

CE 212
Mechanics of Solids Sessional
Lab Manual



DEPARTMENT OF CIVIL ENGINEERING
AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

FALL 2022



PREFACE

The **Mechanics of Solids Sessional Lab Manual** describes the experiments in the Mechanics of Solids Sessional course (CE 212). Each experiment is explained thoroughly along with related theory and background. The experiments are selected to apply some concepts from strength of materials such as analysis of material properties based on tension, compression, hardness, bending, buckling, direct shear, impact, torsion, behavior of spring etc. This is one of the vital laboratory courses in the course curriculum of the Bachelor of Civil Engineering program. Students can learn variety of engineering and structural materials and their mechanical and engineering properties, different testing procedure and testing standards, testing equipment, materials stress-strain behavior and failure patterns, types of materials based on characterization, report writing process and evaluation of the experimental results and so on. In civil engineering profession, the use of structural behavior and understanding the quality of product will be discussed in this course. Some complementary topics are also presented such as using of measuring tools like digital slide calipers. The use of these tools will help the students to understand how to measure objects precisely, which is a crucial skill in lab. Experimental data analysis techniques and graph formation in MS Excel are also discussed to help the students to prepare graphs.

The manual is prepared mostly by gathering the information and contents from Mechanics of Solids Sessional Manual, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) prepared by Professor Dr. Ishtiaque Ahmed, Department of Civil Engineering, BUET and another Mechanics of Solids Sessional Manual, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) prepared by Md. Ruhul Amin, Assistant professor, Department of Civil Engineering, BUET. Many figures are taken from different web pages of internet. Also, the relevant ASTM codes are used as reference to prepare the manual.

Md. Mashfiqul Islam

Assistant Professor

Department of Civil Engineering

Ahsanullah University of Science and Technology (AUST)

TABLE OF CONTENT

Experiment No.	Name of the Experiment	Page No.
1	HARDNESS TEST OF METAL SPECIMENS.....	4
2	COMPRESSION TEST OF TIMBER SPECIMEN.....	14
3	IMPACT TEST OF METAL SPECIMEN.....	22
4	TENSION TEST OF MILD STEEL SPECIMEN.....	33
5	STATIC BENDING TEST OF STEEL AND TIMBER BEAM...	46
6	BASICS OF SHEAR FORCE AND BENDING MOMENT.....	53
7	TEST OF SLENDER COLUMN.....	57
8	DIRECT SHEAR TEST OF METAL SPECIMENS.....	64
9	TEST OF HELICAL SPRING.....	69
10	BASICS OF SHEAR CENTRE.....	80
-	ACKNOWLEDGEMENT.....	85
-	REFERENCES.....	85
-	APPENDIX.....	86

EXPERIMENT NO.: 1

HARDNESS TEST OF METAL SPECIMENS



Experiment No.: 1

Hardness test of Metal Specimens

1. OBJECTIVES

- To study the Rockwell Hardness testing machine
- To determine the Hardness of the given specimens using Rockwell Hardness Testing Machine.
- To observe the failure pattern of different metals tested in different scale.

2. ASTM REFERENCE

ASTM E 8M-13a	Standard Test Methods for Tension Testing of Metallic Materials
ASTM E 370-07a	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A 48	Standard Specification for Gray Iron Castings
ASTM E 18-15	Standard Test Methods for Rockwell Hardness of Metallic Materials

3. SIGNIFICANCE

This experiment provides fundamental knowledge on hardness of materials, hardness test procedure, hardness testing types, hardness testing machine, hardness of different metal specimens, failure patterns etc.

4. APPARATUS

Rockwell Hardness Testing Machine

5. SPECIMEN

Specimen of mild steel (MS), brass, cast iron, aluminum and high strength steel (HSS).

6. THEORY

Hardness is a measure of the resistance of material to permanent deformation. Hardness represents the resistance of material surface to abrasion, scratching and cutting above all resistance to permanent deformation. Hardness gives clear indication of strength. In all hardness tests, a defined force is mechanically applied on the test piece, varies in size and

shape for different tests. Common indenters are made of hardened steel or diamond. Hardness test is used to give a guide to the overall strength of a material.

Hardness is a measure of a material plastic flow resistance, and especially useful for this purpose when comparative assessments are made. Moreover, since hardness test are more convenient to carry out than other tensile tests, the hardness test has found widespread use in industrial applications and research studies.

Depending on the particular deformation type (or for that matter particular of stressing), hardness may be of the following types:

- (1) Indentation hardness test (by indenting)
- (2) Scratch hardness test (by scratching, Moh's Scale)
- (3) Dynamic hardness test (by impact)
- (4) Rebound hardness test (by the rebound of a falling ball)
- (5) Wear hardness (by abrasion)
- (6) Machinability (by cutting or drilling)

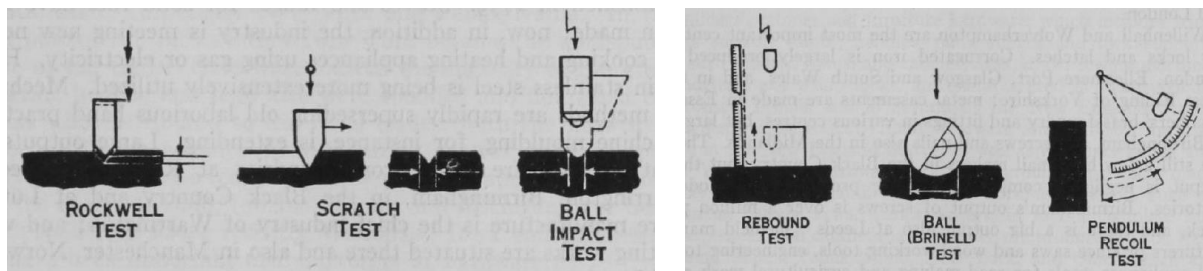


Figure 1: Various method of hardness test

Four indentation hardness tests are customarily used:

- (1) Brinell
- (2) Vickers
- (3) Rockwell
- (4) Shore scleroscope

The first three is known as static indentation hardness test and the last one is called dynamic indentation hardness test. Hardness number depends on (i) the applied load, (ii) the shape of the indentation and (iii) the depth to which the indenter penetrates the specimen.

Rockwell B scale: For softer materials, a 1/16-inch diameter steel ball is used, the major load is 90 kg and minor load is 10 kg (100 kg load in total) and the hardness is

$$HRB = 130 - \frac{d}{0.002}$$

where, d =depth of the indenter in mm, relative to the zero position.

Rockwell C scale: For harder materials, a conical – shaped diamond of 120 apex angle is used, the major load is 140 kg and minor load is 10 kg (150kg load in total), and the hardness is

$$HRC = 100 - \frac{d}{0.002}$$

Rockwell hardness tester presents direct reading of hardness number on a dial provided with the machine. Principally this testing is similar to Brinell hardness testing. It differs only in diameter and material of the indenter and the applied force. Although there are many scales having different combinations of load and size of indenter but commonly ‘C’ scale is used and hardness is presented as HRC. Here the indenter has a diamond cone at the tip and applied force is of 150 kgf. Soft materials are often tested in ‘B’ scale with a 1.58mm dia. steel indenter at 100 kgf.



Figure 2: Rockwell Hardness testing machine

7. SPECIFICATION OF HARDNESS TESTING MACHINE AND INDENTERS

A hardness test can be conducted on Brinell hardness testing machine, Rockwell hardness machine or Vicker hardness testing machine. The specimen may be a cylinder, cube, thick or thin metallic sheet. A Rockwell hardness testing machine along with the specimen is shown in Figure 2.

Table 1: Various scales in Rockwell hardness test

Scale	Type of indenter (Dimension)	Initial/Minor load (kgf)	Major load (kgf)	Kind of material may be tested
HRA	Cone, 120°	10	50	Much harder such as carburized steel, cemented carbides, plastics & polymers
HRB	Ball, 1.58mm	10	90	Soft steels, copper, aluminum, brass, grey cast iron.
HRC	Cone, 120°	10	140	Hard steels, HSS, Ti, W, Va, etc.

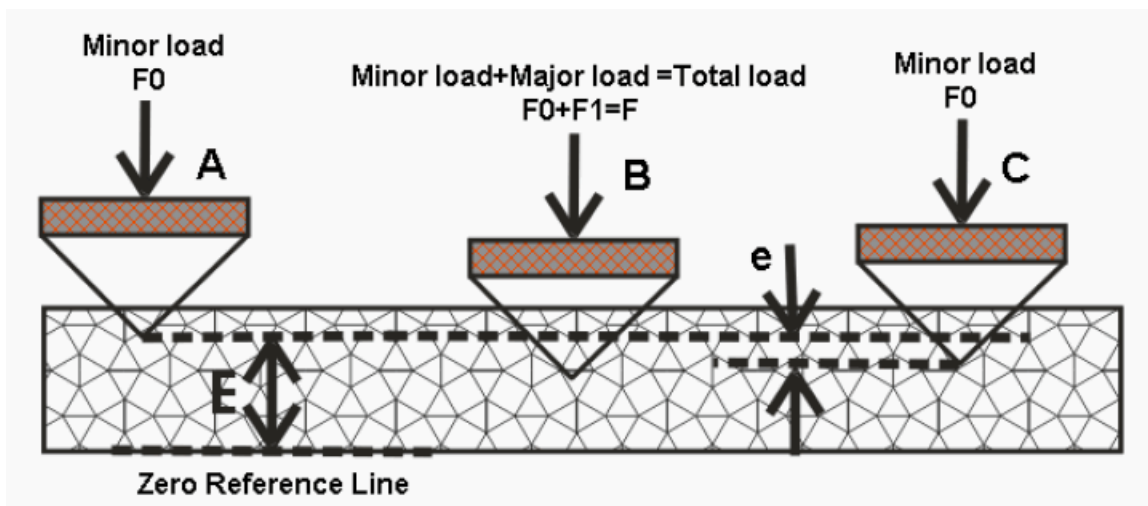


Figure 3: Major and minor load

Rockwell Method

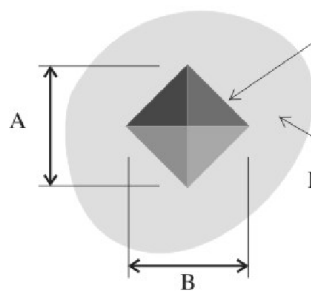
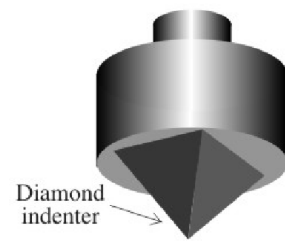


(a) Cone Indenter



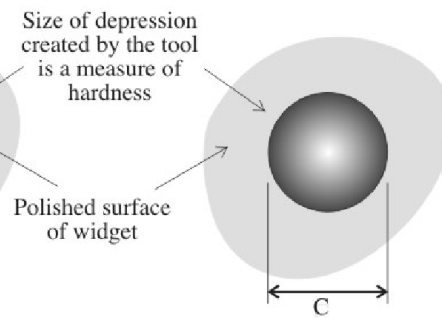
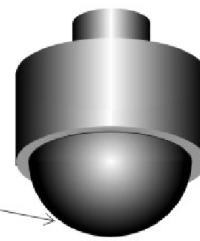
(b) Ball Indenter

Vickers Method



Hardness: $\text{Load}/A.B$

Brinnell Method



Hardness: Load/C^2

(c) Vicker's method

(d) Brinell Method

Figure 4: Typical Indenters of Hardness testing



Figure 5: Typical specimens of Hardness test

Table 2: Approximate hardness conversion numbers for non-austenitic steels (ASTM A370-07a)

HRC	Appx.Tensile Strength (ksi)	HRB	Appx.Tensile Strength (ksi)
68	-	100	116
67	-	99	114
66	-	98	109
65	-	97	104
64	-	96	102
63	-	95	100
62	-	94	98
61	-	93	94
60	-	92	92
59	351	91	90
58	338	90	89
57	325	89	88
56	313	88	86
55	301	87	84
54	292	86	83
53	283	85	82
52	273	84	81
51	264	83	80
50	255	82	77
49	246	81	73
48	238	80	72
47	229	79	70
46	221	78	69
45	215	77	68
44	208	76	67
43	201	75	66
42	194	74	65
41	188	73	64
40	182	72	63
39	177	71	62
38	171	70	61
37	166	69	60
36	161	68	59
35	156	67	58
34	152	66	57
33	149	65	56
32	146	64	-
31	141	63	-
30	138	62	-
29	135	61	-
28	131	60	-
27	128	59	-
26	125	58	-
25	123	57	-
24	119	56	-
23	117	55	-
22	115		
21	112		
20	110		

Note: Table 2 gives the approximate relationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in these Tables.

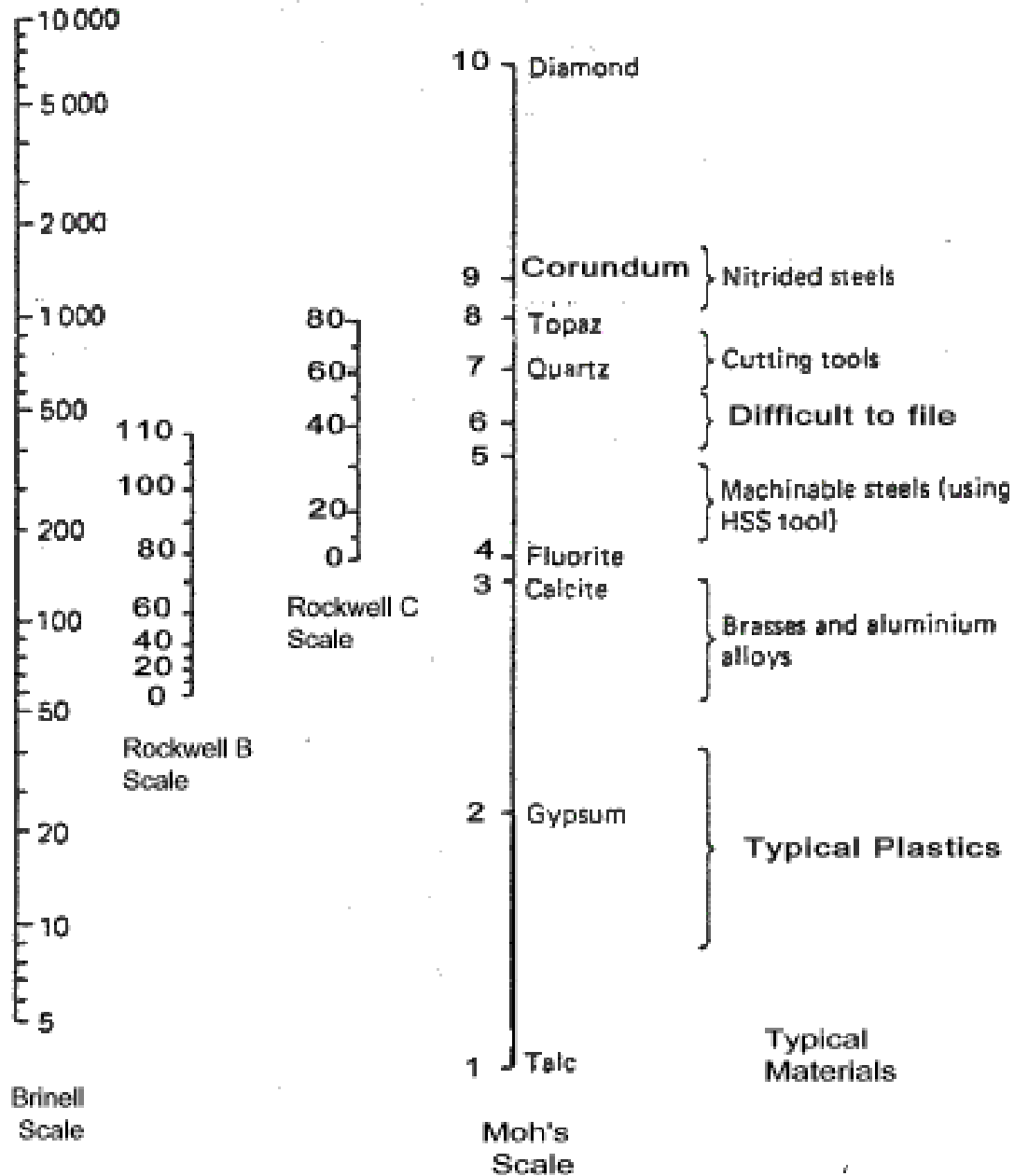


Figure 6: Relation among different hardness scales.

8. PROCEDURE

1. Examine the machine and make sure that the correct scale (A, B or C) is set for testing.
2. Place the specimen upon the anvil of the machine.
3. Raise the anvil and the test piece by elevating screw until the specimen comes in contact with the indenter.
4. Firstly, apply minor load on the specimen by touching the pointer to the specimen.
5. Then apply the major load on the same specimen by pressing upward.
6. After few seconds of the application of load, a beep sound would be heard.
7. Read carefully and record the hardness number from the display of the machine.

