minimum diameter after fracture d_y (at necking) =
Initial area of cross-section, $A_0 = \pi d^2 / 4$ =
Initial gauge length, L_0=
Cross sectional area after fraction, $A_f = \pi d_y^2/4$ =
Gauge length after fracture, L_f=

Sl.No.	Load (P)	Elongation (δ)	Stress P/A_0	Strain δ/L

RESULTS:

Yield stress = yield load/ area of cross section =

Ultimate stress = ultimate load/ area of cross section =

Failure stress = Failure load/ area of cross section =

% of elongation =

% of reduction in area of cross-section =

Young's modulus = stress/strain =

GRAPH: Stress (Y axis) vs Strain (X-axis) for mild steel specimen

NOTE: If percentage of elongation is less than 5% at fracture on a gauge length of 100, then such specimen is called brittle specimen.

SAMPLE QUESTIONS FOR VIVA

1. How gauge length is calculated?

2. What is the formula for least count of vernier calipers?

3. What is a] ultimate load and stress
   b] failure load and stress
   c] yield load and stress ?

4. Explain Hooke's law.

5. What is ductile material?

6. What is elasticity?

7. What is plasticity?

8. Differentiate between ductile failure and brittle failure of tension specimen.

9. Ductile material elongates more than brittle material. True/ False?

10. How to identify yield load practically?

*11. What is engineering/ conventional stress-strain curve and true stress-strain curve?

12. Stress is independent of modulus of elasticity. True or False?

13. Explain how cup-cone failure occurs in ductile member subjected to tension.

14. Why 0.2% offset is taken for high strength steels (Tor steel)? Justify!

15. For what region of stress-strain curve is Hooke's law applicable?

16. Is cast iron ductile or brittle?

17. What is ductile specimen?

18. What is brittle specimen?

19. Compared to rubber and glass, which is elastic?

*20. Name a few tests that can be conducted using UTM.

21. What are the S.I. units of Normal stress?

*22. Differentiate between stress and strength.

2. BENDING TEST OF SIMPLY SUPPORTED BEAM

OBJECTIVE: 1) To find out the maximum deflection experimentally

2) To calculate modulus of elasticity

APPARTUS: Simply supported beam setup, dial gauge and scale.

THEORY: When a simply supported beam is subjected to central point load, the maximum deflection, bending moment and bending stress occurs at the point of application of the load itself that is at the centre of the span.

The maximum deflection for centrally loaded simply supported beam = $PL^3/48EI$

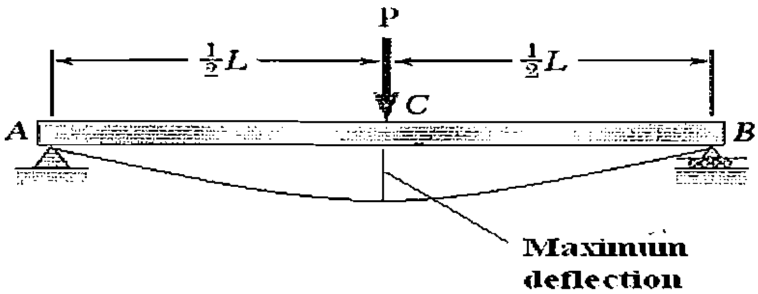


Figure 1: Simply Supported beam with central point load

PROCEDURE:

1) Consider a slender beam of steel material with rectangular cross section

2) Note down breadth (b) and depth (d) of cross section

3) Calculate moment of inertia about axis of bending

4) Place the beam on the supports

5) Place the dial gauge at the centre

6) Apply load (P_1) at the centre

7) Note down the corresponding deflection which is found experimentally

8) Now, find out modulus of elasticity

9) Repeat the above procedure for loads P_2, P_3..........

10) Plot the graph between load (X axis) and deflection (Y axis)

OBSERVATION:

S. No	Load P (N)	Dial gauge reading	Deflection (mm) = Dial gauge reading * L.C.	E (N/mm^2)

RESULT: The modulus of elasticity is ___________

GRAPH: Plot the graph between load (X axis) and deflection (Y axis)

SAMPLE QUESTIONS FOR VIVA

1. Explain the procedure of test.
2. Write the formula for least count of dial gauge.
3. Consider two specimens a and b. Specimen 'a' has E = $2*10^5$ N/mm^2 and specimen 'b' has E = $3*10^5$ N/mm^2. If loading, length of specimens and cross sections of both specimens are same and identical, which specimen undergoes large deflection?
4. 1 Kgf = _________ N?

3. BENDING TEST OF CANTILEVER BEAM

OBJECTIVE: 1) To find out the maximum deflection experimentally

2) To calculate modulus of elasticity

APPARTUS: Cantilever beam setup, dial gauge and scale.

THEORY: When a cantilever beam is subjected to point load at free end, the maximum deflection occurs at the point of application of the load itself that is at the free end of the beam. But maximum bending moment and bending stress occurs at the fixed end. The maximum deflection for centrally loaded simply supported beam = $PL^3/3EI$.

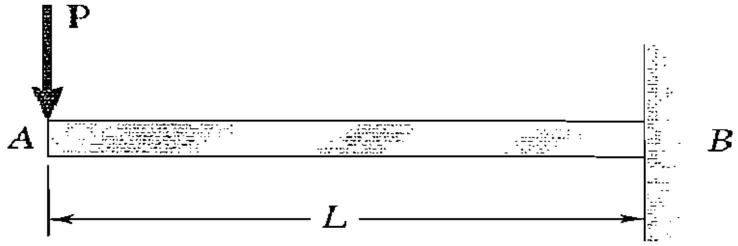


Figure 1: Cantilever beam with point load at free end

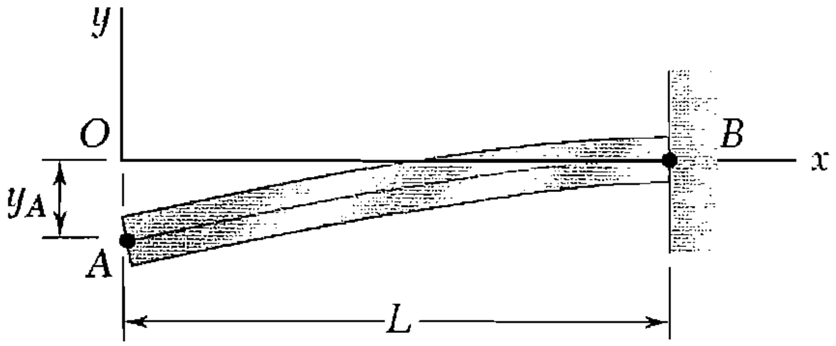


Figure 2: Deflection profile of cantilever beam with point load at free end

PROCEDURE:

1) Consider a slender beam of steel material with rectangular cross section

2) Note down breadth (b) and depth (d) of cross section

3) Calculate moment of inertia about axis of bending

4) Place the beam such that one end is fixed and other end is free

5) Place the dial gauge at the free end

6) Apply load (P_1) at the free end

7) Note down the corresponding deflection which is found experimentally

8) Now, find out modulus of elasticity

9) Repeat the above procedure for loads P_2, P_3..........

10) Plot the graph between load (X axis) and deflection (Y axis)

OBSERVATION:

S. No	Load P (N)	Dial gauge reading	Deflection (mm) = Dial gauge reading * L.C.	E (N/mm^2)

RESULT: The modulus of elasticity is ___________

GRAPH: Plot the graph between load (X axis) and deflection (Y axis)

SAMPLE QUESTIONS FOR VIVA

1. Explain the procedure of test.
2. Write the formula for least count of dial gauge.
3. 1 Kgf = ________ N?

4. ROCKWELL HARDNESS TEST

OBJECTIVE: To determine the hardness of a metal using Rock-well hardness testing machine.

EQUIPMENT: Rockwell Hardness Testing Machine, Steel ball or Diamond cone indenter.

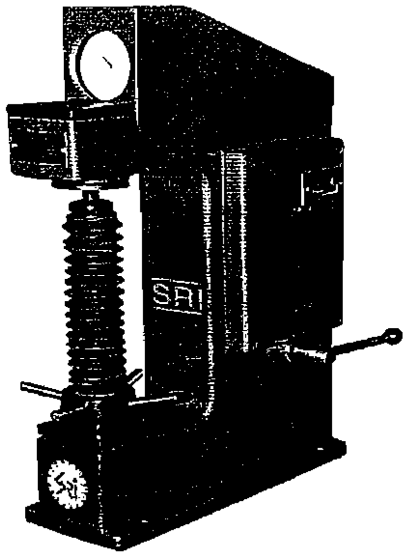


Figure 1: Rockwell hardness tester

HARDNESS: Resistance of a material to scratch, indentation or abrasion. It is the measure of plastic deformation.

THEORY: The Rockwell hardness testing machine measures the depth of the impression on the test specimen in terms of Rock-well number, the penetrator is first loaded with a minor load of 10 Kg. to take out any slackness in the machine and the indicator for measuring the depth of the impression is set to zero. The major load is then applied. After its removal, the dial gauge records the depth of the impression due to the major load in terms of Rockwell number. **Therefore, Rockwell hardness (H.R.) is based on the difference between the depth of impression at major and minor load. Rockwell hardness number is inversely proportional to depth of indentation.** The hardness value may be obtained from either the "B" scale using a steel ball indenter or one from "C" scale using a conical indenter (diamond cone). The reading so obtained gives directly the Rockwell hardness (H.R. or H.R.C) with a suffix indicating the scale used.

Test with Diamond Cone (Rockwell C) :

Preliminary load = 10 Kgf.