9. CALCULATIONS

(Students will fill up this section with their individual observation and calculation about the test, as per teacher's direction.)

For HRB 35 to HRB 100

$$BHN = \frac{7300}{130 - HRB}$$

For HRC 20 to HRC 40

$$BHN = \frac{20000}{100 - HRC}$$

For HRC 41 and above

$$BHN = \frac{25000}{100 - HRC}$$

10. GRAPHS

1. Tensile strength vs. HRC using Table 2.
2. Tensile strength vs. HRB using Table 2.

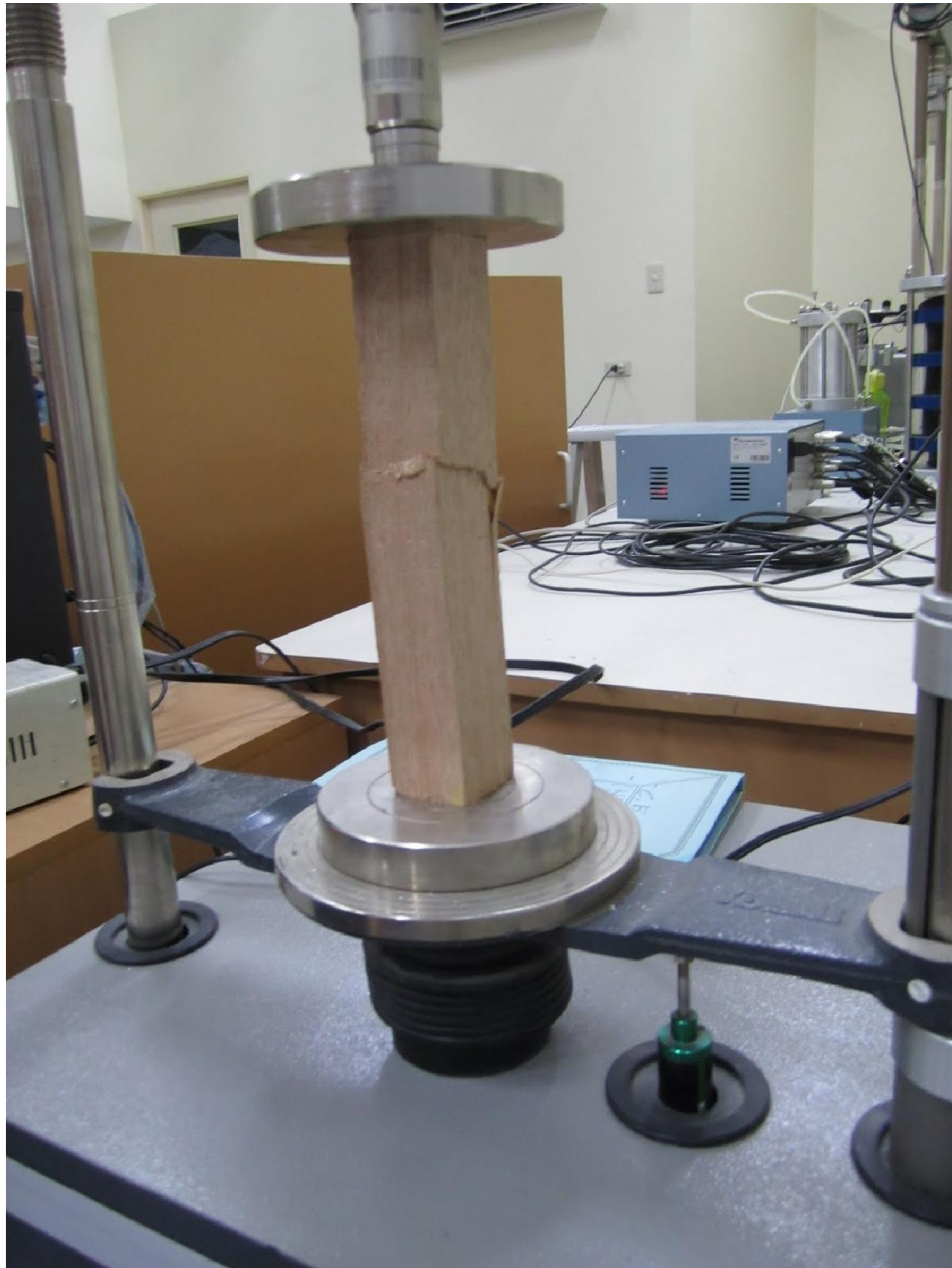
Also show the corresponding tensile strengths of tested specimens in the graphs.

11. DATA TABLE

Sl. No.	Specimen	Name of the metal	Type of indenter	Applied load (kg)	HRB	HRC
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

EXPERIMENT NO.: 2

COMPRESSION TEST OF TIMBER BLOCK



Experiment No.: 2

Compression test of Timber Block

1. OBJECTIVE

- To perform compression test of timber block on UTM.
- To observe the effect of slenderness ratio.
- To study the effects of parallel and perpendicular loading.
- To evaluate the failure patterns based on slenderness ratio and loading direction

2. ASTM REFERENCE

ASTM D 143-09 Standard Test Methods for Small Clear Specimens of Timber

3. SIGNIFICANCE

This experiment provides fundamental knowledge on compression behaviour of materials specially wood/timber, test procedure, universal testing machine and its working principal, compression specimens, failure pattern etc.

4. APPARATUS AND MACHINE

Digital Universal testing machine (UTM), digital slide calipers, steel tape, stop watch and computer.

5. SPECIMEN

Cube shaped 2"x2"x8" (parallel loading) and 2"x2"x6" (perpendicular loading) wooden blocks.

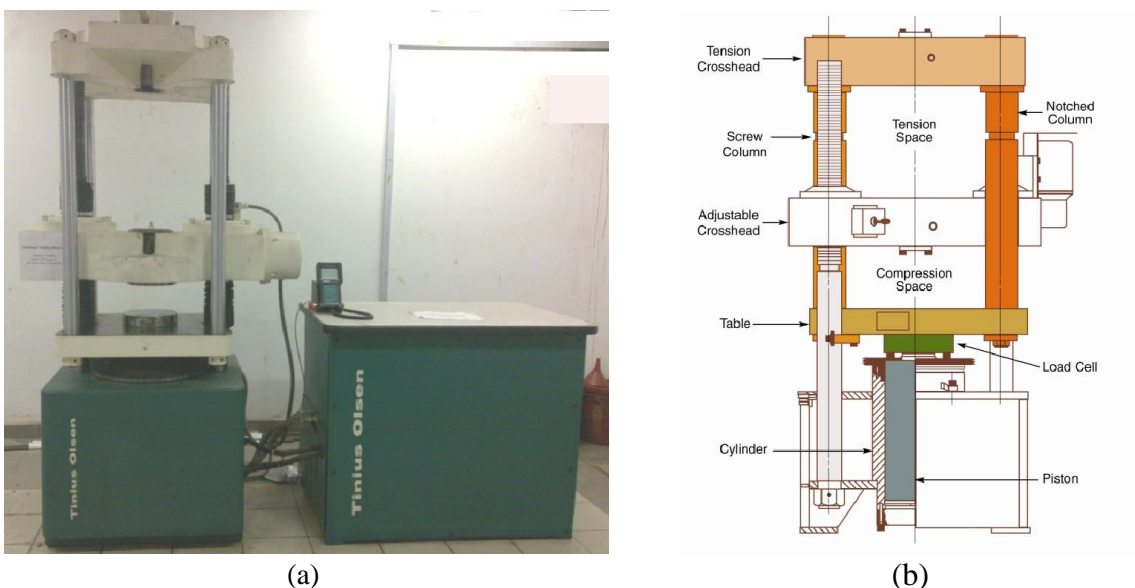
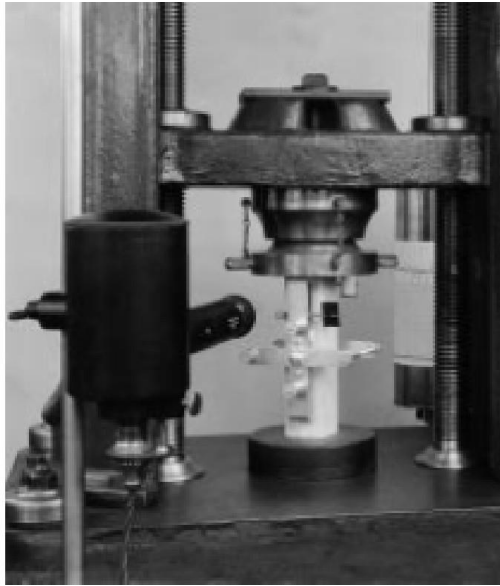
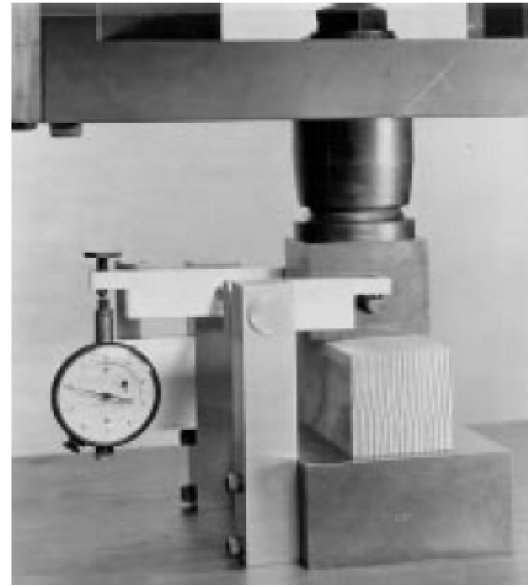


Figure 1: (a) Universal Testing Machine (UTM) (b) Schematic diagram of UTM



(a)



(b)

Figure 3: (a) Compression-Parallel-to-Grain Test Assembly, (b) Compression-Perpendicular-to-Grain Test Assembly (image from ASTM D 143)

6. THEORY

Stress – strain relationship for timber is exceedingly complex, resulting from the facts that,

- (a) Timber does not behave in a truly elastic mode; rather its behavior is time dependent.
- (b) The magnitude of strain is influenced by a wide range of factors; some of those are property dependent, such as density of the timber, angle of grain relative to direction of load application, angle of the micro-fibrils within the cell wall; others are environmentally dependent, such as temperature and relative humidity.

There are several limitations to the compression test to which attention should be directed:

- (1) The difficulty of applying a truly concentric or axial load.
- (2) The relatively unstable character of this type of loading as contrasted to the tensile loading. There is always a tendency for bending stresses to be set up and for the effect of accidental irregularities in alignment with the specimen to be accentuated as loading proceeds.
- (3) Friction between the heads of the testing machine or bearing plates and the end surface of the specimen due to lateral expansion of the specimen. This may alter considerably the results that would be obtained if such a condition of test were not present.
- (4) The relatively larger cross – sectional areas of the compression test specimen, in order to obtain a proper degree of stability of the piece. This results in the necessity for a relatively large –capacity testing machine or a specimen so small and therefore so short

that is difficult to obtain from them strain measurements of suitable precision . It is presumed that the simple compression characteristics of materials are desired and not the column action of structural members, so that attention here confined to the short compression block.

Wood is commonly used engineering material showing different mechanical behavior under tension and compression loading. However, contrary to gray cast Iron or concrete, it does not show brittle characteristics under tensile loading and surprisingly, it is considerably stronger in tension than compression. The fact that the cell structures in the material are stronger in the longitudinal than transverse direction is the major factor leading to this unusual mechanical behavior of wood.

Wood exhibits, under compressive loading, a behavior peculiar to itself. it is anything but an isotropic material, being composed of cell formed by organic growth which align themselves to form a series of tubes or columns in the direction to the grain. As a result of this structure, the elastic limit is relatively low, there is no definite yield point, and considerable set takes place before failure. These properties vary with the orientation of the load with respect to the direction of the grain. For loads normal to grain, the load that causes lateral collapse of the tubes or fibers is the significant load. For load parallel to grain, not only the elastic strength important but also the strength at rupture. Rupture often occurs because of collapse of the tubular fibers as column.

Compression load parallel to grain can be carried by the strongest fibers, whereas compression loads perpendicular to the grain are carried by both weak and strong fibers. Wood in compression parallel to the grain can carry three to four times the load that wood in compression perpendicular to the grain can carry.

Compression failure of wood perpendicular to the grain involves the complete crushing of the wood fiber (the cell with the thinnest walls collapse first, and the action proceeds gradually). Compression failure of wood parallel to the grain involves the bending or buckling of the wood fibers.

Several materials, which are good in tension, are poor in compression. Contrary to this, many materials poor which are in tension but very strong in compression. Several machine and structure components such as columns and struts are subjected to compressive load in applications. These components are made of high compressive strength materials. Not all the materials are strong in compression. That is why determination of ultimate compressive strength is essential before using a material.

Compression test is just opposite in nature to tensile test. Nature of deformation and fracture is quite different from that in tensile test. Compressive load tends to squeeze the specimen. Brittle materials are generally weak in tension but strong in compression. Hence this test is normally performed on cast iron, cement concrete, wood etc. But ductile materials like aluminum and mild steel which are strong in tension are also tested in compression.

A compression test can be performed on UTM by keeping the test-piece on base block and moving down the central grip to apply load. It can also be performed on a compression testing machine. A compression testing machine has two compression plates/heads. The upper head moveable while the lower head is stationary. One of the two heads is equipped with a hemispherical bearing to obtain uniform distribution of load over the test- piece ends. A load gauge is fitted for recording the applied load.

In cylindrical specimen, it is essential to keep $h/d < 2$ to avoid lateral instability due to bucking action. In cubic specimen, d is the minimum width.

7. PROCEDURE

- i) Measure the size of the specimen with a slide calipers.
- ii) Place the block on the proper position of the testing machine.
- iii) Apply load continuously on the specimen until failure.
- iv) Record the maximum load at failure.
- v) Note the characteristics of the fractured surfaces and show the failure plane.

8. SAMPLE CALCULATIONS

Strain rate =

Initial length or height of specimen, $h_i =$

Final length or height of specimen, $h_f =$

Initial minimum width of specimen, $d_i =$

Final minimum width of specimen, $d_f =$

Initial cross-sectional area, $A_i =$

Final cross-sectional area, $A_f =$

9. FAILURE PATTERNS

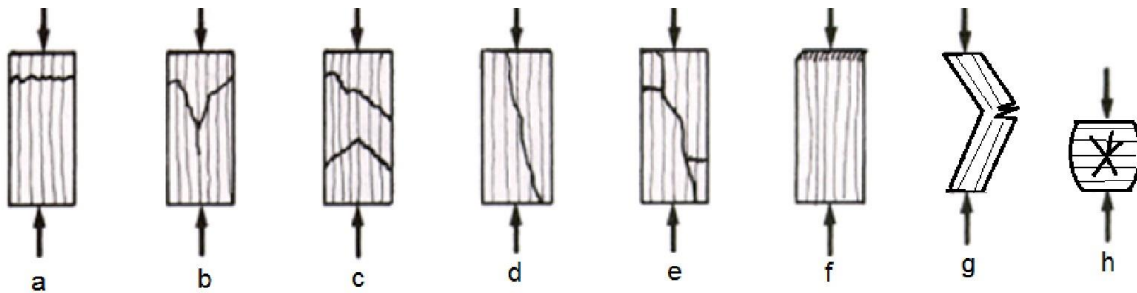
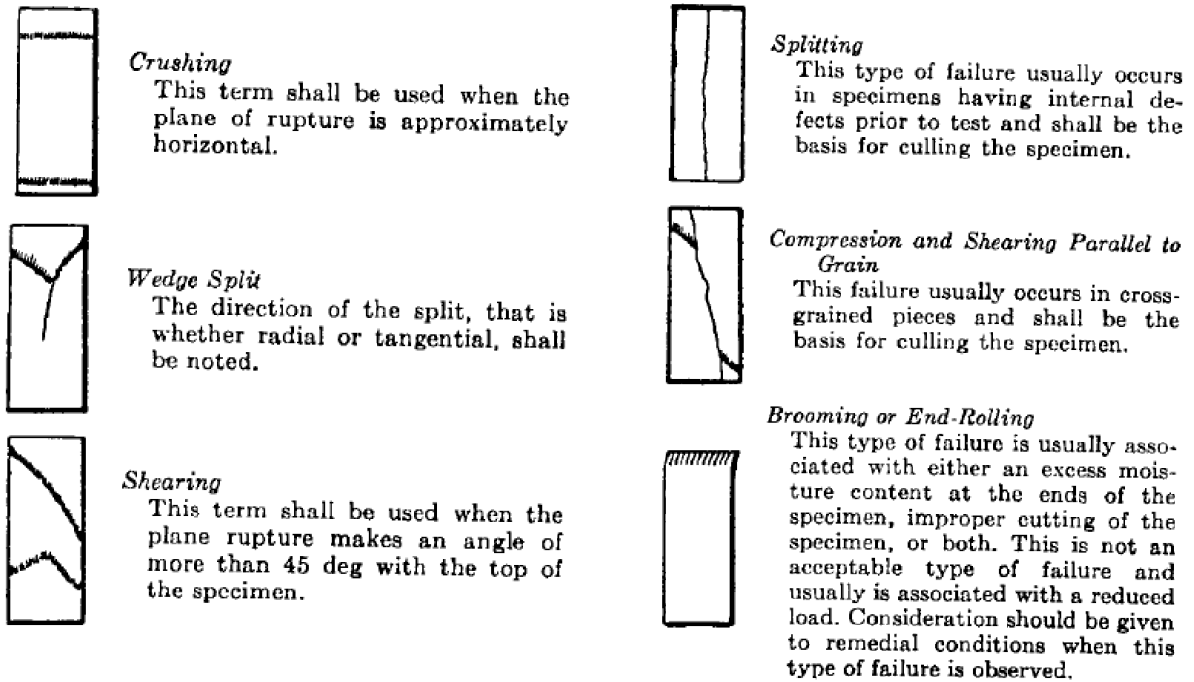


Figure 2: Schematic diagram of failure pattern of wooden specimens.

Parallel Loading:

- a = crushing,
- b = wedge split,
- c = shearing,
- d = splitting,
- e = compression and shearing parallel to plane,
- f = brooming or end rolling,
- g = bending or buckling,

Perpendicular Loading

- h = barreling or bulging

10. SAMPLE CALCULATIONS

1. Draw stress-strain curve in compression.
2. Determine Modulus of Elasticity in compression,

$$E = \frac{\Delta \text{Stress}}{\Delta \text{Strain}}$$

3. Determine proportional limit, σ_{PL} , ultimate (max.) compressive strength, σ_{ult} , and strain at σ_{PL} , ultimate strain ϵ_{ult} from graph.
4. Determine percentage reduction in length (or height) to the specimen

$$\% \text{ Reduction of length} = \frac{h_i - h_f}{h_i} \times 100 \%$$

5. Determine Poisson's ratio,

$$v = \frac{\text{lateral Strain}}{\text{axial strain}} = \frac{\frac{d_f - d_i}{d_i}}{\frac{h_i - h_f}{h_f}}$$

6. Observe failure patterns and failure location w.r.t. loading direction.

11. GRAPH

1. Compressive stress vs. Strain for parallel loading.
2. Compressive stress vs. Strain for perpendicular loading.
3. Combined Compressive stress vs. Strain for all specimens.

12. RESULT

(Students will fill up this section with their individual outcome/result about the test.)

	Case 1 (Parallel loading)	Case 2 (Perpendicular loading)
Ultimate Load, P (N)		
Modulus of Elasticity, E (MPa)		
Ultimate Stress, σ_{ult} (MPa)		
% Reduction in length		
Poisson's ratio, ν		
Ultimate Strain, ϵ_{ult}		
Modulus of Resilience, $G=0.5 \sigma_{PL} \epsilon_{PL}$ (MPa)		
Failure pattern		
Failure location		

13. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.)

Point out the discussion

- 1.
- 2.
3.

14. ASSIGNMENT

1. Compression tests are generally performed on brittle materials, why? Justify your answer.
2. Which will have a higher strength: a small specimen or a full-size member made of the same material?
3. What is column action? How does the h/d ratio of specimen affect the test result?
4. How do ductile and brittle materials differ in their behavior in compression test?

EXPERIMENT NO.: 3

IMPACT TEST OF METAL SPECIMEN



Experiment No.: 3

Impact test of Metal Specimen

1. OBJECTIVE

- To study the Impact testing machine
- To evaluate the energy absorbing characteristics of metal materials at room temperature using the Charpy, Izod, and tension impact methods.
- To observe the failure patterns and failure surface

2. ASTM REFERENCE

ASTM E 23-16b Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

ASTM A370-07a Standard Test Methods and Definitions for Mechanical Testing of Steel Products

3. SIGNIFICANCE

This experiment provides fundamental knowledge on impact behaviour of materials, test procedure, impact testing machine and its working principal, impact specimens, failure patterns etc.

4. APPARATUS AND MACHINE

Digital pendulum impact testing machine.

5. SPECIMENS

Charpy (simple beam specimens), Izod (cantilever specimens), Tension Impact specimens made of different metals.

6. THEORY

An impact test normally determines the energy absorb in fracturing a test piece under high speed loading. Toughness is often measured by impact testing rather than by load – deformation (stress vs. strain) curves.

An impact test is a dynamic test in which a selected specimen which is usually notched, is struck and broken by a single blow in a specially designed machine. Using an impact Machine, the energy absorbed while breaking the specimen is measured.

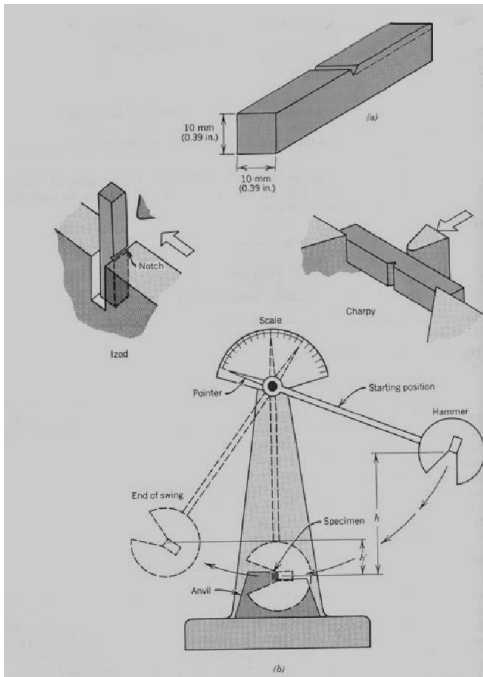
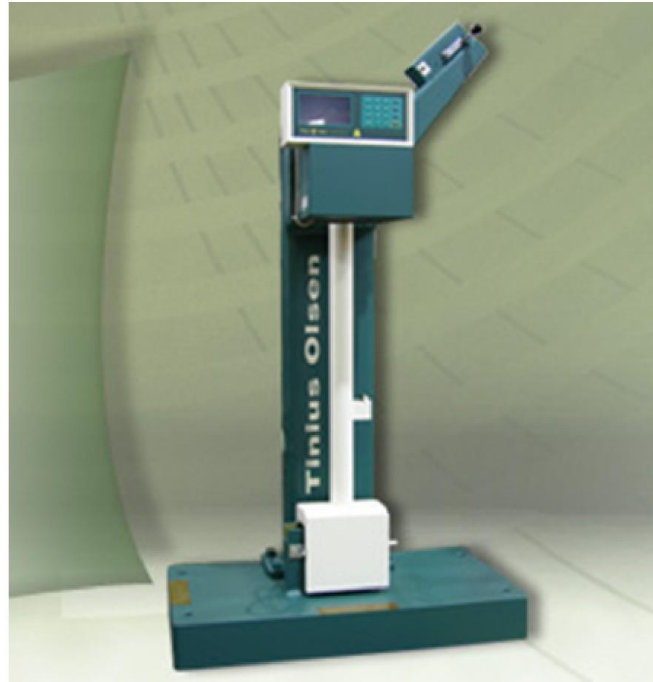


Figure 1: (a) Impact test mechanism
(Image source: Internet)



(b) Impact testing machine
(Image source: Internet)

Dynamic Load is that load which varies with respect to time.

Types of dynamic Load:

- (1) Harmonic Load (machine)
- (2) Periodic Load (dancing)
- (3) Transient Load (walking)
- (4) Impact Load (jumping)

Impact or shock loading differs from static and cyclic loads in two respects:

- (i) Load is applied rapidly, that is with appreciable speed, and
- (ii) Loading is seldom repeated, since failure often occurs on the first application, if it occurs at all.

Types of impact test are as follows:

- (a) Bending impact test
 - (1) Charpy simple beam
 - (2) Izod cantilever beam
- (b) Tensile impact test

In both methods the tested pieces are notched. The intention of the notch is to approximate end use conditions; the notch serves as a stress concentrator. These tests give a

value for toughness, yet their respective values are not directly comparable. This is due to the differences in how they are tested.

The major factors that affect the results of an impact test are:

- (a) Velocity (b) Specimen (c) Temperature

Table 1: Features of different types of fracture

Ductile fracture	Brittle fracture
A mode of fracture characterized by the slow crack propagation which usually follows a zigzag path along planes where a maximum resolved shear stress has occurred.	A mode of fracture characterized by the nucleation and rapid propagation of a crack, with little accompanying plastic deformation.
A surface experiencing ductile fracture generally has a dull, fibrous appearance.	Brittle fracture surfaces in crystalline materials can be identified by the shiny, granular appearance.
Example: Fracture of mild steel, aluminum,	Example: Fracture of cast iron, high carbon steel.

Table 2: Effect of angle of notch on energy of rupture of mild steel

Angle of notch (degree)	Sketch of specimen	Charpy impact value
0		22.1
30		24.4
45		23.1
90		25.9
120		41.8
150		66.2
180		63.1

In manufacturing locomotive wheels, coins, connecting rods etc. the components are subjected to impact (shock) loads. These loads are applied suddenly. The stresses induced in these components are many times more than the stress produced by gradual loading. Therefore, impact tests are performed to assess shock absorbing capacity of materials subjected to suddenly applied loads.

Impact tests provide information on the resistance of a material to sudden fracture where a sharp stress rise or flaw is present. In addition to providing information not available from any other simple mechanical test, these tests are quick and inexpensive. The data obtained from such impact test is frequently employed for engineering purposes.

Various standard impact tests are widely employed in which notched specimens are broken by a swinging pendulum. The most common tests of this type are the Charpy V-notch test and the Izod test which are described in ASTM E23, Standard test Methods for notched bar impact testing of metallic materials. Another test method, although not a standard test method, is the tension impact test.

These types of impact tests have given way to testing methods that make use of fracture mechanics. Fracture mechanics allow more sophisticated analysis of materials containing cracks and sharp notches. However, the advantages of fracture mechanics are achieved at the sacrifice of simplicity and economy. Impact tests such as the Charpy, Izod, and tension impact have thus remained popular despite their shortcomings, as they serve a useful purpose in quickly comparing materials and obtaining general information on their behavior.

Many materials, including metals, exhibit marked changes in impact energy with temperature. It is known that there tends to be a region of temperatures over which the impact energy increases rapidly from a lower level that may be relatively constant to an upper level that may also be relatively constant. Such temperature transition behavior is common for metal materials. This temperature dependence for various steel alloys with the same hardness but different carbon contents is graphically shown in Figure 2. This figure shows the impact energy obtained from Charpy V-notch impact specimens as a function of temperature. The temperature transition behavior is of engineering significance since it aids in comparing materials for use at various temperatures. In general, a material should not be severely loaded at temperatures where it has low impact energy.

In Charpy test, the specimen is placed as 'Simply supported beam' and In Izod test, the specimen is placed as 'cantilever beam' (Figure 3). The specimens have V-shaped notch of 45° . U-shaped notch is also common. The notch is located on tension side of specimen during impact loading. Depth of notch is generally taken as $t/5$ to $t/3$ where 't' is thickness of the specimen. Table 2 represents typical response of angle of notch on Charpy impact strength

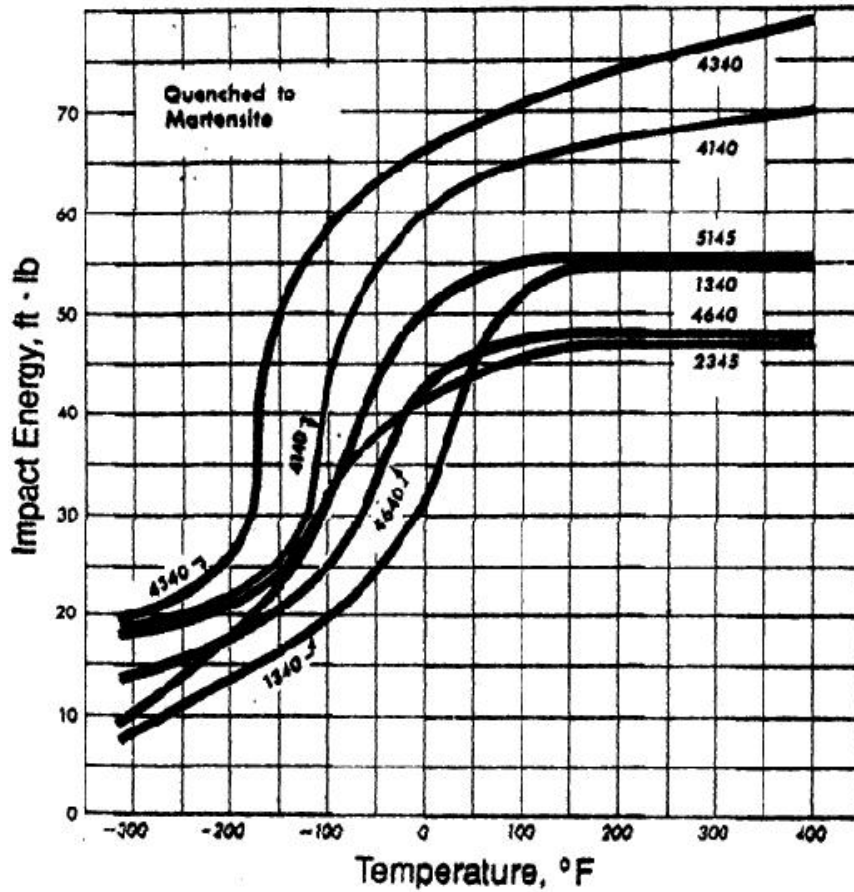


Figure 2: Temperature Dependence of Charpy V-Notch Impact Resistance for Different Alloys Hardened to HRC 34 (N.E. Dowling). (Image source: Internet)

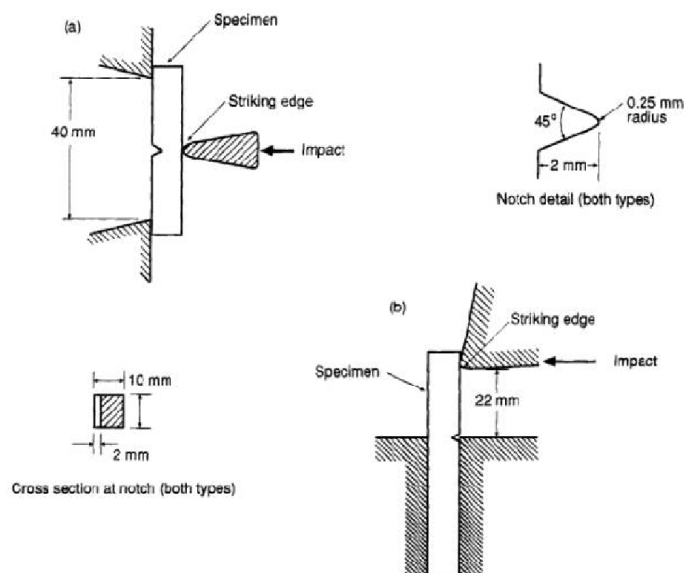


Figure 3: (a) Charpy setup (b) Izod setup (Image source: Internet)

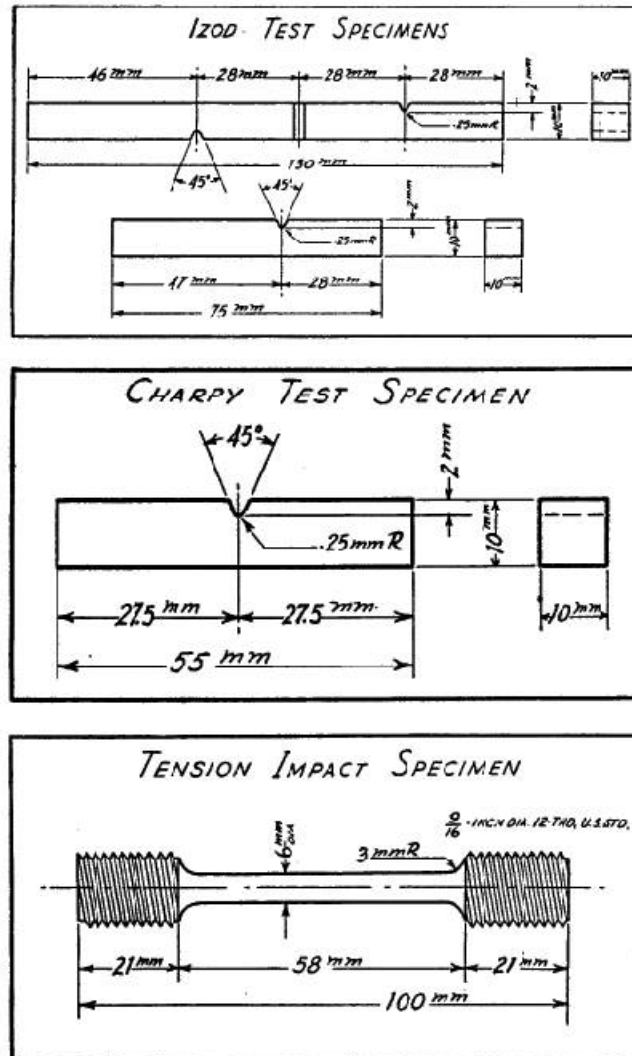


Figure 4: Impact test specimen with specification (Image source: Internet)

7. SPECIFICATION OF MACHINE AND SPECIMEN

Impact testing machine:

Impact capacity = 407.74 joule

Weight of striking hammer = 27.22 kg (60 lb)

Swing radius of hammer = 900.1 mm (35.437 inch)

Angle of hammer before striking = 160°

Striking velocity of hammer = 5.47 m/sec. (17.9 ft/sec.)