Additional lead =140 Kgf.

Total load = 10 + 140 = 150 Kgf.

Test with Steel Ball (Rockwell B):

Preliminary Load = 10 Kgf.

Additional Lead = 90 Kgf.

Total load = 10 + 90 = 100 Kgf.

The indenter generally used is Brale indenter in form of 120^0 diamond cone. The Rockwell hardness shall be denoted by the symbol HR proceeded by the hardness value and supplemented by a letter indicating the scale. For example, 60 HRC indicates a Rockwell hardness of 60 measured on the C scale.

PROCEDURE

For carrying out tests, the following procedure should be adopted very carefully. Any negligence may leads to the spoil of the indenter.

1. Select the load in the "LOAD SELECTOR DISC" depending the Material and indentor. The respective figure of weight will be visible in the window.
2. Keep the lever at position "A".
3. Place specimen securely on Testing Table.
4. Turn the hand-wheel clockwise, so that specimen will push the indenter and show a reading on dial gauge as small pointer at 'B'. A red spot is put against 3 not to have any confusion. The long pointer automatically stops at '0' on Black scale i.e. 'B-30' on Red scale. If little error exists the same can be adjusted by rotating the outer ring of Dial-gauge.
5. Turn the lever from position 'A' to 'B' slowly so that the total lead is brought into action without jerks.
6. When the long pointer of Dial Gauge reaches a steady position, take back the lever to 'A' position slowly. (Sudden release of the lever from 'B' to 'A' may show erratic readings). The weights are thereby lifted off, only the initial load remaining active.
7. Read off the figure against the long pointer. That is the direct reading of the hardness of the specimens. Outer scale on dial should be used in case of tests on 'A' and C scales and inner scale for tests on 'B' scale only.
8. Turn back the hand wheel and remove the specimen. Carry on the same procedure for further specimens.

OBSERVATIONS

S.No.	Material	Indentor	Load in Kgf.	Scale	H.R.B. or H.R.C.	Average H.R.B. or H.R.C.

RESULT: The rockwell hardness number (HRC/HRB) is __________

ADVANTAGES OF ROCKWELL HARDNESS TEST OVER BRINELL'S HARDNESS TEST

1. Can be performed on very small parts in finished or unfinished condition.
2. Because of indentation being very small, the finished surface is not spoilt and unfinished surface does not affect the indentation.
3. Since no measurement of indentation and consequent calculation are needed, the method is direct, fast and free from personal error.

PRECAUTIONS

1. The thickness of the plate specimen must be at least ten times the depth of indentation so that any effect of indentation to pass through the thickness is avoided.
2. The distance between two adjacent impressions should at least be three times the size of indentation.
3. The hardness read from indenting the curved surface must be corrected for curvature.
4. The surface on which indentation is made must be clean and smooth and it should be well seated upon a clean platform.
5. The rate of load application is controlled in Rockwell hardness testing machine and it is Achieved by a dashpot adjustment corresponding to a standard rate of loading.

COMMON CAUSES OF ERRORS IN HARDNESS TESTING AND THEIR SYMPTOMS

	Cause of Error	*Readings*
1.	Improper choice of anvil or scale	Erratic
2.	Dirt or nicks on anvil top or bottom surface or no penetrator shoulder or no top of screw	Erratic
3.	Chipped diamond penetrator or striking penetrator with work	High or Low
4.	Scale, oxide film, pits, scratches or foreign material on top or bottom surface of specimen. Top and bottom surfaces of specimen not parallel.	Erratic, Low
5.	Test piece or case hardening too thin for scale used.	Erratic High or Low
6.	Improper calibration of hardness test, using wrong side of test block (only one side of test block is to be used).	Consistently High or Low
7.	Bringing work against penetrator too rapidly or jerkily. Bringing loading handle forward too soon.	Erratic, High
8.	Sudden or jerky operation of loading handle, bringing handle forward too late.	Erratic, Low
9.	Failure to seat and center round work securely in anvil, or failure to use round work correction chart.	Low
10.	Impression too close to edge, pit or previous impression. Excessive vibration from adjacent equipment.	Low

REFERENCE Code IS : 3804-1966 and IS : 1585-1968

SAMPLE QUESTIONS FOR VIVA

1. Explain hardness.

2. For a metal specimen, diamond indentor is most suitable. True/False? Justify your answer!

3. Rockwell hardness indicates __________?

4. Name any two causes of errors.

5. What is initial load and final load? Why initial load is applied?

5. BRINELL HARDNESS TEST

OBJECTIVE: To determine the hardness of a given material by Brinell hardness number.

EQUIPMENT: Brinell's hardness testing machine, specimen, microscope.

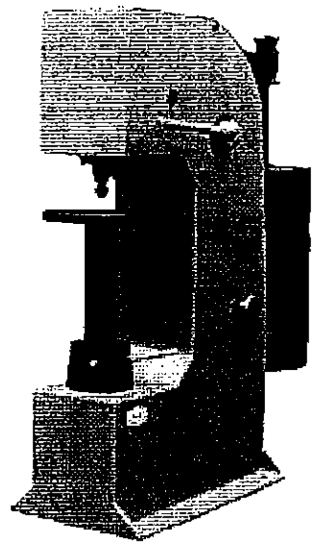


Figure 1: Brinell hardness tester

THEORY: J.A. Brinell in 1900 introduced the method of hardness test using ball indenter. A steel ball of 10mm diameter is used as indenter. The indenter is first placed upon the surface whose hardness is to be measured and then a gradually increasing load of 3000 kgf is applied upon the indenter. When the load is removed an indentation is left upon the surface. Load is applied for a standard time of 30 sec. The indentation or the impression so obtained on the specimen is then measured by a micrometer microscope and the Brinell hardness number, gives the comparative hardness of a body.

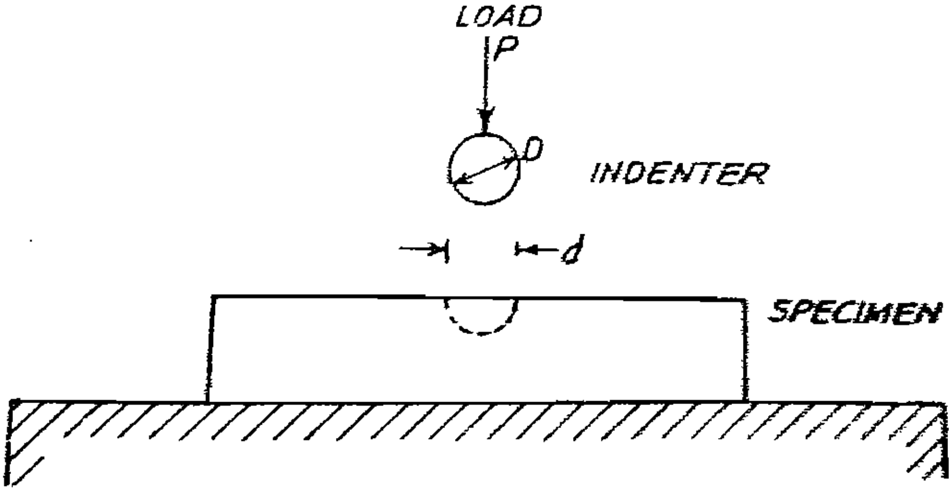
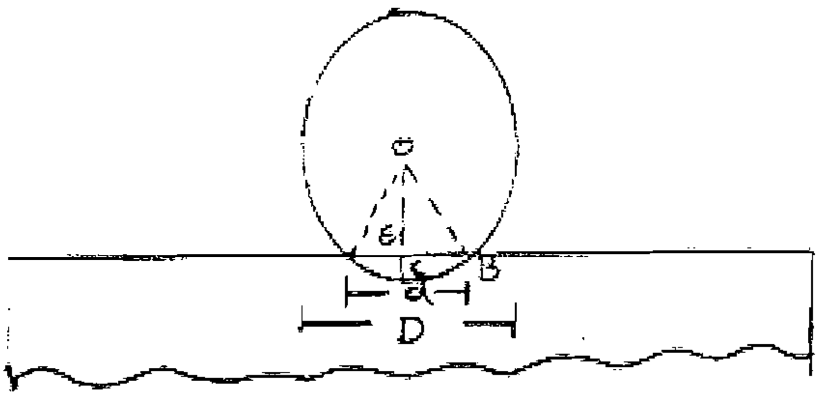


Figure 1: Ball indenter



Brinell hardness number is given by

$$BHN = \frac{Load\ applied\ (P)}{Spherical\ area\ of\ indentation}$$

where spherical area of indentation = Area ABC = πD x (CE)

But OE = $\sqrt{((OB)^2 - (BE)^2} = \sqrt{((D/2)^2 - (d/2)^2}$

CE = $OC - OE = D/2 - \sqrt{((D/2)^2 - (d/2)^2)} = 1/2(D - \sqrt{D^2 - d^2})$

Spherical area of indentation = $\pi D/2(D - \sqrt{(D^2 - d^2)}$

BHN = $P/\left(\pi D/2(D - \sqrt{D^2 - d^2})\right) = 2P/\pi D(D - \sqrt{(D^2 - d^2)}))$

Where P = load applied in kgf
D = diameter of ball in mm
And d = diameter of indentation in mm.

Although from definition and formula it is obvious that B.H.N ha units kgf/mm^2, this does not convey any physical meaning as load P is not uniformly distributed. It is found from extensive research that the ratio P/D^2 is constant and may be taken as 30 for the standard condition. The brinell hardness test is useful for specimens with hardness number less than 500. The thickness of the plate should such that it is 10 times the depth of impression.