Specimen:

Specimen size = (Figure 4)

Type of notch = (Figure 4)

Angle of notch = (Figure 4)

Depth of notch = (Figure 4)

8. PROCEDURE

- i) Measure the lateral dimensions of the specimen at full section and at the notch.
- ii) Place the specimen in proper position. Set the hammer block at a certain height and then release it.
- iii) When the hammer block stops swinging, record the value of absorbed energy displayed on the screen.

9. DATA

Obs. No.	Type of test	Name of metal	Specimen type	Specimen depth	Specimen width	Depth of notch	Depth at notch	Absorbed Energy, E (J)
1	Charpy							
2	Izod							
3	Tension							

Depth at notch = Specimen depth - Depth of notch

Cross sectional area at notch, $A_{Notch} = \text{Depth at notch} \times \text{Specimen width}$

Energy required to break the specimen = Absorbed Energy, E

Notch impact strength / Impact toughness, $U = \text{Absorb energy} / \text{Effective cross section area at notch} = E/A_{Notch}$

10. FAILURE PATTERNS



Figure 5: Fractured pieces of Charpy Impact specimens



Cup-and-cone fracture in aluminum.



Brittle fracture in a mild steel.

Figure 6: Fractured piece of Charpy tension Impact specimens



Figure 7: Fractured piece of Izod(top) and Charpy(bottom) specimens

11. PRECAUTIONS

1. The specimen should be prepared in proper dimensions.
2. Do not stand in front of swinging hammer or releasing hammer.
3. Place the specimen in proper position.

12. GRAPHS

1. Charpy Impact Strength vs. HRB
2. Izod Impact Strength vs. HRB
3. Tension Impact Strength vs. HRB

13. RESULT

Table 1: Charpy simple beam

Obs. No.	Name of metal	Group	Area at notch, A_{Notch} (mm)	HRB	Absorbed Energy, E (J)	Impact toughness, $U=E/A_{\text{Notch}}$ (J/mm^2)	Failure Pattern	Failure Surface
1								
2								
3								
4								
5								
6								

Table 2: Izod cantilever beam

Obs. No.	Name of metal	Group	Area at notch, A_{Notch} (mm)	HRB	Absorbed Energy, E (J)	Impact toughness, $U=E/A_{\text{Notch}}$ (J/mm^2)	Failure Pattern	Failure Surface
1								
2								
3								
4								
5								
6								

Table 3: Tension Impact Specimen

Obs. No.	Name of metal	Group	Area at notch, A_{Notch} (mm)	HRB	Absorbed Energy, E (J)	Impact toughness, $U=E/A_{\text{Notch}}$ (J/mm^2)	Failure Pattern	Failure Surface
1								
2								
3								
4								
5								
6								

14. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.)

Point out the discussion

- 1.
- 2.
3.

15. ASSIGNMENT

- 1) Discuss the relative toughness and hardness values obtained for all materials tested.
- 2) What is the necessity of making a notch in impact test specimen?
- 3) Describe the fracture surface of the different materials tested.
- 4) If the sharpness of V-notch is more in one specimen than the other, what will be its effect on the test result?
- 5) What is the effect of temperature on the values of rupture energy and notch impact strength?

EXPERIMENT NO.: 4

TENSION TEST OF MILD STEEL SPECIMEN



Experiment No.: 4

Tension test of Mild Steel Specimen

1. OBJECTIVE

- To determine the mechanical properties of steel specimen.
- To perform the tensile test of mild steel.
- To observe the tensile strength of different steel grades.
- To study the failure pattern of different steel grades.
- To compare the performances of different steel grades.

2. ASTM REFERENCE

ASTM E 8M-13a Standard Test Methods for Tension Testing of Metallic Materials

3. SIGNIFICANCE

This experiment provides fundamental knowledge on tension behaviour of materials specially mild steel, test procedure, universal testing machine and its working principal, tension specimens, failure patterns etc.

4. APPARATUS AND MACHINE

UTM, stop watch, digital slide calipers and computer.

5. SPECIMEN

Mild steel specimens (40, 60, and 72.5 grades) of 25mm diameter and 28in length.

6. THEORY

Elasticity & Plasticity: When external forces are applied on a body, made of engineering materials, the external forces tend to deform the body while the molecular forces acting between the molecules offer resistance against deformation or displacement of the particles continues till full resistance to the external forces is setup. If the forces are now gradually diminished, the body will return, wholly or partly to its original shape. Elasticity is the property by virtue of which a material deformed under the load is enabled to return to its original dimension when the load is removed. If a body regains completely its original shape, it is said to perfectly elastic.

Plasticity is the converse of elasticity. A material in plastic state is permanently deformed by the application of load, and it has no tendency to recover. Every elastic material possesses the property of plasticity. Under the action of large forces, most engineering materials become plastic and behave in a manner similar to a viscous liquid. The characteristic of the material by which it undergoes inelastic strains beyond those at the elastic limit is known as plasticity. When large deformations occur in a ductile material loaded in the plastic region, the material is said to undergo plastic flow.

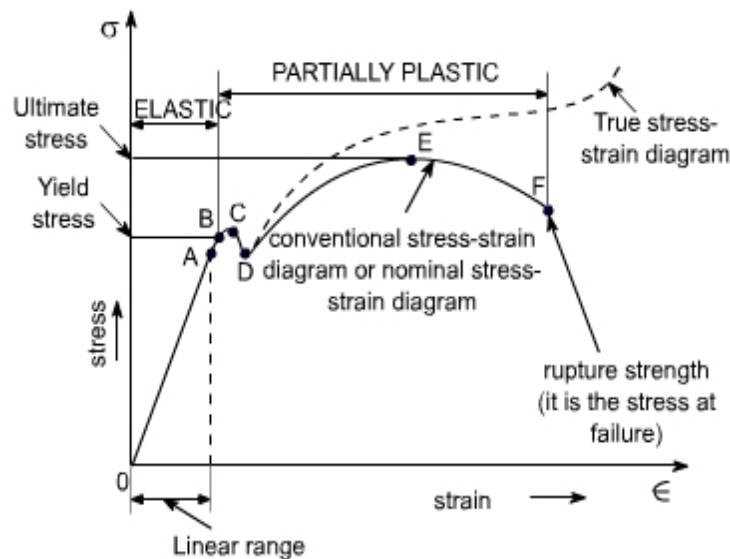


Figure 1: Stress-strain diagram of Mild Steel in tension

Proportional Limit (Point A): It is the limiting value of the stress upto which stress is proportional to strain.

Elastic Limit (Point B): This is the limiting value of stress upto which if the material is stressed and then released (unloaded), strain disappears completely the original length is regained. Its determination, experimentally, is extremely difficult, and therefore its exact location on the stress-strain diagram is usually not known, even though it is generally higher than the proportional limit.

Permanent set/permanent deformation: If the load exceeds the elastic limit before it is removed, the material does not fully regain its initial dimensions. In such a case the material is said to experience a permanent deformation.

Elastic Recovery: The recovered deformation after removal of load.

Yield stress (Point C and D): Soon after the stress the elastic limit, low carbon steel attains its yield point stress. The yield point of a material is defined as that unit stress that will cause an increase in deformation without an increase in load. Upon the arrival of yield point, a ductile material such as low carbon steel stretches an almost unbelievable amount, frequently 10% of the original length. When the yield stress is reached elongation takes place more rapidly as plastic flow takes place over and atoms move into new positions and a return to the original shape of the test piece is impossible.

Upper Yield Point (Point C): This is the stress at which the load starts reducing and the extension continues.

Lower Yield Point (Point D): At this stage the stress remains same but strain increases for some time.

The upper yield point is influenced considerably by the shape of the test specimen, speed of testing, accuracy of alignment, the condition of the test piece (especially the presence of residual stresses in a test on the full cross section) and by the testing machines itself and is sometimes completely suppressed. The lower yield points much less sensitive and is considered to be more representative.

Yield Strength by Offset Method: For materials having a stress-strain diagram such as shown in figure (those that do not exhibit a well-defined yield point) a value of stress, known as the yield strength for the material, is defined as one producing a certain amount of permanent strain.

Ultimate Strength/Tensile Strength (Point E): This is the maximum stress the material can resist. The ultimate strength represents the ordinate to the highest point in the stress-strain diagram and is equal to the maximum load carried by the specimen divided by the original cross-sectional area.

Breaking Strength/Fracture Strength/Rupture Strength (Point F): The stress at which finally the specimen fails is called breaking point. It is the engineering stress at which specimen fracture and complete separation of the specimen parts occurs.

Strain Hardening/Work Hardening: If a ductile material can be stressed considerable beyond the yield point without failure, it is said to strain harden (When a material deformed plasticity, it work hardens, that is, the stress has to be increased to give further deformation).

Necking: After reducing the maximum stress, a localized reduction in area, called necking, begins, and elongation continues with diminishing load until the specimen breaks.

Modulus of Rigidity (G): It is defined as the ratio of shearing stress to shearing strain within elastic limit.

Modulus of Resilience: The work done on a unit volume of material, as a simple tensile force is gradually increased from zero to such a value that the proportional limit of the material is reached, is defined as the modulus of resilience.

Modulus of Rupture/ Modulus of Toughness: The work done on a unit volume of material as a simple tensile force is gradually increased from zero to the value causing rupture is defined as the modulus of toughness.

Various machine and structure components are subjected to tensile loading in numerous applications. For safe design of these components, their ultimate tensile strength and ductility to be determined before actual use. A material when subjected to a tensile load resists the applied load by developing internal resisting force. These resistances come due to atomic bonding between atoms of the material. The resisting force for unit normal cross-section area is known as stress.

The value of stress in material goes on increasing with an increase in applied tensile load, but it has a certain maximum (finite) limit too. The minimum stress, at which a material fails, is called ultimate tensile strength.

The end of elastic limit is indicated by the yield point (load). This can be seen during experiment as explained later in procedure with increase in loading beyond elastic limit, initial cross-section area (A_i) goes on decreasing and finally reduces to its minimum value when the specimen breaks. Some typical mechanical properties of mild steel are as follows:

Proportional Limit, $\sigma_p = 30\sim 65$ ksi (larger for stronger specimens)

Yield Strength, $\sigma_y = 35\sim 75$ ksi (larger for stronger specimens)

Ultimate Strength, $\sigma_{ult} = 60\sim 100$ ksi (larger for stronger specimens)

Modulus of Elasticity, $E = 29000\sim 30000$ ksi (almost uniform for all types of specimens)

Poisson's Ratio, $\nu = 0.20\sim 0.30$ (larger for stronger specimens)

Modulus of Resilience = $0.02\sim 0.07$ ksi (larger for stronger specimens)

Modulus of Toughness = $7\sim 15$ ksi (smaller for stronger specimens)

Ductility = $10\sim 35\%$ (smaller for stronger specimens)

Reduction of Area = $20\sim 60\%$ (smaller for stronger specimens)

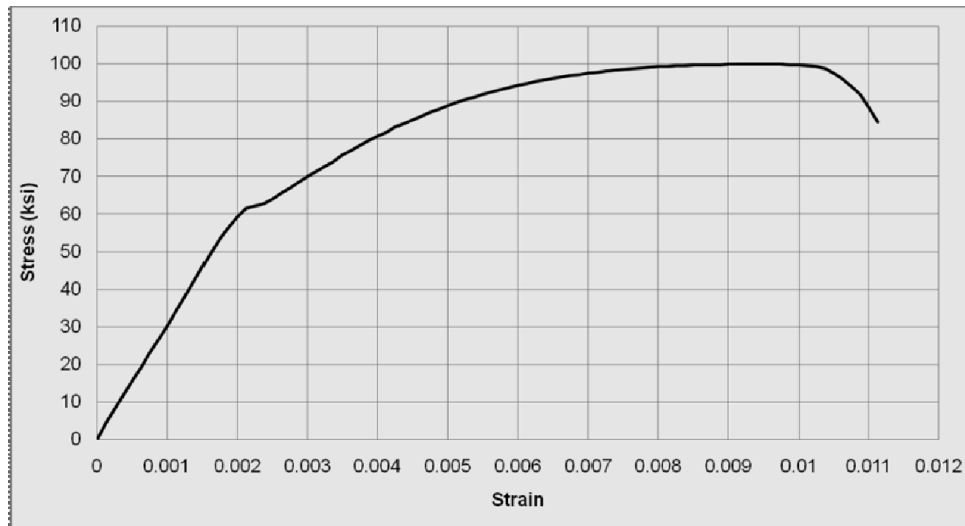


Figure 2: Typical stress-strain curve of Mild Steel in Tension done in the lab.

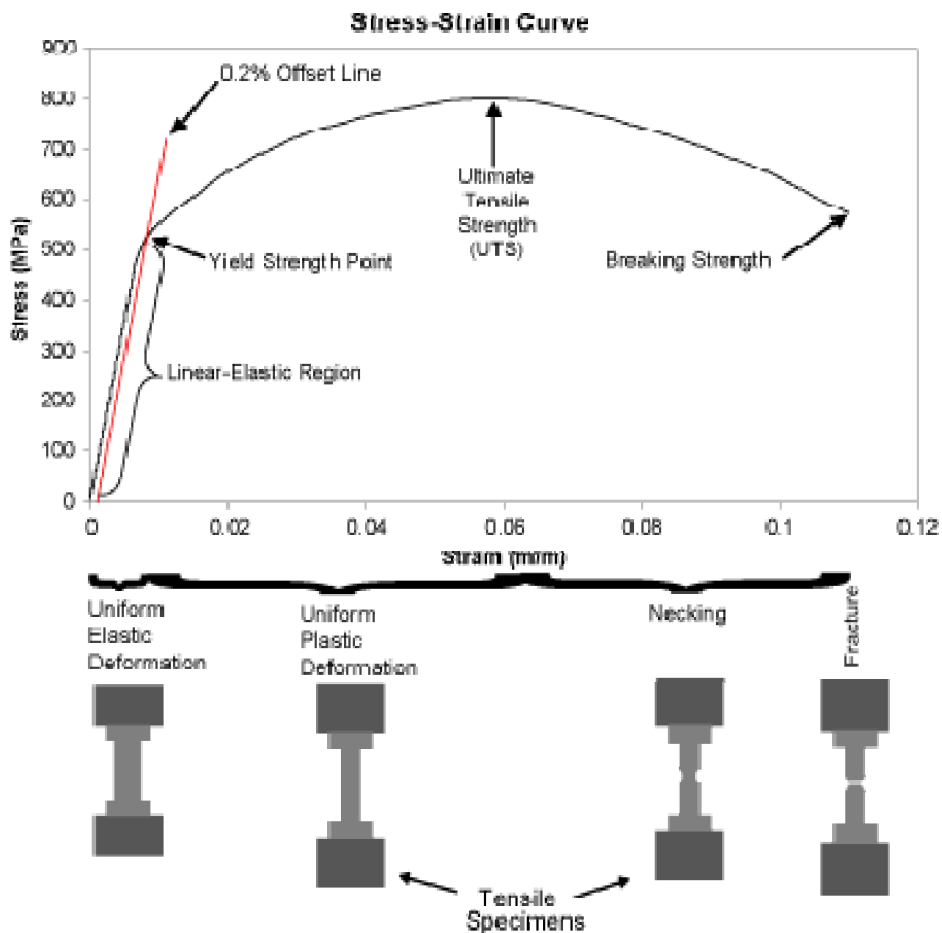


Figure 3: Specimen condition in the stress-strain curve of Mild Steel in Tension.

7. FAILURE PATTERNS



Cup-cone fracture (necking found, i.e. Ductile)



Incomplete Cup-cone fracture (necking found, i.e. Ductile)



Incomplete Cup-cone fracture (necking found, i.e. Ductile)



Figure 4: Different ductile and brittle failure patterns of mild steel specimen.