PROCEDURE

1. Select the proper diameter of the ball and place proper weights on the weight hanger such that the combination suits the material being tested. Weights of total 2500 kgf are placed. The initial weigh- applied by main lever is 250 Kgf. and the hanger, weight of shaft and bottom weight is equivalent to 250 Kgf. (Total 3000 Kgf.)
2. Operate the hand lever from A to B several times to raise and lower the weights
3. Keep the hand lever in position **A.**

4. Start the motor and wait until the weight hanger reaches its top position.
5. Place the specimen securely on testing table.
6. Turn the hand-wheel in clockwise direction, so that the specimen long pointer will stop at zero and small pointer at red dot, when the initial load of 250 Kg(f) is applied.
7. Turn the hand lever from position A to B so that the total load is brought into action. Keep the lever in B position for about 15 seconds.
8. For releasing the load, take back the lever to position A. The weights will be lifted off and only the initial load remains active.
9. Turn the hand wheel in anticlockwise direction and remove the specimen.
10. Measure the diameter of indentation by microscope along two perpendicular directions (dl & d2) and find out average diameter and then calculate brinell hardness number using the formula.

OBSERVATION

Sl. No.	Material	d1	d2	Average D	Diameter of indentor D	Load applied P	Brinell hardness number

RESULT: The average brinell hardness number (BHN) is __________

PRECAUTIONS

1. The centre of the impression shall not be less than two and a half times the diameter of the impression from any edge of the test piece.
2. The thickness of test piece should be such that no marking showing the effect of the load shall appear underneath of the specimen.
3. This test should not be used for steel with hardness exceeding BHN450 as no indentation will be formed on the surface.

SAMPLE QUESTIONS FOR VIVA

1. Explain hardness?

2. Regarding what parameter, the brinell hardness number is found?

3. For standard condition, what is the F/D^2 value that can be taken?

4. Define brinell hardness number.

5. Explain the procedure.

6. What are the precautions to be taken?

6. TORSION TEST OF CIRCULAR SHAFT/BAR

OBJECTIVES: To find the elastic properties of a given specimen by a torsion test.
To find experimentally the Modulus of Rigidity of a given specimen.
To represent the relationship between Torque "T" Vs. Twist ϕ graphically.
To calculate the modulus of rigidity from the T-ϕ Graph.

EQUIPMENT: Torsion Testing Machine, specimen , micrometer.

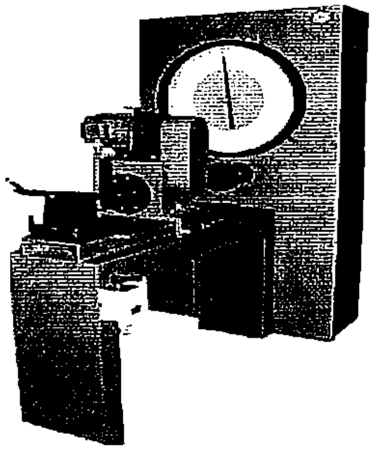


Figure 1: Torsion testing machine

SPECIMEN FOR THE TEST: The specimen should be of such size as to permit the desired strain measurement to be made with sufficient accuracy. It should be of such properties that the stress due to gripping ends does not affect the portion of the specimen on which measurements are made. The ends of the specimen should be such that they can be securely gripped without any local failure at the grips. Find the diameter of the road at three places.

Average diameter of the rod =

Gauge length of the rod =

THEORY: For a circular shaft subjected to a Torque "T", the relation between Torque, Shear Stress and angle of Twist is given by

$$T/I_P = \tau/R = G\phi/l$$

T = Maximum Torque in Kg.cm

I_P = Polar moment of Inertia in cm^4.

τ =shear stress at a radius R of the shaft in Kg/cm^2.

R = Radius of the shaft in cm.

G = Modulus or rigidity in Kg/cm^2.

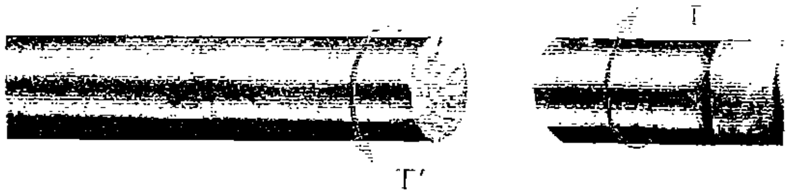
ϕ = Angle of Twist in Radians (1 degree = 0.01745 Radians)

l= length of the shaft in cm.

Hence, $G = T/I_P \times 1/Q$

For a solid circular shaft of Diameter "d", $I_P = \pi d^4/64$

TYPES OF FAILURE



(*a*) Ductile failure

(*b*) Brittle failure

Figure 2: Failure due to torsion

Ductile failure occurs due to shear stress where as brittle failure occurs due to tensile stress developed due to shear stress along the diagonal of element.

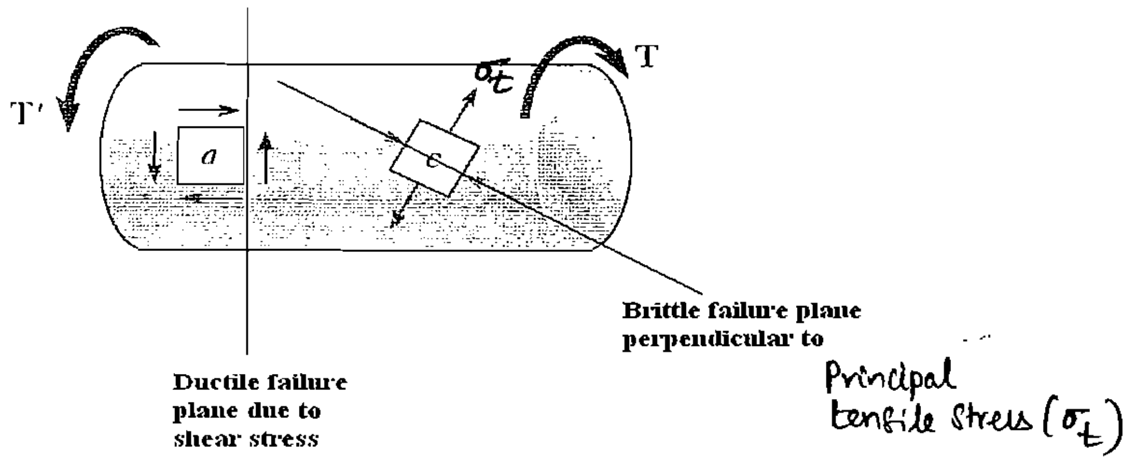


Figure 3: Failure planes

PROCEDURE

1. Measure the diameter of mild steel specimen using vernier callipers
2. Measure the gauge length of the specimen.
3. Hold the specimen between the plates with holders in position and tight the specimen within the holders by rotating the hand wheel till the indication dial is just on the point of showing deflection of the pointer.
4. Adjust the circular scale measuring angle of twist to zero.
5. Apply an increasing torque to the specimen in suitable increments by turning the hand wheel.

6. Record the corresponding readings of applied torque and angle of twist.
7. Continue the test and record the corresponding readings of torque and angle of twist, until fracture occurs.
8. Plot a graph of torque Vs. angle of twist.

OBSERVATIONS

Diameter of the specimen "d" =

Gauge length "l" =

Polar moment of inertia I_p =

Sl.No.	Angle of Twist ϕ in degrees	Angle of twist in radians "ϕ"	Torque in Kg.cm. "T"	$G=Tl/I_P\phi$

RESULT: The rigidity modulus of given specimen is ____________

Draw a graph between "T" Vs. "ϕ" and calculate the modulus of rigidity G from graph.

$$G = T/\phi \times l/I_P$$

PRECAUTIONS

1. The test piece should, as far as possible, be straight and of sufficient length to provide the desired length between the grips.
2. Any straightening should be done by hand without damaging the test piece.
3. The free length between the grips should be provided strictly to I.S.Code: 1717-1971.
4. If the failure of the specimen takes place within twice the diameter of the grips, the test should be considered as invalid and should be repeated.
5. The surface of the test piece after failure should be examined so that it is free from cracks.

SAMPLE QUESTIONS FOR VIVA

1. Explain the procedure
2. Explain about ductile failure.
3. Explain about brittle failure.

*4. Explain about torsional ductility with formula.

5. Due to torque ____________ stresses are induced with in the shaft.

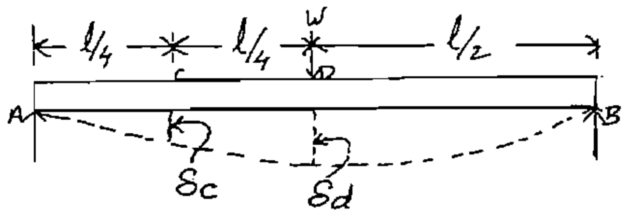
6. The torsion formula is applicable to bars/shaft of ________ cross section only.

7. VERIFICATION OF MAXWELL'S RECIPROCAL THEOREM

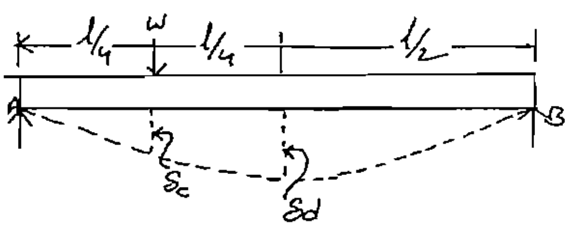
OBJECTIVE: To find the Young's modulus of the material of the given beam and verify the Maxwell's reciprocal theorem.