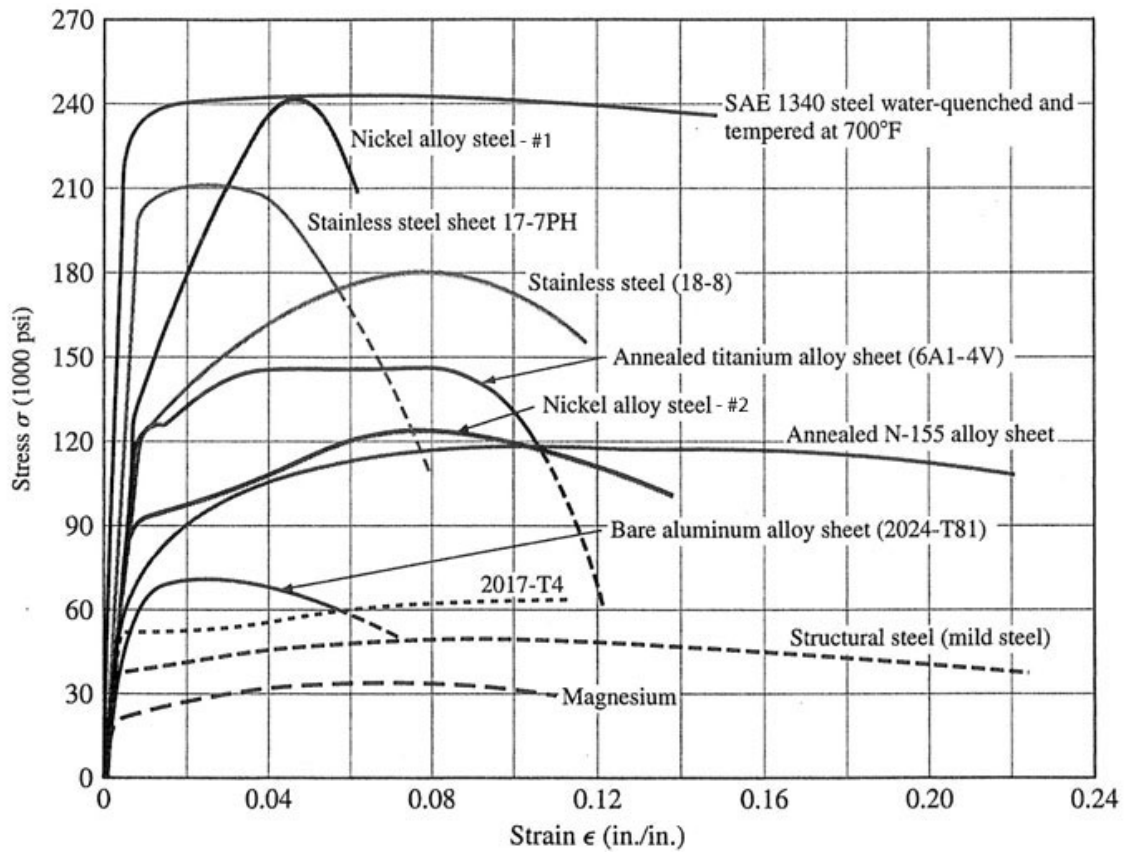


Figure 5: Comparative stress-strain diagram of different metals and alloys

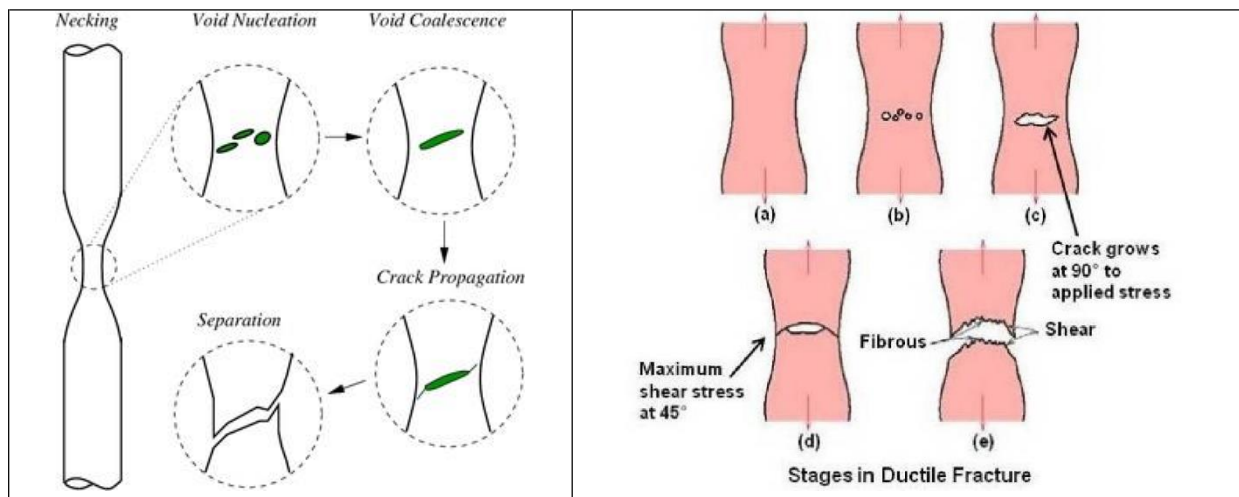


Figure 6: Mechanism of necking

Typical tension test result

TENSION TEST OF DEFORMED M.S. BARS

Sr. General Manager(Marketing& Sales), Ratanpur Steel Re-rolling Mills Ltd.,

Sent by: Nahar Mansion, 116 CDA Avenue, Muradpur, Chittagong

Project: Test of deformed MS bars for RSRM

Date of Test: 16/10/2014
Contractor: -

Sl. No.	Frog Mark	Nominal Dia mm	Actual Dia mm	Actual Unit Weight kg/m	Average Actual Unit Weight kg/m	Yield or Proof Load kN	Yield or Proof Strength * MPa	Average Yield or Proof Strength (YS) MPa	Ultimate Load kN	Ultimate Strength * MPa	Average Ultimate Strength (TS)		TS/YS	Elongation (%) (Gauge length = 203.2 mm)	Average Elongation (%) (G. length = 203.2 mm)	Band Test (ISO 6935)	Rebend Test (ISO 6935)
											MPa	(TS)					
1	RSRM.G60.400W	25	24.8	3.795		225	458	469	368	750	725	1.54	19	20	20	Satisfactory	-
2	RSRM.G60.400W	25	24.9	3.809	3.810	226	460	(680000 psi)	339	690	(1050000 psi)		20	20	20	Satisfactory	-
3	RSRM.G60.400W	25	24.9	3.825		240	489	(4780 kg/sq.cm)	363	740	(7390 kg/sq.cm)		20	20	20	Satisfactory	-
4	RSRM.G60.400W	20	19.9	2.441		140	446	452	216	690	700	1.55	19	16	17	Satisfactory	-
5	RSRM.G60.400W	20	19.9	2.435	2.440	144	459	(655000 psi)	227	725	(1020000 psi)		16	17	17	Satisfactory	-
6	RSRM.G60.400W	20	19.9	2.445		142	452	(4610 kg/sq.cm)	217	690	(7150 kg/sq.cm)		17	17	17	Satisfactory	-
7	RSRM.G60.400W	16	15.9	1.560		86.4	430	425	136	680	670	1.58	19	19	19	Satisfactory	-
8	RSRM.G60.400W	16	15.9	1.558	1.558	86.4	430	(615000 psi)	134	670	(975000 psi)		19	19	19	Satisfactory	-
9	RSRM.G60.400W	16	15.9	1.557		83.3	415	(4335 kg/sq.cm)	134	670	(6850 kg/sq.cm)		19	19	19	Satisfactory	-
10	RSRM.G60.400W	12	12.0	0.883		48	425	425	71	625	625	1.48	18	18	18	Satisfactory	-
11	RSRM.G60.400W	12	12.0	0.884	0.884	46.9	425	(615000 psi)	71	625	(910000 psi)		18	18	18	Satisfactory	-
12	RSRM.G60.400W	12	12.0	0.884		48.6	430	(4335 kg/sq.cm)	71	625	(6400 kg/sq.cm)		19	19	19	Satisfactory	-
13	RSRM.G60.400W	10	10.0	0.621		36.7	455	465	55	700	700	1.51	15	15	15	Satisfactory	-
14	RSRM.G60.400W	10	10.0	0.622	0.624	37.2	471	(675000 psi)	56	705	(1020000 psi)		15	15	15	Satisfactory	-
15	RSRM.G60.400W	10	10.1	0.628		36.3	459	(4740 kg/sq.cm)	55	695	(7150 kg/sq.cm)		16	16	16	Satisfactory	-

8. PROCEDURE

- i) Measure the diameter of the specimen by slide calipers. Record gage length.
- ii) Fix the specimen in proper position and apply the load
- iii) Record the maximum load and apply load till the breakage.
- iv) Remove the broken specimen and measure the smallest cross-sectional area and the final length between the gage marks by fitting the two ends of the broken pieces together.
- v) Note the characteristics of the fractured surface.

9. SAMPLE CALCULATIONS

Strain rate =

Initial length of specimen, $h_i =$

Final length of specimen, $h_f =$

Initial diameter of specimen, $d_i =$

Final diameter of specimen, $d_f =$

Initial cross-section area, $A_i =$

Final cross-section area, $A_f =$

1. Draw stress-strain curve in tension.

2. Determine Modulus of Elasticity,

$$E = \frac{\Delta \text{Stress}}{\Delta \text{Strain}}$$

and Modulus of Resilience in tension

3. Determine ultimate (max.) tensile strength from graph

4. Determine yield stress from graph

5. Determine percentage elongation in length of the specimen, initial length,

$$\% \text{ Elongation of length} = \frac{l_f - l_i}{l_i} \times 100\%$$

6. Determine EMF (elongation at maximum force) from graph

7. Also determine proportional limit (σ_p), elastic limit (σ_E), yield point (σ_y), ultimate stress (σ_u), breaking strength (σ_b), etc.

10. DATA TABLE

Deformation rate=		mm/min,		Grade=		ksi, Brand=	
Time (s)	Load (N)	Time (s)	Load (N)	Time (s)	Load (N)	Time (s)	Load (N)
0		470		560		740	
10		480		570		750	
20		490		580		760	
30		500		590		770	
40		510		600		780	
50		520		610		790	
60		530		620		800	
70		540		630		810	
80		550		640		820	
90		560		650		830	
100		570		660		840	
110		580		670		850	
120		590		680		860	
130		600		690		870	
140		610		700		880	
150		620		710		890	
160		630		720		900	
170		640		730		910	
180		650		740		920	
190		660		750		930	
200		670		760		940	
210		680		770		950	
220		690		780		960	
230		700		790		970	
240		710		800		980	
250		720		810		990	
260		730		820		740	
270		740		830		750	
280		750		840		760	
290		760		560		770	
300		770		570		780	
310		780		580		790	
320		790		590		800	
330		800		600		810	
340		810		610		820	
350		820		620		830	
360		830		630		840	
370		840		640		850	
380		470		650		860	
390		480		660		870	
400		490		670		880	
410		500		680		890	
420		510		690		900	
430		520		700		910	
440		530		710		920	
450		540		720		930	
460		550		730		940	

11. GRAPH

1. Tensile stress vs. strain curve of 40 Grade bar.
2. Tensile stress vs. strain curve of 60 Grade bar.
3. Tensile stress vs. strain curve of 72.5 Grade bar.
4. Combined Tensile stress vs. strain curve of 40, 60 and 72.5 grade bar.
5. Show all the points on the graphs 1, 2, and 3.

12. RESULT

(Students will fill up this section with their individual outcome/result about the test. Write the stress values in psi and MPa as shown in Table)

Properties	40 grade steel	60 grade steel	72.5 grade steel (500W grade)
E, psi (MPa)			
σ_p , psi (MPa)			
ϵ_p , in/in (mm/mm)			
σ_E , psi (MPa)			
ϵ_E , in/in (mm/mm)			
σ_y , psi (MPa)			
ϵ_y , in/in (mm/mm)			
σ_u , psi (MPa)			
ϵ_u , in/in (mm/mm)			
σ_b , psi (MPa)			
ϵ_b , in/in (mm/mm)			
Ductility ratio, σ_u/σ_y			
% Elongation			
EMF, in/in (mm/mm)			
Failure pattern			
Failure type			

13. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.) Point out the discussion

14. ASSIGNMENT

1. Which type of steel have you tested? What is its carbon content?
2. What general information is obtained from tensile test regarding the properties of a material?
3. Which stress have you calculated: nominal/engineering stress or true stress?
4. What kind of fracture has occurred in the tensile specimen and why?
5. Which is the most ductile metal? How much is its elongation?

EXPERIMENT NO.: 5

STATIC BENDING TEST OF STEEL AND TIMBER BEAM



Experiment No.: 5

Static Bending Test of Steel and Timber Beam

1. OBJECTIVE

- To observe the bending behavior of beams with different moment of inertia (I).
- To determine the Modulus of Elasticity (E) of wood by conducting bending test.
- To evaluate the deflection of beam w.r.t. load increment.
- To evaluate the failure patterns due to bending.

2. ASTM REFERENCE

ASTM D143-09 Standard Test Methods for Small Clear Specimens of Timber

3. SIGNIFICANCE

This experiment provides fundamental knowledge on bending behaviour of materials specially timber beam, test procedure, universal testing machine and its working principal, bending specimens, failure patterns etc.

4. APPARATUS

Universal Testing Machine (UTM), strain gauge or deflectometer, Support attaching system, steel tape, stop watch and computer.

5. SPECIMENS

Timber beams

6. THEORY

Beam: A bar subject to forces or couples that lie in a plane containing the longitudinal axis of the bar is called a beam. The forces are understood to act perpendicular to the longitudinal axis.

The most economical beam is the one with least cross-sectional area and consequently the least weigh per foot of length. In general, for a given area, a deeper beam is stronger than a shallower one.

Bending Moment: The algebraic sum of the moments of the external forces to one side of any cross-section of the beam about an axis through that section is called the bending moment at that section.

Type of Bending: If couples are applied to the ends of the beam and on forces acts on the bar, then the bending is termed *pure bending*. For example, in Figure 2 the portion of the beam between the two downward forces is subjected to pure bending. Bending produced by forces that do not form couples is called ordinary bending. A beam subject to pure bending has only normal stresses with no shearing stresses set up in it; a beam subject to ordinary bending has both normal and shearing stresses acting within it.

Neutral Surface: There always exists one surface in the beam containing fibers that do not undergo any extension or compression, and thus are not subject any tensile or compressive stress. This surface is called the neutral surface of the beam.

Neutral Axis: The intersection of the neutral surface with any cross-section of the beam perpendicular to its longitudinal axis is called the neutral axis.

Navier's Assumption: States that “plane section (normal to neutral axis) before bending remains plane after bending”.

Theory of Simple Bending: Bending is usually associated with shear. However, for simplicity we neglect the effect of shear and consider moment alone to find the stresses due to bending (i.e. bending stress). Such a theory which deals with finding stresses at a section due to pure moment is called simple bending theory.

Assumptions in theory of Simple Bending: The following assumptions are made in simple theory of bending:

- (1) The beam is initially straight and every layer of it is free to extend or contract & bends into a circular arc
- (2) The material is a homogeneous, isotropic & elastic continuum
- (3) Young's Modulus is same in tension and compression.
- (4) The beam material obeys Hooke's law and stresses are within elastic limits.
- (5) Plane section remains plane even after bending
- (6) The radius of curvature is large compared to depth of beam
- (7) Beam deformation due to shear effects is neglected
- (8) Effects of localized (concentrated) loads are neglected
- (9) The beams bends about one of its principal axes
- (10) Stresses are induced only in the longitudinal direction of the beam

For a simply supported beam with central loading, deflection under the load is given by

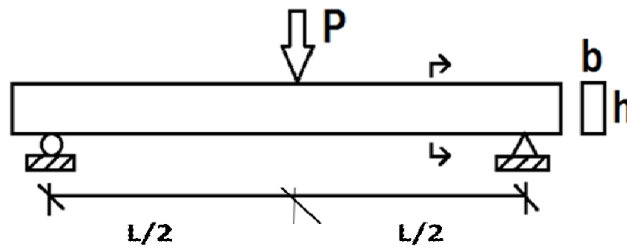


Figure 1: Simply supported beam with one-point load.

Maximum Deflection for one point loading, $\delta_{max} = \frac{PL^3}{48EI}$

where,

P = Applied load.

L = Effective span of the beam.

E = Modulus of Elasticity of wood.

I = Moment of inertia

δ_{max} = Mid-span deflection under the load.

For two-point loading, at distances ‘a’ from either support, where L is the span of the beam is shown in Figure 2, the portion of the beam between the loads (P/2 each) is free from any shear and is subjected to purely flexural stress.

Maximum deflection (in the elastic range) at the center of the beam for such a loading,

$$\delta_{max} = \frac{Pa(3L^2 - 4a^2)}{48} EI$$

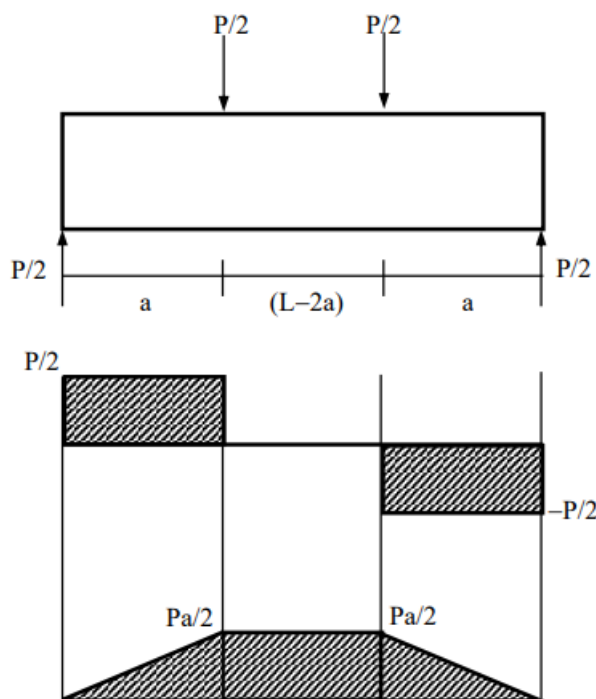


Figure 2: Simply supported beam with two-point load.