APPARATUS: Simply supported beam, scale, dial gauge and weight hanger with weights.

PRINCIPLE: Maxwell's reciprocal theorem states that "in a linearly elastic structure in equilibrium, the displacement at a coordinate i due to a unit force acting at a coordinate j is equal to the displacement at coordinate j due to a unit force at coordinate I". Hence, according to Maxwell's reciprocal theorem, deflection produced at point C due to unit load at point D in a simply supported beam must be same as the deflection produced at point D due to unit force at point C.



Case (i)



Case (ii)

Case 1: Theoretically deflection at C, δ_c is given by $\delta_c = \frac{11WL^3}{768EI}$

Case 2: Theoretically deflection at D, δ_d is given by $\delta_d = \frac{11WL^3}{768EI}$

where E is modulus of elasticity, and I is moment of inertia of the cross-section about horizontal axis passing through centroid. From the above formulae, it is seen that δ_C in case(i) and δ_D in case (ii) are equal. Experimentally also, the theorem should be verified.

The theorem can further be extended to include following statements:

i) The angle of rotation at C due to concentrated load at D is numerically equal to the deflection at D due to couple at C provided that force and couple are also numerically equal.

ii) The angle of rotation at C due to couple at D is equal to the rotation at D due to same couple at C.

PROCEDURE

1. Measure the width and depth of the given beam by vernier calipers.
2. Measure the distance between the two supports with a scale.
3. Set the dial gauge at C and adjust its value on the outer ring to zero, by turning it.
4. Keep the weight hanger at the centre of the beam (at D) and find the deflection in the dial gauge.
5. Place the weights 1 Kgf, 2 Kgf, 3 Kgf, 4 Kgf, 5 Kgf and 6 Kgf in the weight hanger and note down corresponding deflections from the dial gauge.
6. Now, interchange the position of load and point of measuring deflection, i.e. apply loads at C and arrange the dial gauge at D.
7. Repeat procedure as in step 5.

8. Maxwell's reciprocal theorem is verified if the deflection measured at C, when the load is applied at D, and the deflection measured at D, when the load is applied at C are equal.
9. Draw a graph between load on x-axis and deflection on y-axis.
10. Calculate the value of E from observations and also from the graph.

OBSERVATIONS:

Breadth of beam, b = mm

Depth of beam, d = mm

Moment of inertia, $I = bd^3/12 =$ mm^4

Least count of dial gauge =

Sl.No.	Load, W (Kgf)	Dial gauge readings (in divisions)		Deflection, δ (in mm)		Modulus of elasticity, E $=11/768. WL^3/\delta I$ (in N/sq.mm)
		At C (case i)	At D (case ii)	C (case i)	D (case ii)	

RESULT: Average Modulus of elasticity, E =

SAMPLE QUESTIONS FOR VIVA

1. Define 23pparat's reciprocal theorem

2. What is the formula for least count of dial gauge?

3. Maxwell's reciprocal theorem is applicable for a material with in ________ region.

8. SPRING TEST

OBJECTIVE: To determine the Modulus of rigidity of the material of the springs

EQUIPMENT: Spring testing apparatus, spring and vernier calipers

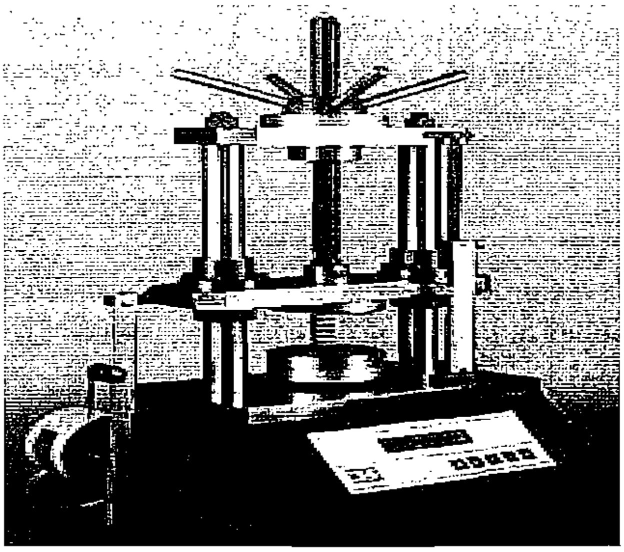


Figure 1: Spring testing digital 24pparatus

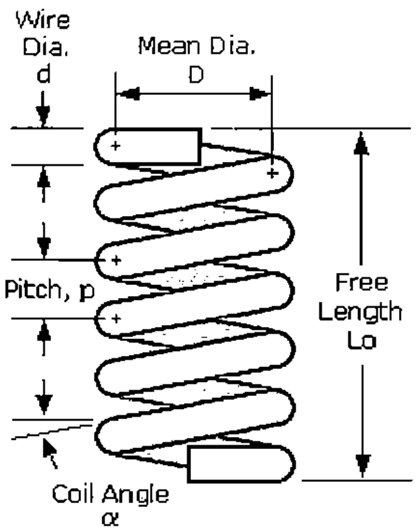
DESCRIPTION: When the spring is subjected to loading, it deforms and when the load is removed it regains its original shape. During the deformation, shear stresses are formed due to twisting which tend to resist the deformation.

The rigidity modulus $G = (64\ WR^3\ n) / \delta\ d^4$

Maximum shear stress $\tau = (8WD/\pi\ d^3)\ ((d/2D)+1)$

Where δ is the deflection

W is the axial load; R is the means radius of the coil; n is the No.of coils; d is the diameter of the wire; D is the mean coil diameter; L is the length of wire



PROCEDURE:

1. Measure the inner and outer diameters of closed helical spring.
2. Measure the diameter of the wire.
3. Count the No.of coils.
4. Place the spring in the apparatus
5. Apply load and note the deflection value by measuring from the scale

OBSERVATION & CALCULATIONS:

W =
R =
n=
d=
δ =
G =

Sl.No.	Load Kgf.	Dial gauge reading	Deflection (cm)	$G = \frac{64WR^3n}{\delta d^4}$

RESULTS:

1. The deflection is ___________
2. The modulus of rigidity is ___________.

SAMPLE QUESTIONS FOR VIVA

1. Explain about close coiled and open coiled springs.
2. Explain the procedure.
3. What stresses are developed in close coiled springs.

9. COMPRESSION TEST ON WOOD

OBJECTIVE: To investigate the load carrying capacity of timber under compressive force and to find out the compressive strength while loading the specimen with grains parallel to and perpendicular to the applied load.

NEED AND SCOPE OF EXPERIMENT: Timber is used as structural members in buildings, in foundations as piles, shuttering etc. and in a variety of ways. In all the applications, it is essential to know the compressive strength of wood. In application, compressive force may be acting parallel to grain or perpendicular to grain. Hence, in both cases, the strength is determined.

COMPRESSION PARALLEL TO GRAIN: (IS: 1708-1969)

1. Test Specimen: Compression parallel to grain test shall be made on specimen 5 x 5 x 20cm in size. The specimen shall be absolutely free from any defects and shall not have a slope of grain more than 1 in 20 parallel to its longitudinal edges. The end planes of the specimen shall be perfectly at right angles to the length of the specimen. Where a standard size is not obtainable the length of the specimen shall be four times the shorter dimension of the cross-section.

2. EQUIPMENT: The tests shall be carried out on Universal Testing Machine or comp. testing machine. At least one plate of the testing machines shall be equipped with a hemispherical bearing to obtain uniform distribution of load over the end of the specimen.

3. PROCEDURE

1] Placing the specimen: The specimen shall be so placed that the centre of the movable head is vertically above the centre of the cross-section of the specimen.

NOTE: It is essential that the ends of the rectangular test specimen are smooth and parallel and normal to the axis and that the testing machines are of such construction that the surfaces between which the test specimen is placed are parallel to each other and remain so during the whole period of test. Unless these precautions are taken, values which may be obtained will be considerably below the true values.

2] RATE OF LOADING: The load shall be applied continuously during the test to cause the movable head of the testing machine to travel at a constant rate of 0.03 mm per minute per centimeter length of the specimen (that is 0.6 mm minute in the case of the standard test specimen of 5 x 5 x 20cm) .

3] Measurement of load: The final reading at the maximum load shall be recorded.

<u>TYPE OF FAILURES</u>: To obtain satisfactory and uniform results the failure may be made to develop on the body of the specimen DV continuing the machine to run for a longer time or by any other method. Compression failures shall be classified according to the appearance of the fractured surface as shown in figure. In case two or more kinds of failures develop, they shall be described in the order of their occurrence (for example, sharing followed by brooming). The failures shall be sketched on the data sheet.