If $a = L/3$, the loading case is known as ‘third point loading’.

$$\text{Maximum Deflection for two point loading, } \delta = \frac{23PL^3}{1296EI}$$

7. PROCEDURE

- i) Measure all dimensions of the beam.
- ii) Place the beam in proper position and apply load.
- iii) Record the load at certain interval.
- iv) Record the peak load from the load cell display of UTM machine.
- v) Note the characteristics of the fractured surface.

8. OBSERVATIONS AND CALCULATIONS

Strain rate = 5mm/min

Calculation of Modulus of Elasticity (E),

Bending Stress (σ_{max}),

$$\sigma_{max} = \frac{M_{max} c}{I}$$

M_{max} = Bending moment, c = distance of N.A. from tension/ compression face, I = moment of inertia

Now, for one-point load,

$$\delta = \frac{PL^3}{48EI}$$

$$\rightarrow E = \frac{\left(\frac{P}{\delta}\right) L^3}{48I} = \frac{\left(\frac{\Delta P}{\Delta \delta}\right) L^3}{48I};$$

Take $-\Delta P/\Delta \delta$ from the load-deflection graph from the tangent at maximum slope.

Now, for two-point load,

$$\delta = \frac{23PL^3}{1296EI}$$

$$\rightarrow E = \frac{23 \left(\frac{P}{\delta}\right) L^3}{1296I} = \frac{23 \left(\frac{\Delta P}{\Delta \delta}\right) L^3}{1296I};$$

Take $-\Delta P/\Delta \delta$ from the load-deflection graph from the tangent at maximum slope.

9. FAILURE PATTERN

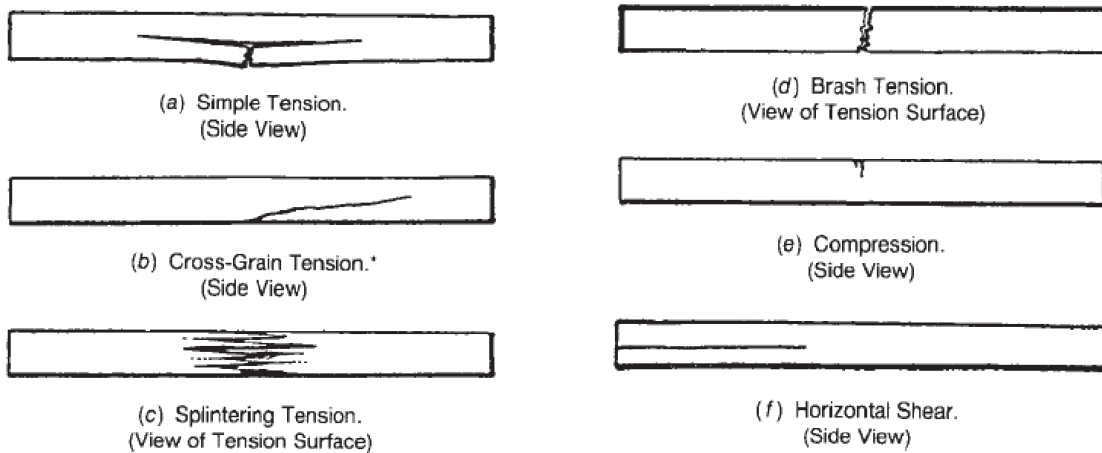


Figure 3: Failure patterns of timber under bending (image from ASTM D 143)

10. GRAPHS

1. Load vs. deflection curve of beam with higher I.
2. Load vs. deflection curve of beam with lower I.
3. Combined Load vs. deflection curve of beam with higher and lower I.
4. Draw SFD and BMD for the beams.

11. RESULT

(Students will fill up this section with their individual outcome/result about the test.)

	Case 1 (Higher I)	Case 2 (Lower I)
P (N)		
δ (mm)		
V_{\max} (N)		
E (MPa)		
M_{\max} (N-mm)		
$\sigma_{\max} = M_{\max}c/I$ (MPa)		
$\Delta P/\Delta \delta$		
Resilience, U		
Failure Pattern		
Failure Location		

12. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.) Point out the discussion

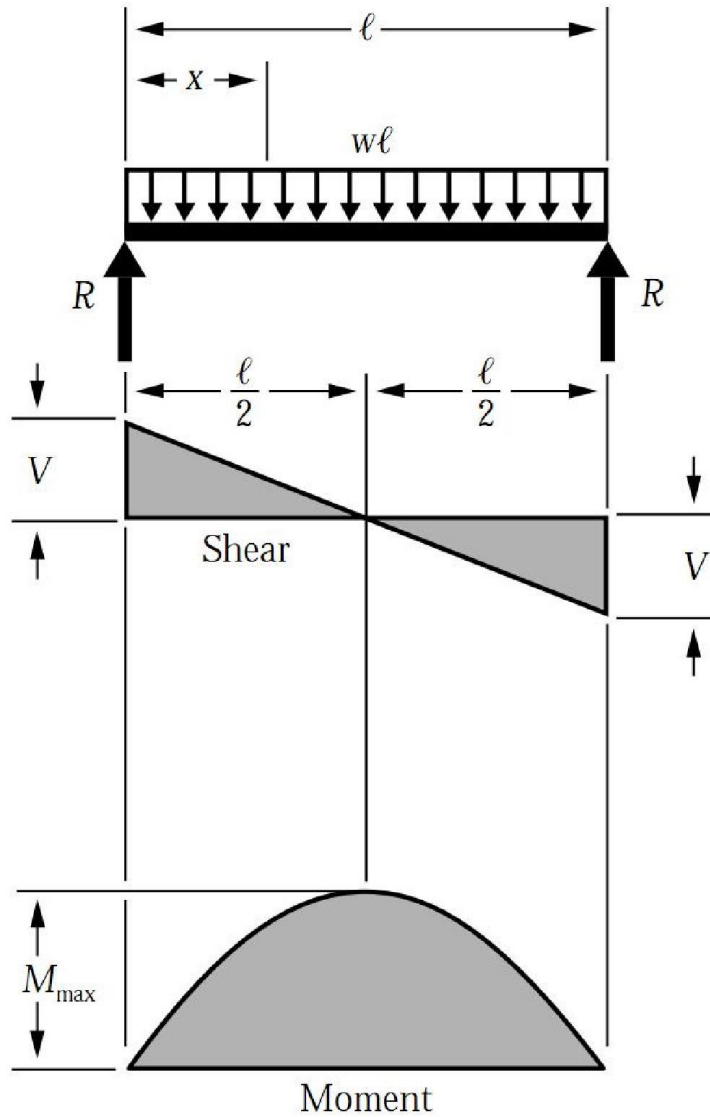
- 1.
- 2.
3.

13. ASSIGNMENT

1. What is the central deflection of a simply supported beam under concentrated load?
2. Why beam are provided with depth larger than width?
3. What is strain controlled test? Describe the advantages of strain-controlled test over stress-controlled test.
4. Your Laboratory test setup was one-point loading setup. Compare one-point loading setup with two-point loading setup. Which loading setup would you adopt if given choice and explain why?
5. Describe the Universal Testing Machine (UTM) being operated at your laboratory; also describe its working procedure.
6. Explain why timber being stronger in tension than compression, always fails at the tension face?

EXPERIMENT NO.: 6

BASICS OF SHEAR FORCE AND BENDING MOMENT



Experiment No.: 6

Basics of Shear Force and Bending Moment

1. OBJECTIVE

To draw shear force and bending moment diagram for a simply supported beam under point and distributed loads.

2. SIGNIFICANCE

This experiment provides fundamental knowledge on Shear Force and Bending Moment calculation, SFD and BMD construction etc.

3. THEORY

Beam: It is a structural member on which the load acts perpendicular to axis. It is that whenever a horizontal beam is loaded with vertical loads, sometimes it bends due to the action of the loads. The amounts by which a beam bends, depends upon the amount and types of loads, length of beam, elasticity of the beam and the type of beam. In general beams are classified as under:

- i. Cantilever beam:** - It is a beam whose one end is fixed to a rigid support and the other end is free to move.
- ii. Simply supported beam:** - A beam supported or resting freely on the walls or columns at its both ends is known as simply supported beam.
- iii. Rigidly fixed or built-in beam:** - A beam whose both the ends are rigidly fixed or built in walls is called a fixed beam.
- iv. Continuous beam:** - A beam support having more than two supports is known as a continuous beam.

Types of loading

- i. Concentrated or point load:** - load acting at a point on a beam is known as concentrated or a point load.

ii. Uniformly distributed load: - A load, which is spread over a beam in such a manner that each unit length is loaded to the same extent.

iii. Uniformly varying load: - A load, which is spread over a beam, in such a manner that its extent varies uniformly on each unit length.

Shear force: The shear force at the cross-section of a beam may be defined as the unbalanced forces acted parallel of the plane to the right or left of the section.

Bending moment: The bending moment at the cross-section of a beam may be defined as the algebraic sum of the moment of forces, to the section.

4. IMPORTANT NOTES

1. If loading is uniformly distributed, then shear force diagram will be a curve of first degree and B.M. diagram will be a curve of second degree.
2. If the loading is point load, then its corresponding S.F. diagram would be a curve of zero degree and the B.M. diagram would be a curve of first degree.
3. If the loading is uniformly varying load its S.F. diagram would be curve of second degree and BMD will be of third degree.
4. Bending moment is maximum where shear force is zero.
5. The first step is to calculate the reactions at the support, and then we proceed in usual manner.
6. Point of contra flexure is the point where BM changes its sign.
7. B.M. at the support is zero for simply supported beam and at pinned support.

5. ASSIGNMENT

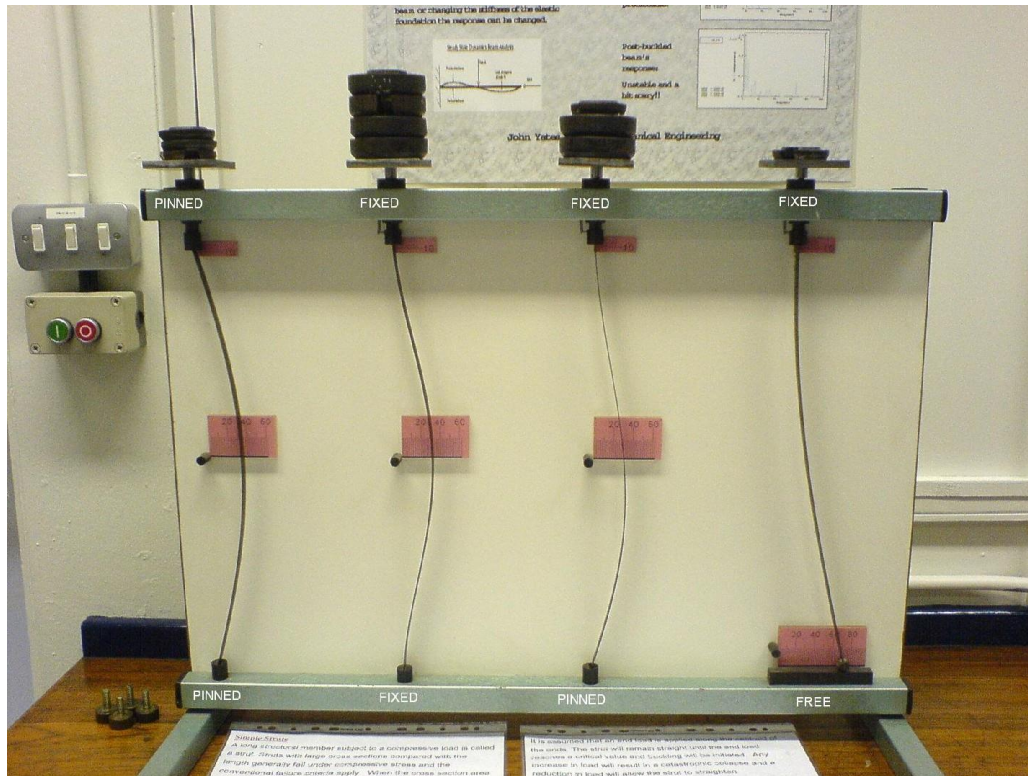
1. What is the point of contra-flexure?
2. What are sagging & hogging moments?
3. Define a beam, a cantilever beam, a fixed beam, and an overhang beam.
4. Define S.F. & B.M.
5. When bending moment will be maximum?
6. Solve the following problems:
 - i. A simply supported beam 4m. long is subjected to two-point loads of 2kN & 4kN each at a distance of 1.5m and 3m from the left end. Draw the S.F & B.M diagram for the beam.
 - ii. Draw the S.F & B.M diagram for the beam of Example-1 for uniformly distributed load of 0.5kN/m throughout the span.



- iii. Draw the S.F & B.M diagram for the test setup of wooden beam bending test, use all necessary data from the said test.
- iv. All the problems discussed in the class.

EXPERIMENT NO.: 7

TEST OF SLENDER COLUMN



Experiment No.: 7

Test of Slender Column

1. OBJECTIVE

- To determine Euler load /critical load /buckling load of slender columns through experiment.
- To determine Euler crippling load /critical load /buckling load of slender columns theoretically from Euler formula for slender columns.
- To compare the experimental critical load and theoretical critical load.
- To draw column strength curves (both experimental plot & theoretical plot).

2. APPARATUS

Digital slide calipers, Column testing apparatus, Steel scale, electronic balance, support system and computer.

3. SIGNIFICANCE

This experiment provides fundamental knowledge on slender column and its behaviour, test procedure, testing machine, Euler's critical load for pinned and fixed ended columns etc.

4. SPECIMENS

Steel column.

5. THEORY

The term column is frequently used to describe a vertical member, whereas the word strut is occasionally used in regard to inclined bars. The vertical members of a building frame or any structural system which carry mainly compressive loads are called as columns. The compression member of a truss is called strut. The common feature of the columns and struts is such that they are subjected to compressive forces. A compression member is generally considered to be column when its unsupported length is more than 10 times its least lateral dimension.

The design of columns presents a problem; some of the reasons are:

1. There is no definite demarcation point between a column that is relatively short and a compression block that is relatively tall.
2. Although a column is, for practical purpose, a straight, homogeneous compression member, it is never made theoretically perfect. Any deviation in its alignment, lack of homogeneity, or presence of internal stresses will act as a source of bending and possible ultimate collapse.
3. The inability to apply perfectly axial load causes slight eccentricities to be imposed upon the column that may contribute markedly on its bending tendency and possible ultimate collapse.
4. The character and magnitude of the end restraint of ordinary columns may vary greatly.

6. CLASSIFICATION OF COLUMNS

The classification of structural column may be classified in three categories; they are as follows:

- (a) Long column
- (b) Intermediate column
- (c) Short column

The distinction between these three is determined by their failure behavior. Long columns fail by buckling or excessive lateral bending; intermediate columns, by a combination of crushing and buckling; Short compression blocks, by crushing/plastic squashing.

Ideal Column & Real Column: Columns that are perfectly straight, loaded exactly through their centroid, free of any residual stress, and manufactured from a perfectly isotropic material are termed as ideal columns. Such columns do not exist. However, ideal column theory contributes greatly to our knowledge of column behavior, as will see.

Because steel column is manufactured by man, it contains certain human flaws. Residual stresses due cooling after rolling, straightening, welding & initial crookedness are always present. Perfectly straight columns do not exist and initial imperfections are to be expected. Further, axial loads are rarely axial. Accidental eccentricity is inevitable. Finally, no construction material is perfectly isotropic. This type of column is termed as a real column. They truly exist.

Type of Failure of a Column: Failure of a column occurs by buckling, i.e. by lateral deflection of the bar. In compression it is to be noted that failure of a short compression member occurs by yielding of the material. Buckling, and hence failure, of a column may occur even though the maximum stress in the bar is less than the yield point of the material.

Crushing failure/Compression failure of column	Buckling failure of column
(1) Occurs in short column (slenderness ratio is small)	(1) Occurs in long slender column (slenderness ratio is high)
(2) Failure occurs due to yielding of material	(2) Failure occurs due to excessive lateral displacement
(3) It crushes/ yields/squashes before buckling (i.e. crushing stress/ yield stress > buckling stress)	(3) It buckles before crushing / yielding (i.e. buckling Stress > crushing stress/ yield stress)
(4) Formula for critical load (direct compression): $P_{cr} = F \times A$	(4) Formula for critical load (direct compression): $P_{cr} = \frac{\pi^2 EI}{(KL)^2}$
(5) In crushing / yielding, normal compressive stress developed	(5) In buckling, bending stress developed

7. EULER'S THEORY FOR AXIALLY LOADED ELASTIC LONG COLUMN

The type of failure of columns due to excessive displacement is called buckling failure. The buckling load depends upon the slenderness ratio of the column, length of the column and also on the end conditions. Leonard Euler (1707-1783), a Swiss mathematician was first to derive theoretical expression for buckling load.

The assumptions made in this theory are:

- The material of the column is homogeneous, isotropic and elastic; and thus obeys Hooke's law.
- The cross-section of the column is uniform throughout its length.
- The column is initially straight and is loaded axially.
- The column fails by buckling alone.
- The self-weight of the column is negligible.
- The formula is applicable for only long slender column (the length of the column is very large as compared its cross-sectional dimension) (i.e. it is not applicable for short and intermediate column).
- The shortening of the column, due to direct compression (being very small), is neglected.








Buckled shape of column is shown by dashed line	(a)	(b)	(c)	(d)	(e)	(f)
						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.0	1.2	2.0	2.0
End condition code		Rotation fixed Rotation free	Rotation fixed Rotation fixed	Rotation fixed Rotation free	Translation fixed Translation fixed	Translation fixed Translation free

Figure 1: Effective length factor, K for different support condition

8. LIMITATIONS OF THE EULER FORMULA

Limitation (1)

Euler's formula is applicable for concentrically (i.e. axially) loaded column, not applicable for eccentrically loaded column.

Limitation (2)

Euler's formula is applicable for long slender column only not for short column because a long column buckles before yielding (i.e. crushing) and short column crush / yields before buckling.

Limitation (3)

Euler's formula is related to stiffness (i.e. modulus of elasticity), not related to strength: Euler's formula shows that the critical load which causes buckling depends not upon the strength of the material but only upon its dimensions and modulus of elasticity.

Limitation (4)

Euler's formula is applicable upto elastic limit only, hence there is limiting value of slenderness ratio, i.e. limiting value of critical stress, limiting value of buckling load.

Limitation (5)

Euler's formula determines critical loads, not working loads. It is therefore necessary to divide the right side of Euler's formula by a suitable factor of safety – usually 2 to 3, depending on the material – in order to obtain practical allowable value.

9. PROCEDURE

- i) At first, measure the geometric dimensions of the column.
- ii) Then place the column in the testing apparatus between the end supports.
- iii) Apply the compressive load axially.
- iv) Record the critical buckling load from the display.
- v) Perform the test for all support conditions (as seen in Fig.1)

10. SAMPLE CALCULATIONS

Calculate slenderness ratio, critical loads, and critical stresses for different support conditions.

11. GRAPH

1. Combined graphs of experimental P_{cr} vs. K and theoretical P_{cr} vs. K .
2. Combined graphs of experimental P_{cr} vs. KL and theoretical P_{cr} vs. KL .
3. Combined graphs of experimental critical stress σ_{cr} vs. slenderness ratio, KL/r and theoretical critical stress σ_{cr} vs. slenderness ratio, KL/r .

12. RESULT

Support Condition	Effective Length Factor, K	Length, L (mm)	Radius of gyration, r (mm)	Slenderness ratio, KL/r	Analytical Critical Load, P_{cr} (N)	Experimental Critical Load, P_{cr} (N)	Critical Stress, σ_{cr} (Analyt.)	Critical Stress, σ_{cr} (Exp.)
F-F	0.5							
H-F	0.7							
H-H	1.0							
H-Free	2							
F-Free	2							

*H= Hinge, F= Fixed.

13. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.)

Point out the discussion

- 1.
- 2.
3.

14. ASSIGNMENT

1. Define the Euler critical buckling load.
2. Derive the equation of Euler critical load for pin ended column.

EXPERIMENT NO.: 8

DIRECT SHEAR TEST OF METAL SPECIMENS



Experiment No.: 8

Direct Shear Test of Metal Specimens

1. OBJECTIVE

- To make a shear of metal specimens approximating the conditions of shear existing in rivets, pins, and bolts
- To determine the strength in single and double shear
- To observe the shape and texture of the fractured surface.

2. APPARATUS AND MACHINE

UTM, shear tool, Slide calipers, stop watch and computer.

3. SIGNIFICANCE

This experiment provides fundamental knowledge on direct shear behaviour of materials, test procedure, universal testing machine and its working principal, specimens, failure patterns etc.

4. SPECIMENS

Steel screws.

5. THEORY

Shearing stress is one that acts parallel or tangential to stressed surface. It is different from normal stress that acts perpendicular to the stressed surface, e.g. tension, compression or bending stresses. It resists the tendency of a part of the body on one side of the plane to slide against the other side of the same plane.

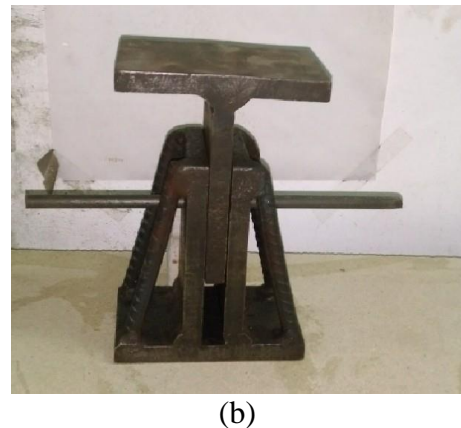
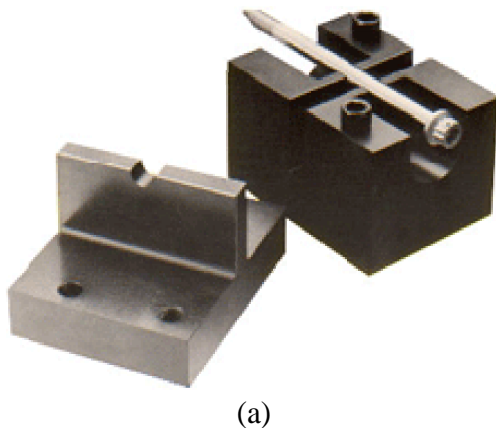


Figure 1: (a) Johnson Shear Tool, (b) Customized Shear Tool

The direct shear test (also called transverse shear test) gives an approximation to the correct values of shearing strength. This test is usually done in a Johnson type shear (Figure 1) of shear tool by clamping a portion of a material so that bending stress are minimized across the plane along which the shearing load is applied. Because of inevitable bending and friction between part of tool, it gives an indication of the shearing resistance of materials. The direct shear test has further limitation for the determination of elastic strength or of the modulus of rigidity or shear rigidity, because of difficulty to measure shearing strain.

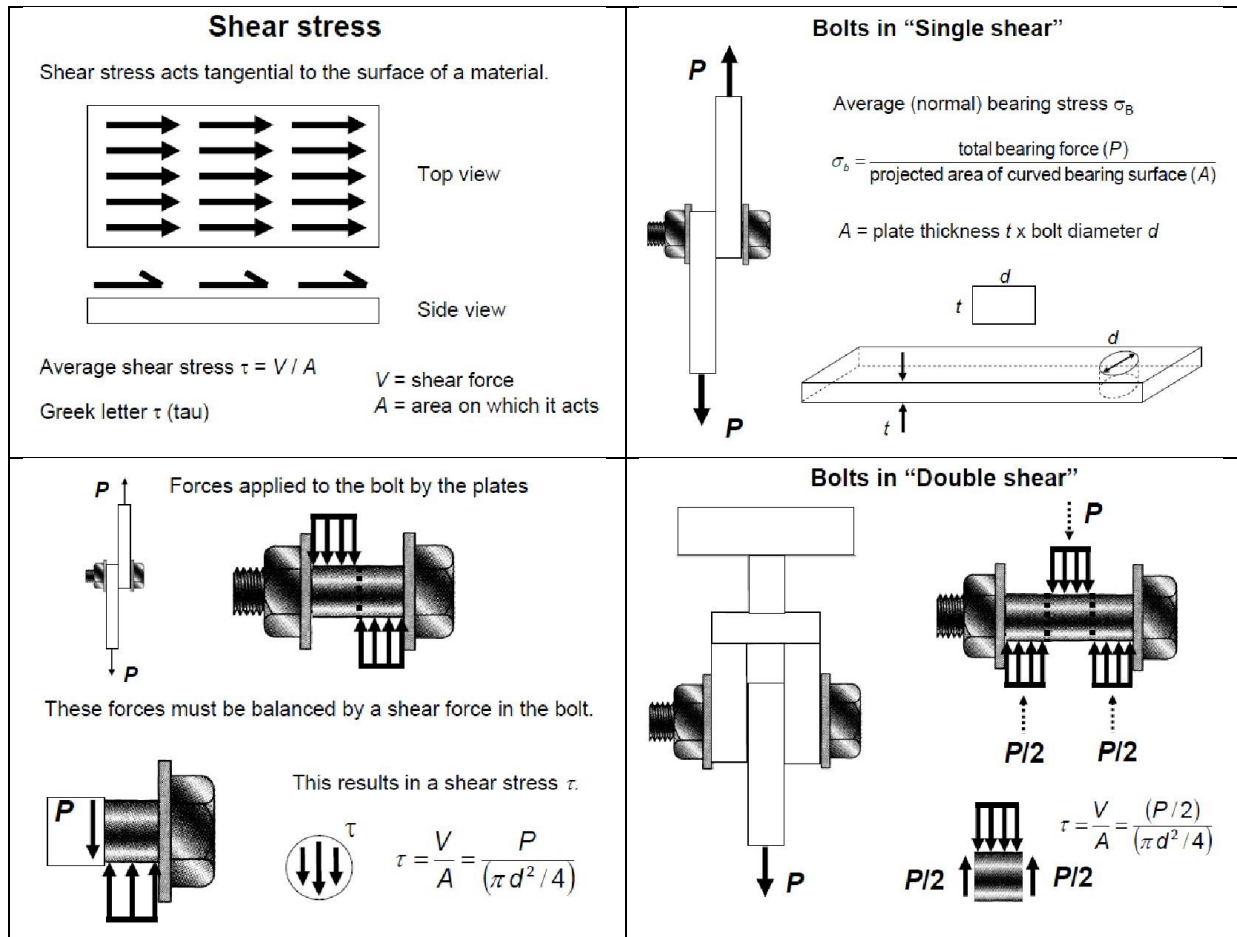


Figure 2: Shear force acted upon the specimens in single and double shear

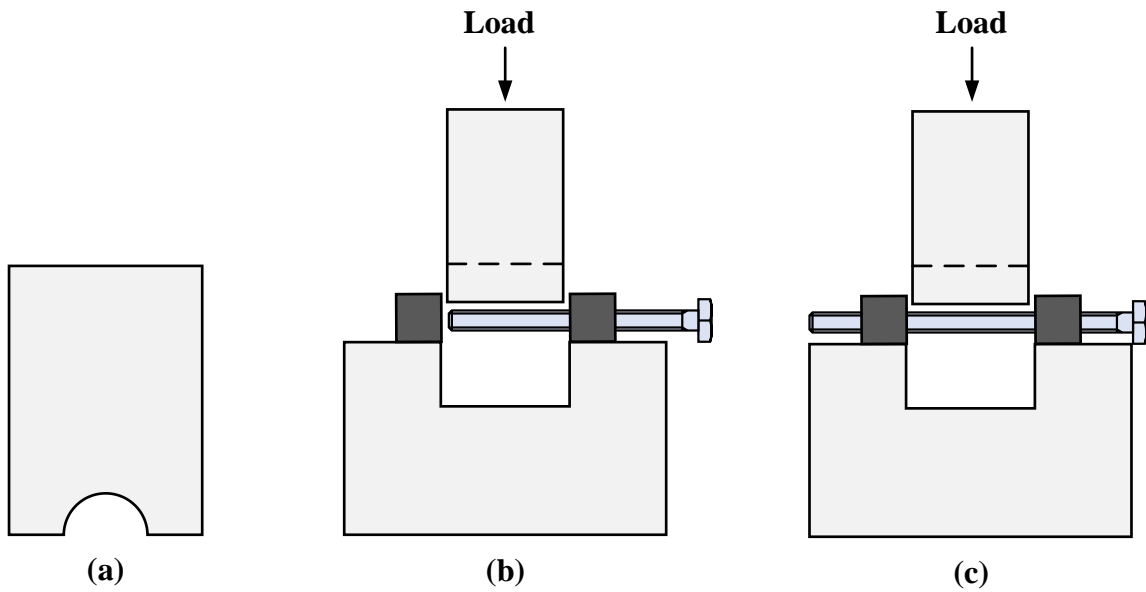


Figure 3: Schematic representation of Johnson shear tool, (a) Shear cutter, (b) Single shear and (c) Double shear.

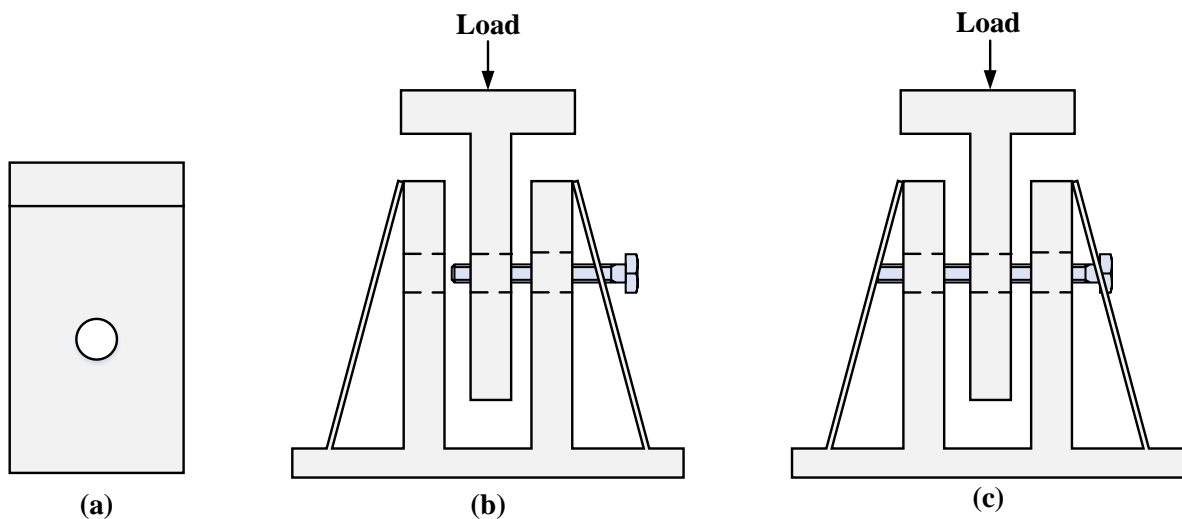


Figure 4: Schematic representation of modified Johnson shear tool, (a) Shear cutter, (b) Single shear and (c) Double shear.

6. PROCEDURE

- i) Measure the diameter of the specimen with the slide calipers.
- ii) Fix the specimen in the shear tool such that it is in single shear and apply load until rupture takes place.
- iii) In the same way test the specimen for double shear.

7. SAMPLE CALCULATIONS

Calculate double, unit double and single shear stresses from maximum shear force data.

8. GRAPH

1. Combined Double Shear, Unit Double Shear and Single Shear force vs. displacement graph.

9. RESULT

Type of Shear	Dia (mm)	Shear Area (mm ²)	Maximum force (N)	Maximum Shear stress or Shear strength (MPa)	Failure pattern	Fracture surface
Double Shear						
Unit Double Shear						
Single Shear						

10. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.)

Point out the discussion

- 1.
- 2.
3.

11. ASSIGNMENT

1. Why single shear strength is greater than unit double shear?
2. How we can measure shear rigidity?

EXPERIMENT NO.: 9

TEST OF HELICAL SPRING



Experiment No.: 9

Test of Helical Spring

1. OBJECTIVE

- To observe the load deflection relationship (stiffness) of the helical spring
- To determine some of its physical properties.

2. APPARATUS

Universal Testing Machine (UTM), digital slide calipers, steel scale and computer.

3. SIGNIFICANCE

This experiment will provide fundamental knowledge on behaviour of helical spring, test procedure, universal testing machine and its working principal, type of spring tested etc.

4. SPECIMENS

Closely-coiled helical spring.