FIG. FAILURE OF SPECIMEN UNDER COMPRESSION PARALLEL TO GRAIN

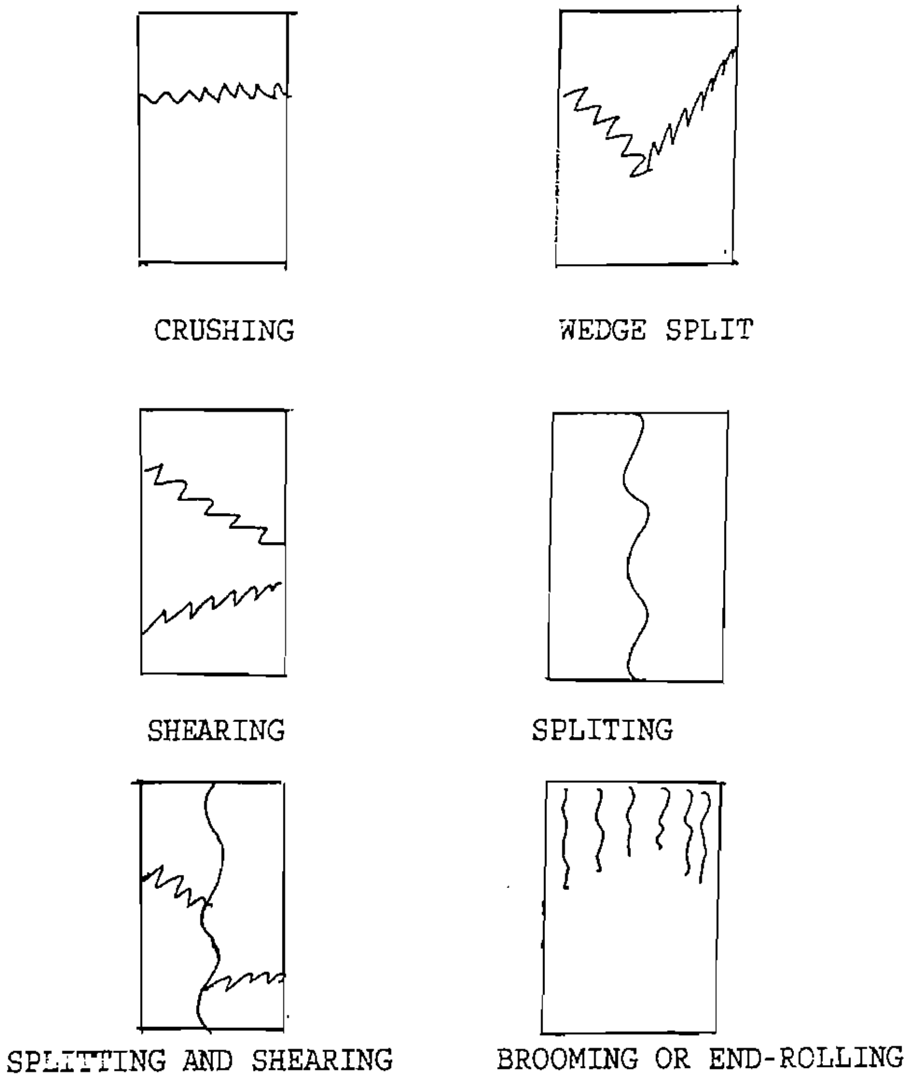


Figure 1: FAILURE OF SPECIMEN UNDER COMPRESSION PARALLEL TO GRAIN

OBSERVATION:

Sl.No.	Area of cross-section mm^2 (A)	Ultimate load P_u kN	Ultimate compressive strength P_u /A (N/mm^2)

COMPRESSION PERPENDICULAR TO GRAIN: (Ref. IS: 1708-1969)

1. Test Specimen: Test for compression perpendicular to the grain shall be made on the central portion of the specimen 5x5x15 cm size. The specimens shall be free from defects.
2. Equipment: The tests shall be carried out on a suitable testing machine namely, Universal Testing Machine or Comp. Testing Machine. The load shall be applied through metal bearing plate 5 cm in width and of at least 15 mm thickness placed centrally across the upper surface of the specimen at equal distances from the ends and at right angles to the length.
3. Procedure:

3.1. Placing the specimen: Unless otherwise required specially, the specimen shall be so placed that the load will be applied through the bearing plate to a radial, surface.

3.2. Rate of Loading: The load shall be applied continuously throughout the test such that the movable head of the testing machine travels at a constant rate of 0.6mm per minute.

OBSERVATIONS

Sl.No.	Area of cross-section mm^2 (A)	Ultimate load P_u kN	Ultimate compressive strength P_u /A (N/mm^2)

RESULT: The maximum compressive strength of the given specimen is __________

SAMPLE QUESTIONS FOR VIVA

1. Explain the procedure.

2. Explain the types of failure of wood specimen under compression.

3. A wood specimen under compression must have grains _________ to load for greater strength.

10. IZOD IMPACT TEST

OBJECTIVE: To determine the impact resistance of the given specimen by Izod impact test.

APPARATUS: Impact testing machine, specimen, vernier calipers and scale.

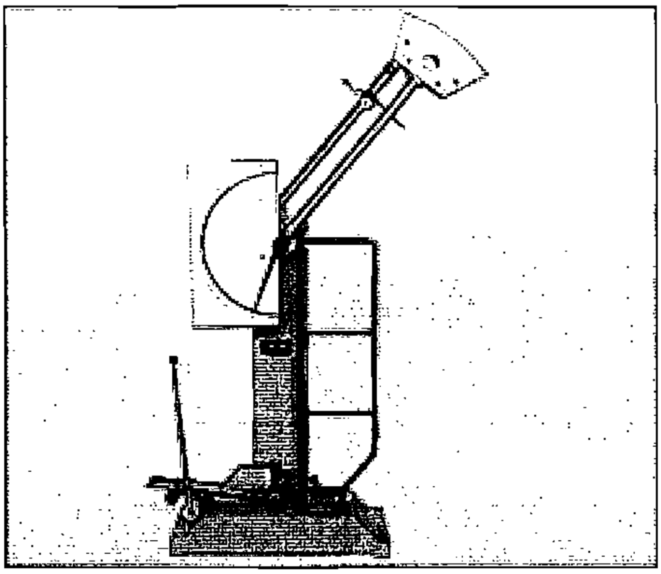


Figure 1: Impact test machine

NEED AND SCOPE OF THE EXPERIMENT

In practice the loads on machine members such as chains hocks, springs, buffers are more or less suddenly applied and usually fail by brittle fracture. Hence, there is a need for studying the effects produced by dynamic loading. Although static tests give valuable information, it is insufficient to bring out all the characteristics that occur in service conditions.

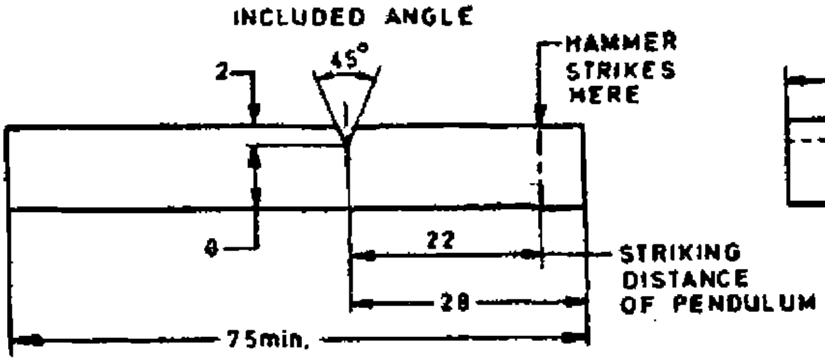
The principal measurement from the impact test is the energy absorbed in fracturing the specimen (expressed as Joules (J)) which can be read directly from a calibrated dial on the impact tester. The ratio of energy absorbed by the specimen to the **cross-sectional area below the notch** is known as "**Impact Strength**". The unit of impact strength is J/mm^2.

Another common measurement obtained from the impact test results from the examination of the fracture surface to determine whether it is fibrous (ductile) fracture or granular (brittle) fracture, or a mixture of both (and to assess the percentage area of brittle fracture).

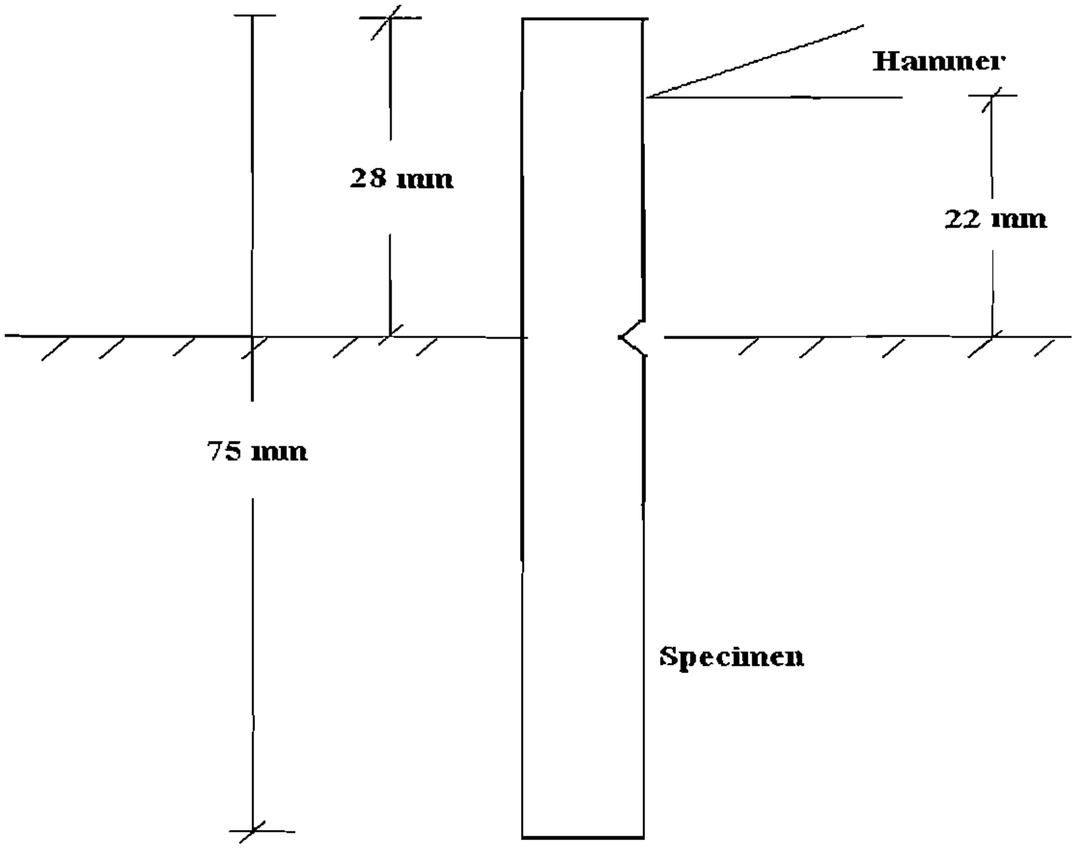
The third quantity that is sometimes measured is the ductility as indicated by the percentage contraction of the specimen cross sectional area at the root of the notch.

The ratio of energy absorbed by the specimen to the **volume of the specimen below the notch** is known as "**Impact Modulus**". The unit of impact modulus is J/mm^3.

SPECIMEN & TEST SETUP: The specimen's cross section is generally square. The dimensions of the specimen are **10mm*10mm*75mm** and cane read as width of c/s * thickness of c/s* length of the specimen. The specimen contains V-notch of 45° included angle and **depth of notch is 2mm. The specimen is placed vertically for izod test with lower part fixed.** The notch is situated at 28mm from the free end. The specimen is placed such that half of the notch is above meaning that 28 mm free portion is left. The hammer strikes the specimen at 22 mm from lower end of free portion. The angle of release of hammer is 85°21' to 90°. The striking velocity of the hammer is 3.857 m/sec.



All dimensions in millimetres.



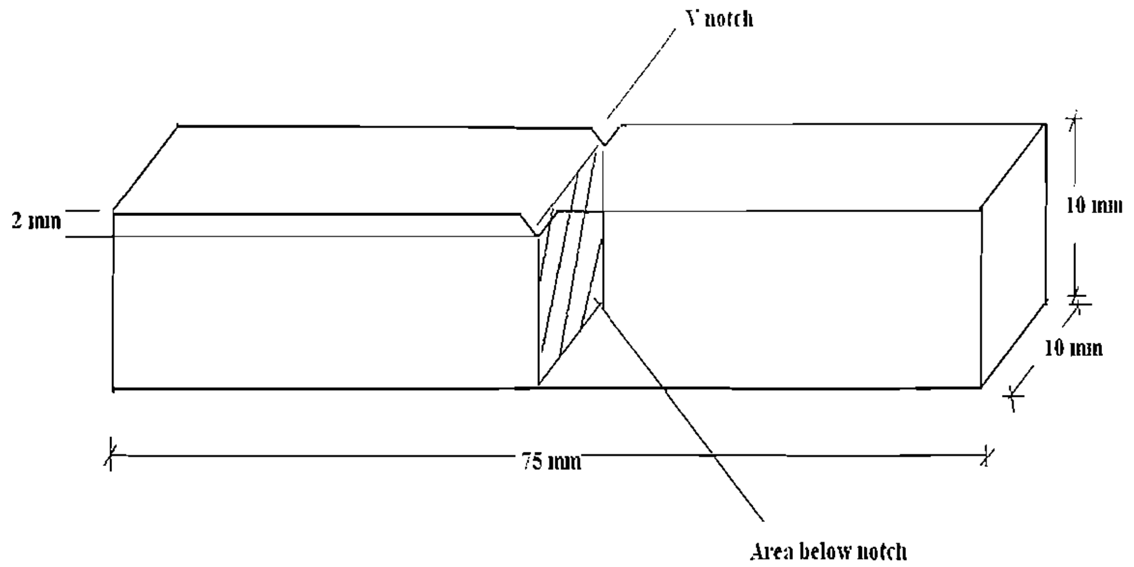


Figure 2: Specimen

PROCEDURE

1. Check the dimensions of the specimen and its grove.
2. Place the pendulum in the trigger.
3. Release the trigger and note the reading on the calibrated dial gauge. The reading should read zero otherwise, note the initial reading.
4. Keep the specimen in the correct position as shown in the figure.
5. Release the trigger.
6. Note the reading on the dial gauge which will directly give the energy absorbed by the specimen.
7. Note the nature of fracture.
8. Repeat the above procedure for different materials.

OBSERVATIONS

Sl.No.	Material	Energy absorbed by the specimen for the IZOD test

CALCULATION:

Area below groove (A) =

Energy absorbed (K) =

Impact strength = K/A =

RESULT: The impact strength of the material is _________

PRECAUTIONS

1. The longitudinal axis of the test piece shall lie in the plane of swing of the centre of gravity of the hammer.
2. The notch shall be positioned so that its plane of symmetry coincides with the top face of the grips.
3. The notch shall be at right angles to the plane of swing of the centre of gravity of the hammer. This is ensured by the form of the test pieces and method of grip.
4. The test piece shall be gripped tightly in the anvil.
5. The temperature of the test piece at the moment of breaking shall not exceed 27°C+2°C and it is to be recorded during testing.

REFERENCE: Indian standard IS: 1598-1960 for IZOD Impact Test.

SAMPLE QUESTIONS FOR VIVA

1. What are the standard dimensions of specimen?

2. What is impact strength?

3. What is impact modulus?

4. What is the angle of strike in izod test?

5. Impact occurs for

   a) static loading

   b) dynamic/ sudden loading

   c) any load

*6. Impact tests are used to study _________ fracture

7. Temperature does not affect the impact strength. True/ False?

* 8. The mass of the hammer is distributed in _________ plane in Izod test.

11. CHARPY IMPACT TEST

OBJECTIVE: To determine impact resistance of the given specimen by charpy impact test.

APPARATUS: Impact testing machine, specimen, vernier calipers and scale.

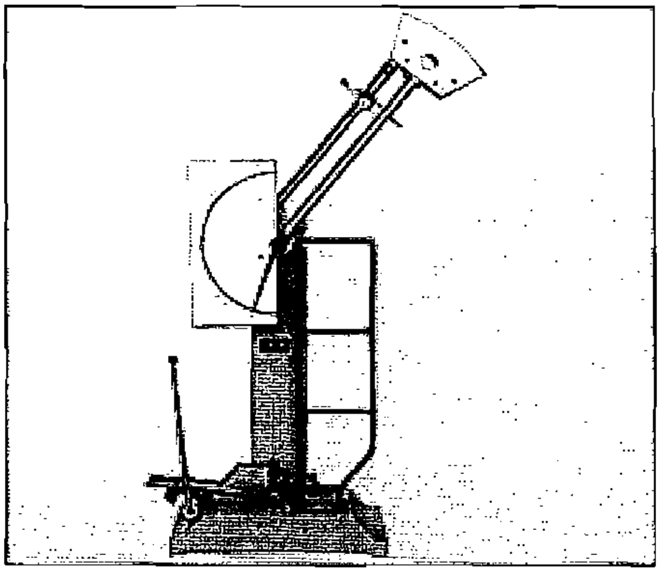


Figure 1: Impact test machine

NEED AND SCOPE OF THE EXPERIMENT

In practice the loads on machine members such as chains hocks, springs, buffers are more or less suddenly applied and usually fail by brittle fracture. Hence, there is a need for studying the effects produced by dynamic loading. Although static tests give valuable information, it is insufficient to bring out all the characteristics that occur in service conditions.

The principal measurement from the impact test is the energy absorbed in fracturing the specimen (expressed as Joules (J)) which can be read directly from a calibrated dial on the impact tester. The ratio of energy absorbed by the specimen to the **cross-sectional area below the notch** is known as "**Impact Strength**". The unit of impact strength is J/mm^2.

Another common measurement obtained from the impact test results from the examination of the fracture surface to determine whether it is fibrous (ductile) fracture or granular (brittle) fracture, or a mixture of both (and to assess the percentage area of brittle fracture).

The third quantity that is sometimes measured is the ductility as indicated by the percentage contraction of the specimen cross sectional area at the root of the notch.

The ratio of energy absorbed by the specimen to the **volume of the specimen below the notch** is known as "**Impact Modulus**". The unit of impact modulus is J/mm^3.

SPECIMEN & TEST SETUP: Specimen of 10mm x 10mm. square cross section and 55mm length, with a V-notch of included angle 45°, 2mm deep and 0.25mm root radius along the middle of the length. For a U-notch specimen, the dimensions are 5mm deep, 2mm width and 1mm root radius. The specimen is kept as a simply supported beam in horizontal position and leaded behind the notch by the impact of a heavy swinging hammer. The angle of drop of hammer is 120^0 to 140^0. The impact velocity is approximately 5.3465m/sec.

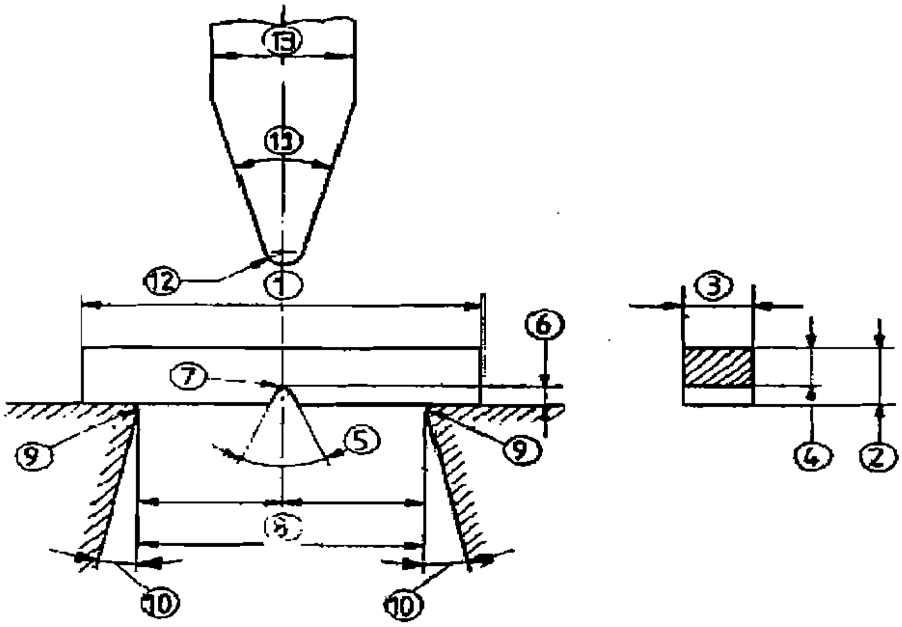


FIG. 1 CHARPY IMPACT TEST (V-NOTCH)

TABLE 1 DESIGNATIONS AND UNITS
(Clause 3 and Fig. 1)

Number	Designation	Unit
1.	Length of test piece	mm
2.	Height of test piece	mm
3.	Width of test piece	mm
4.	Height of test piece minus depth of notch (height below notch)	mm
5.	Angle of notch	deg
6.	Depth of notch	mm
7.	Radius of curvature of base of notch	mm
8.	Distance between anvils	mm
9.	Radius of anvil	mm
10.	Angle of taper of anvil	deg
11.	Angle at tip of striker	deg
12.	Radius of curvature of tip of striker	mm
13.	Width of striker	mm
—	Energy absorbed by breakage, *KV*	Joule

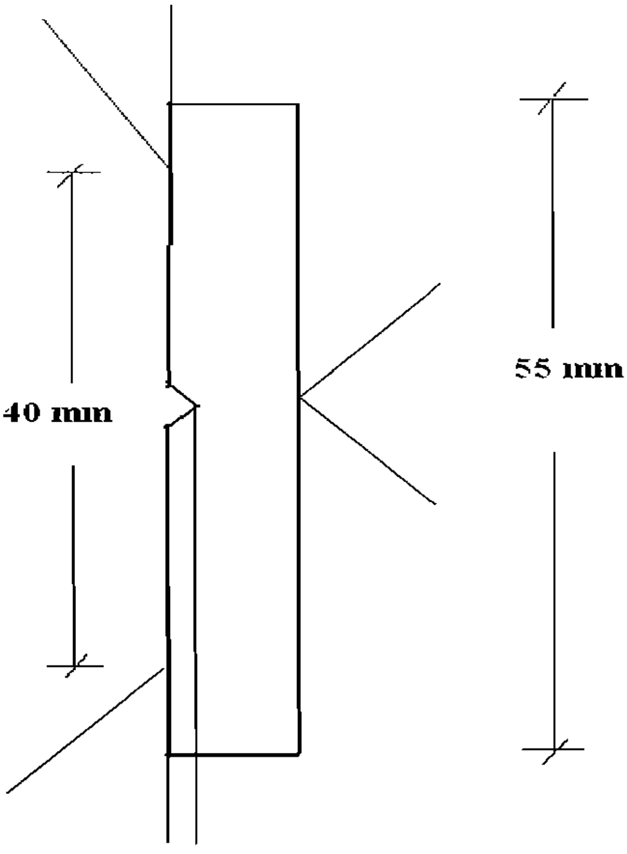


Figure 2: Test set up

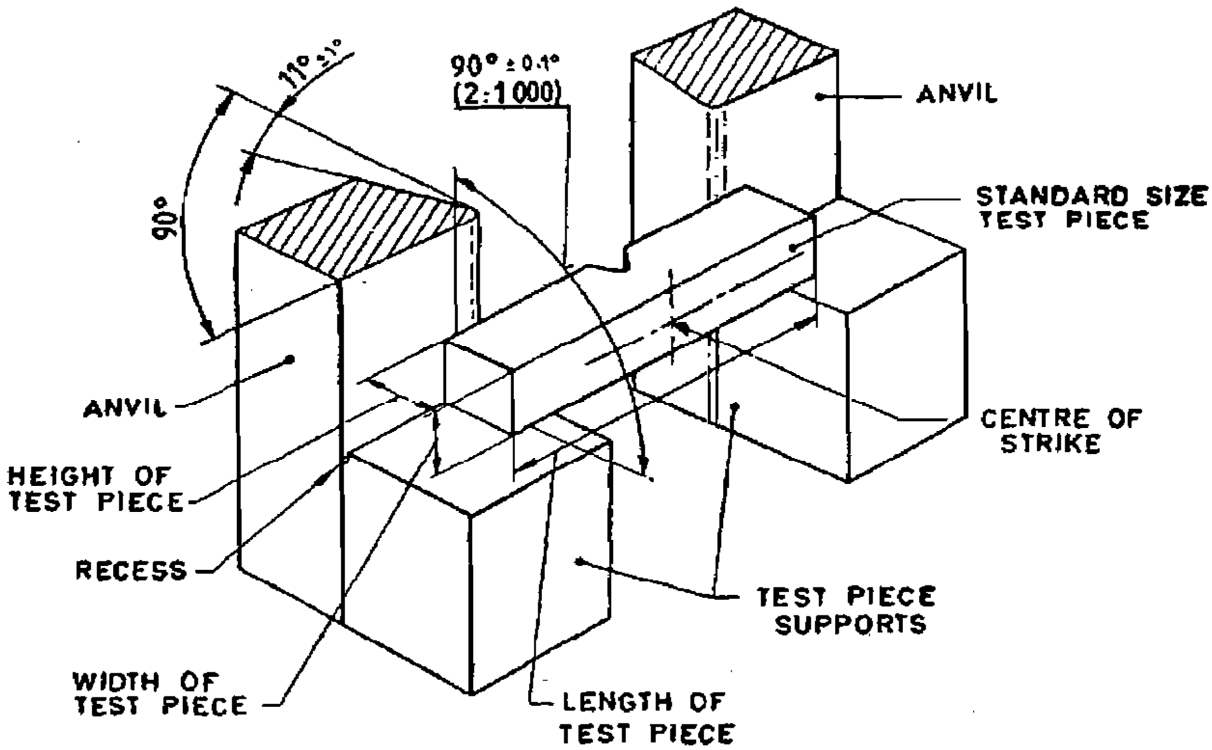


Fig.3 CONFIGURATION OF TEST PIECE SUPPORTS AND ANVILS

PROCEDURE

1. Check the dimensions of the specimen and its grove.
2. Place the pendulum in the trigger.
3. Release the trigger and note the reading on the calibrated dial gauge. The reading should read zero otherwise, note the initial reading.
4. Keep the specimen in the correct position as shown in the figure.
5. Release the trigger.
6. Note the reading on the dial gauge which will directly give the energy absorbed by the specimen.
7. Note the nature of fracture.
8. Repeat the above procedure for different materials.

OBSERVATIONS

Sl.No.	Material	Energy absorbed by the specimen for the CHARPY test

CALCULATION:

Area below groove (A) =

Energy absorbed (K) =

Impact strength = K/A =

RESULT: The impact strength of the material is ________

PRECAUTIONS

1. The longitudinal axis of the test piece shall lie in the plane of swing of the centre of gravity of the hammer.
2. The notch shall be positioned so that its plane of symmetry coincides with the top face of the grips.
3. The notch shall be at right angles to the plane of swing of the centre of gravity of the hammer. This is ensured by the form of the test pieces and method of grip.
4. The test piece shall be simply supported in horizontal position on the anvil.
5. The temperature of the test piece at the moment of breaking shall not exceed 27°C+2°C and it is to be recorded during testing.

REFERENCE: Indian standard IS: 1757-1988 for Charpy Impact Test.

SAMPLE QUESTIONS FOR VIVA

1. What are the standard dimensions of specimen?

2. What is impact strength?

3. What is impact modulus?

4. What is the angle of strike in charpy test?

5. Impact occurs for

    a) static loading

    b) dynamic/ sudden loading

    c) any load

*6. Impact tests are used to study __________ fracture

7. Temperature does not affect the impact strength. True/ False?

* 8. The mass of the hammer is distributed in __________ plane in charpy test.

12. SHEAR TEST

OBJECTIVE: To determine the ultimate shear strength of the given steel specimen by conducting direct shear test.

APPARATUS: Shear test assembly, specimen to be tested, Micrometer.

THEORY: Consider the effect of applying a force **F** acting on the bar. The bar is supported as shown in Figure 1. If the supports are rigid and are placed such that no bending of the bar can occur and only shear failure is possible, the force F can cause the material of the bar to deform and fail along the planes identified by *AB* and *CD*. From the free body diagram of the unsupported center segment of the bar (Figure 2) it can be observed that shear force **V** = F/2 must act on each section for equilibrium.

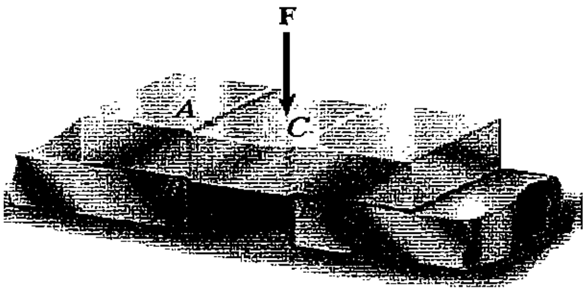


Figure 1

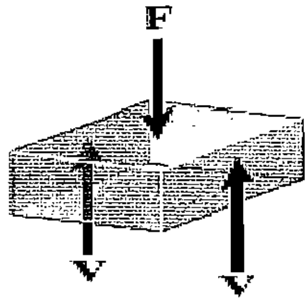


Figure 2

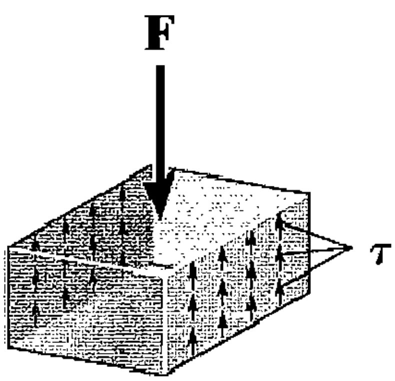


Figure 3

Due to the shear force, shear stress is developed as shown in Figure 3. The shear stress can be mathematically defined as

$$\tau = V/A$$

$$\tau = (F/2)/A$$

$$\tau = F/2A$$

Practically the load is gradually applied. The load at which shear failure occurs is taken as ultimate load F_u. Then the corresponding ultimate shear stress is

$$T_u = F_u/2A$$

The test can be applied to circular bars also.

PROCEDURE

1) Measure the diameter of the specimen at three sections and find the average diameter "d".
2) Start the UTM, open the inlet valve slightly and when the load pointer just kicks adjust the pointer to read zero. Open the inlet valve.
3) Increase the load gradually until the specimen breaks. Record the maximum load (P_u).
4) Stop the machine, take out the shear attachment and remove the broken pieces of the specimen.
5) Examine the nature of the failure of the specimen.

CALCULATIONS

Average diameter of the specimen, d =   mm

Sl.No.	Ultimate load Pu (in Newtons)	Ultimate shear strength $\tau_u=P_u/A$ (N/mm^2)

RESULT: The ultimate shear strength of the specimen is _________

SAMPLE QUESTIONS FOR VIVA

1. What is meant by equilibrium?
2. Describe the nature of failure of mild steel and tor steel.
3. Is the failure single shear failure or double shear failure?

13. ELECTRICAL RESISTANCE STRAIN GAUGES

OBJECTIVE: The objective of this experiment is to become familiar with the electric resistance strain gage techniques and utilize such gages for the determination of unknown quantities such as strain and stress at prescribed conditions of a cantilever/ simply supported beam.

APPARATUS: Beam test set up and strain gauges

THEORY: Strain gauge is essentially an electric wire of small diameter or thickness if the cross section is circular or rectangular respectively. Normally a gauge with round wire element is referred to as "**wire gauge**" and that rectangular section is called as "Foil gauge". Both wire and foil gauges may have several strands making total length of the conductor. The length of one strand is called as **"Gauge Length".**

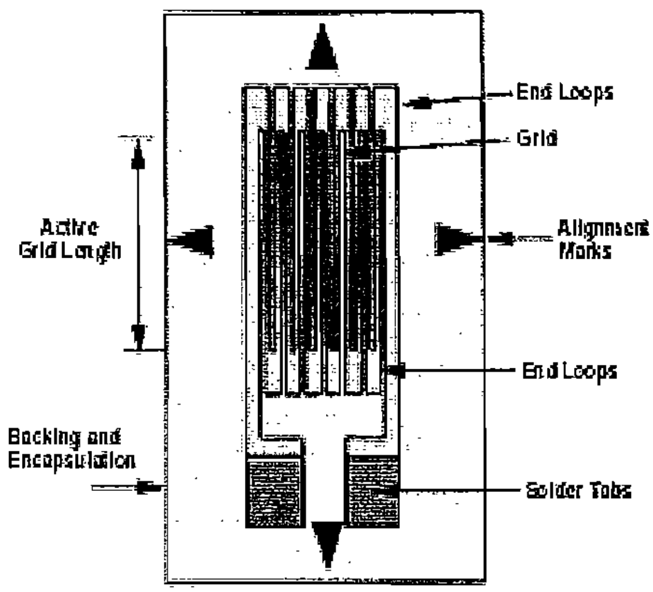


Figure 1: Strain gauge

The wire made in shape of loops is placed between non-conducting papers which are cemented together and from which two thick terminals protrude. The gauges have the alignment arrows in two perpendicular directions. These direction marks help to align gauge in the direction of any line on the surface. The strain gauge is fixed flat on the surface on which a thin layer of cement is spread. After cement being dried, a strong bond between the surface and the gauge is created so that any change in length on surface is truly transmitted to the gauge. This causes the wire of the gauge (each strand of the gauge) to undergo the same change in length and hence strain is found.

In 1856 Lord Kelvin had pointed out that "With change in length of wire, its resistance changes though the change is small". If a wire of length 'l' and resistance 'R' is extended or shortened in length by Δl, then its resistance will change by ΔR such that

$$(\Delta R/R) \propto (\Delta l/l)$$

In which the constant of proportionality is named as **gauge factor.**

Thus $(\Delta R/R) = F\,(\Delta l/l)$ where F is the gauge factor which is "the change in resistance of a wire 1 Ω resistance if (Δl/l) is unity i.e., the change in length is equal to the original length"

Gauge material can be nichrome , manganin, karma, nickel, platinum and so on.

The gauge circuits most commonly used are potentiometer and wheatstone bridge. The wheat stone bridge consists of four arms each made up of resistance. The strain measuring gauge is called active gauge and other are called as dummy gauges.

Strain sensitivity is related to circular output ΔE. The ratio of ΔE to strain measured ε is called strain sensitivity of circuit.

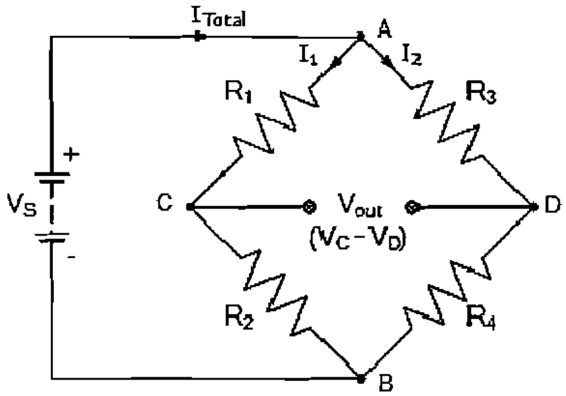


Figure 2: Wheatstone Bridge

PROCEDURE

1. Place the beam test set up.

2. Attach at least two strain gauges at desired locations.

3. Apply the load at free end of cantilever beam and note the value of strain.

4. Divide the strain with number of strain gauges used (active gauges) to get actual strain without the effect of strain sensitivity.

5. From basic flexural equation the young's modulus can be found.

CALCULATION:

Bending moment (M) =

Bending stress (σ) =

From $\sigma = E\,\varepsilon$, E =

RESULT: 1) The strain is __________

2) The modulus of elasticity of the given specimen is ___________

SAMPLE QUESTIONS FOR VIVA

1. Differentiate between active and dummy gauges.
2. Explain about gauge length and gauge factor.
3. What are the two major gauge circuits?
4. What is strain sensitivity?
5. How does length of wire affect resistance?

14. CONTINUOUS BEAM DEFLECTION TEST

OBJECTIVE: To calculate deflections at points of application of loads.

APPARATUS: Continuous beam test set up and dial gauges.

THEORY: Continuous beams are statically indeterminate beams. The deflections of the beams can be calculated manually for beams of less number of spans by using moment-area method or integration method. A continuous beam with point loads and corresponding deflection profile is shown in Figure 1.

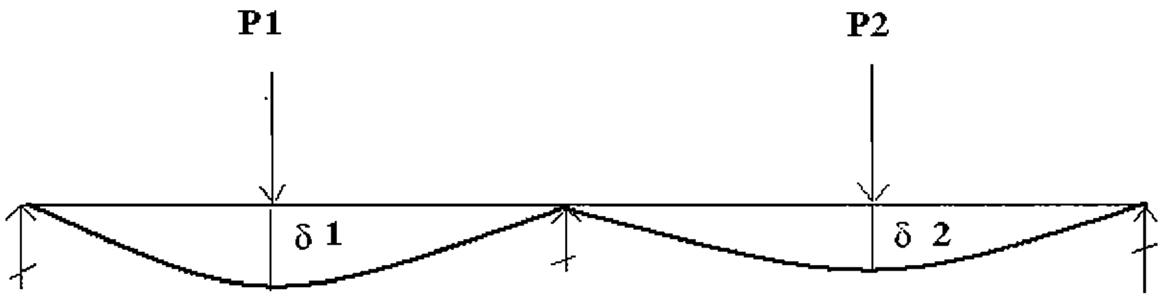


Figure 1: Continuous beam with point loads

PROCEDURE:

1. Place the beam set up.

2. Mark the points where loads on each span are to be applied.

3. Place the dial gauges at the points of application loads.

4. Apply the point loads by placing weights in the hanger.

5. Note the readings.

6. Validate the results by manual calculation

OBSERVATION:

S.No.	Load P1	Dial gauge reading 1	Deflection 1	Load P2	Dial gauge reading 2	Deflection 2

MANUAL CALCULATION:

RESULT: The value of deflection 1 is ____________ and deflection 2 is ____________.

SAMPLE QUESTIONS FOR VIVA

1. Is continuous beam statically determinate or indeterminate beam?

2. Explain the procedure.

3. Name the theoretical methods for finding deflections of statically indeterminate beams.

4. What do you mean by least count?