Figure 1: Different types of spring

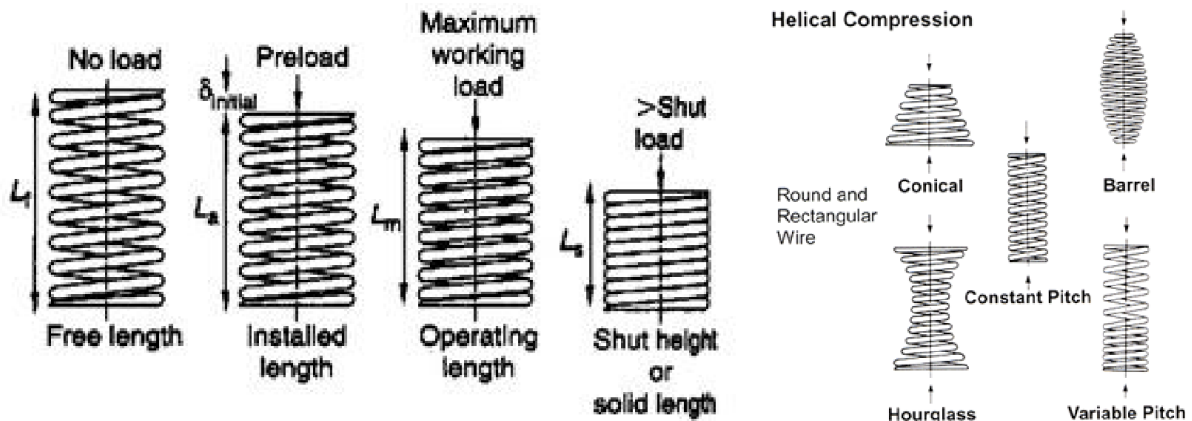


Figure 2: Various lengths associated with a spring.

5. THEORY

A spring is a resilient member capable of providing large elastic deformation, and basically defined as an elastic body whose function is to distort when loaded and to recover its original shape when the load is removed. Mechanical springs are used in machines to exert force, to provide flexibility and to store or absorb energy.

Helical springs (Figure 1, 2, 3) of round or square wire that are cylindrical or conical in shape and are made to resist tensile, compressive, or torsional loads.

6. FEW DEFINITIONS

Free length: Length of spring at unloaded condition

Solid/Block height: Length of compression spring while loading make all coils touch adjacent coil.

Block force: Force at which spring is detected being block.

Active coli: Those coils which are free to deflect

Total no. of coil: Number of active coils plus coils forming the ends.

Pitch: Centre to centre distance of coil/wire.

Mean coil dia: outer dia – one wire/coil dia

Slenderness ratio: Ratio of spring length to mean coil dia



(a)



(c)



(b)



(d)

Figure 3: (a) close coil helical spring, (b) open coil helical spring, (c) bending spring (leaf spring) (d) plate/flat spiral spring

7. ASSUMPTION OF SPRING

Any one coil of a closely coiled helical spring is assumed to lie in the plane which is nearly perpendicular to the axis of the spring. Thus a section taken perpendicular to the spring rod may be taken to be vertical.

8. TYPES OF SPRING

Depending on arrangement of coils

1. Close coiled helical spring

In a close-coiled helical spring, the coils are close together. The angle of helix is small and the spring wire is subjected predominantly to torsional shear stress.

2. Open coiled helical spring

In an open-coiled helical spring, the coils are not close together hence the angle of helix cannot be considered as small. The spring wire is subjected predominantly to bending stress.

3. Plate/flat springs

Flat spiral springs, which release slowly over a period of time, are used to store energy in clock.

4. Close-coiled conical spiral spring

The spring is conical in shape.

Depending on the load to be carried

1. Bending spring

A bending spring is the one which is subjected to a bending moment only. The resilience of such a spring is mainly due to bending. It is of two categories, 1. Semi-elliptic 2. Quarter-elliptic

2. Torsion spring

A torsion spring is the one which is subjected to a twisting moment. The resilience of such a spring is mainly due to torsion.

Depending on the Stiffness of spring

Stiffness of a spring can be defined as the load required to produce unit axial deformation:

$$K = \frac{P}{\delta}$$

Figure 4 demonstrates three types of curves between load (P) and deflection (δ) corresponding to three types of springs,

1. Linear spring

A linear spring is one in which deflection is proportional to the applied load.

2. Hard spring

A hard spring is one in which the rate of deflection decreases with the increase in the load.

3. Soft spring

A soft spring is one in which the rate of deflection increases with the increase in the load.

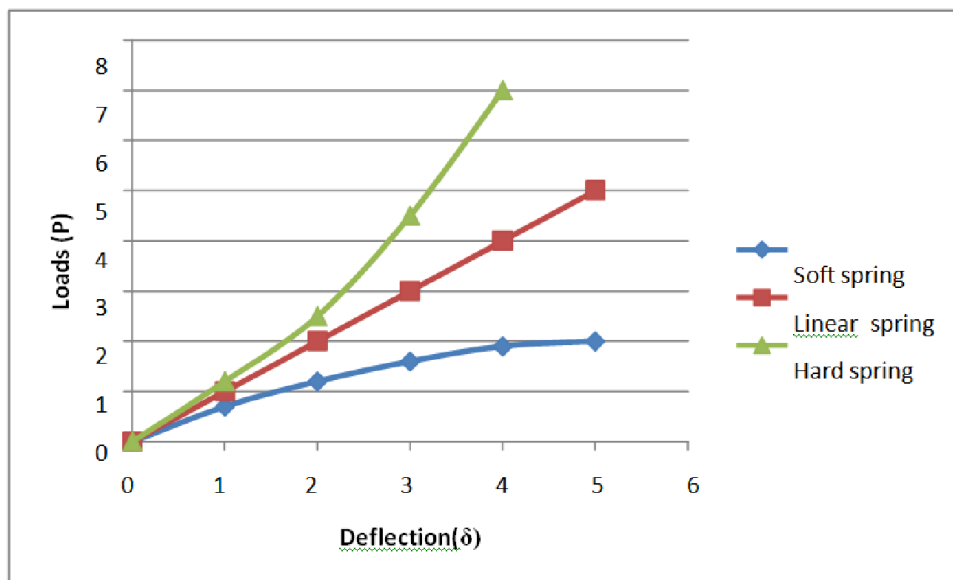


Figure 4: Load-deflection curve for three types of spring

Ordinary helical springs are linear spring. Hard spring and soft springs are the two categories of non-linear springs.

9. RESILIENCE OF THE SPRING/ AND STRAIN ENERGY (U)

Resilience of the spring is the energy stored during extension/compression. It is calculated as under the area of the load-deflection (P- δ) curve which is actually work done by the applied force (Figure 5).

$$\text{Resilience of spring, } U = \frac{1}{2} P\delta = \frac{P^2}{2K}$$

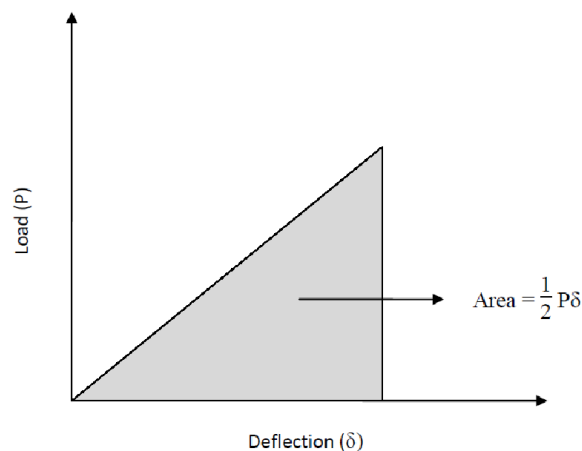


Figure 5: Strain energy of the spring

10. STRESSES IN THE SPRING

When an axial load P is applied to helical spring stresses on cross section of wire may come from

1. Direct shear
2. Torsional shear due to twisting moment
3. Bending moment

The stresses due to direct shear and bending are very small and may be neglected in comparison to torsion. So closely coiled helical spring is a torsion spring.

Shear Stresses

Consider a helical spring of circular cross section is loaded with a axial force P (Figure 6). One important assumption need to be made here is that any one coil lies nearly in a plane perpendicular to the axis of the helix (spring).

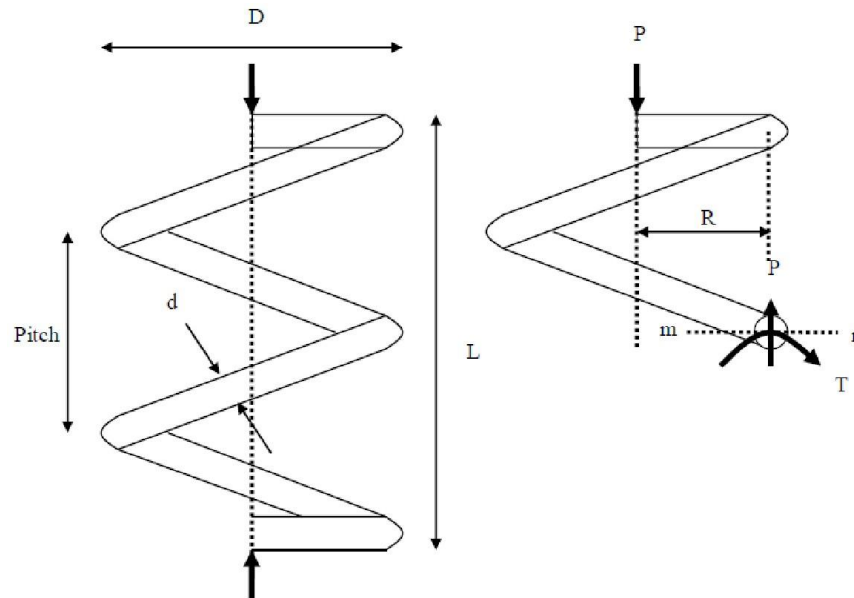


Figure 6: Closely-coiled helical spring

Considering the equilibrium of the upper portion of the spring bounded by an axial section $m-n$ (parallel to the plane contain spring axis) it can be concluded from the equations of statics that the stresses over the section $m-n$ of the coil reduce to a shearing force P through the center of cross section and a torsion acting in a clockwise direction in the plane of the cross section of magnitude, $T = PR$

The torsion twists the coil which develops shear stress.

$$\text{Direct shear stress, } \tau_{DS} = \frac{P}{A} = \frac{P}{\pi r^2}$$

$$\text{Torsional shear stress, } \tau_{TS} = \frac{Tr}{J} = \frac{PRr}{\left(\frac{\pi r^4}{2}\right)}$$

$$\begin{aligned} \text{Maximum shear stress, } \tau_{max} &= \tau_{DS} + \tau_{TS} \\ &= \frac{P}{\pi r^2} + \frac{PRr}{\left(\frac{\pi r^4}{2}\right)} \\ &= \frac{P}{A} \left(1 + \frac{2R}{r}\right) \end{aligned}$$

***Torsional shear stress varies over the section and maximum at the outer surface.

where, P= Axial force applied on the spring

R= mean radius of the coil (i.e. distance from the axis of the spring to the centroid of the rod's cross section

D = outer diameter of spring

d = diameter of spring's wire or rod

r = d/2= radius of spring's wire or rod

N = Number of turns of the spring

L = Total length of spring's rod=2πrN

J = Polar moment of inertia of the spring's rod

12. DEFLECTION

An equation for the axial deflection of a helical spring in terms of the axial load, spring dimensions, and materials constant may be conveniently determined by equating the work required to deflect the spring to the strain energy in the twisted wire.

$$\text{Deflection, } \delta = \frac{PR^2L}{GJ} = \frac{PR^2(N \times 2\pi r)}{GJ} = \frac{64PR^3N}{Gd^4}$$

$$\text{Modulus of Rigidity, } G = \frac{64PR^3N}{\delta d^4} = \frac{64KR^3N}{d^4}$$

13. DATA

Spring No.	Spring type	No. of Active coil	Radius of wire, r (mm)	Dia. of wire, r (mm)	Outer dia., D (mm)
1	Closely coiled helical spring	8	10.025	20.05	120.23

14. PROCEDURE

- i) Measure the diameter of the spring wire at several locations to find the mean diameter.
- ii) Record the number of turn of the spring as N.
- iii) Measure the outer and inner diameter of the helical spring and hence find the mean radius of the spring.
- iv) Place the spring in proper position in UTM machine.

- v) Apply load at a certain interval and record the corresponding displacement from the load cell display.
- vi) Continue applying load upto 3500N.
- vii) After reaching 3500N load, unload the spring and then record the displacement value at the same interval.

15. SAMPLE CALCULATION

Area of the wire, $A = \pi r^2$

Maximum shear stress, $\tau_{max} = \frac{P}{A} \left(1 + \frac{2R}{r} \right)$

% of direct shear stress, $\tau_{max} = \frac{\tau_{DS}}{\tau_{max}} \times 100$

% of torsional shear stress, $\tau_{max} = \frac{\tau_{TS}}{\tau_{max}} \times 100$

Deflection, $\delta = \frac{64PR^3N}{Gd^4}$

Modulus of Rigidity, $G = \frac{64PR^3N}{\delta d^4}$

Spring stiffness, $K = \frac{Gd^4}{64R^3N}$

16. GRAPHS

- 1. Load vs. displacement graph for spring.

17. RESULT

Spring No.	A (mm ²)	P (N)	σ_{DS} (N/mm ²)	σ_{TS} (N/mm ²)	σ_{max} (N/mm ²)	ϕ (mm)	K (N/mm)	U (N-mm)	G (N/mm ²)	Type of spring
1										

18. DISCUSSION

(Discuss on the results found, graphs, and failure patterns and also compare the results found, graphs and failure patterns.) Point out the discussion

- 1.
- 2.
- 3.

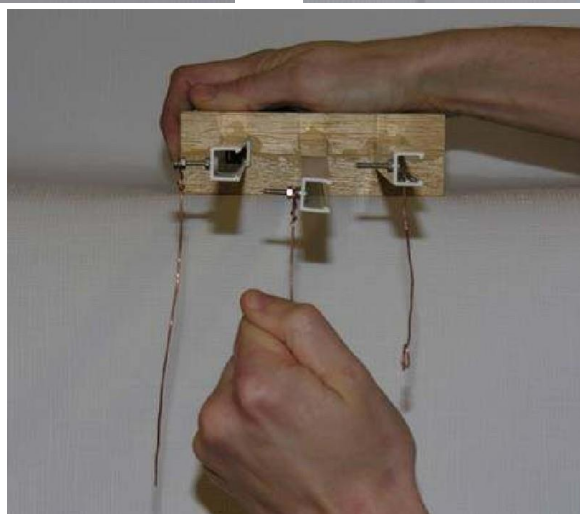
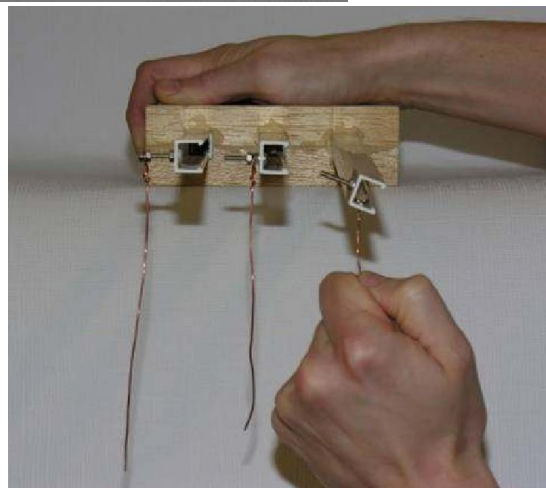
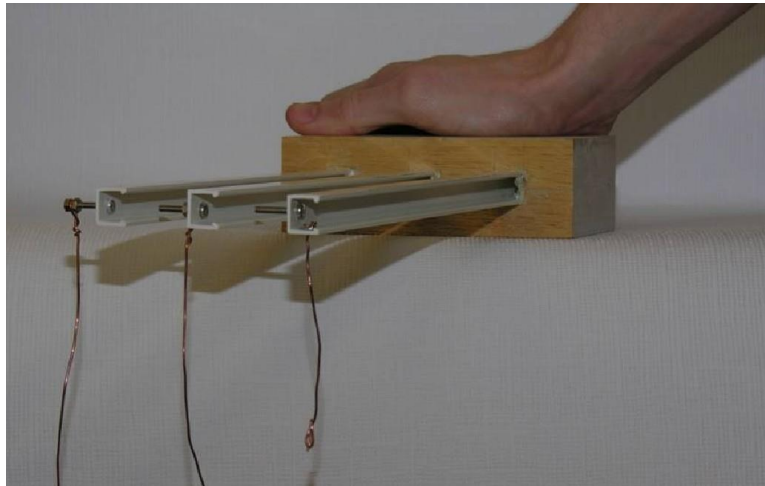


19. ASSIGNMENT

1. Define stiffness, modulus of rigidity, shear stress.
2. Classify the spring from the shape of the P- δ curve.
3. Give some practical applications of helical spring.

EXPERIMENT NO.: 10

BASICS OF SHEAR CENTRE



Experiment No.: 10

Basics of Shear Centre

1. SHEAR CENTRE

The point where a shear force can act without producing any twist in the section. In general, not the centroid, but a point through which a force transverse to the axis of a beam section can act and not cause any twisting of the beam section.

At shear center, resultant of internal forces passes. On symmetrical sections, shear center is the center of gravity of that section.

If external force is applied along the unsymmetrical axis that passes through the centroid of the section, then in addition to bending, twisting is also produced. To avoid twisting, and cause only bending, it is necessary for the forces to act through the particular point, which may not coincide with the centroid. The position of this point is a function only of the geometry of the beam section. It is termed as shear center.

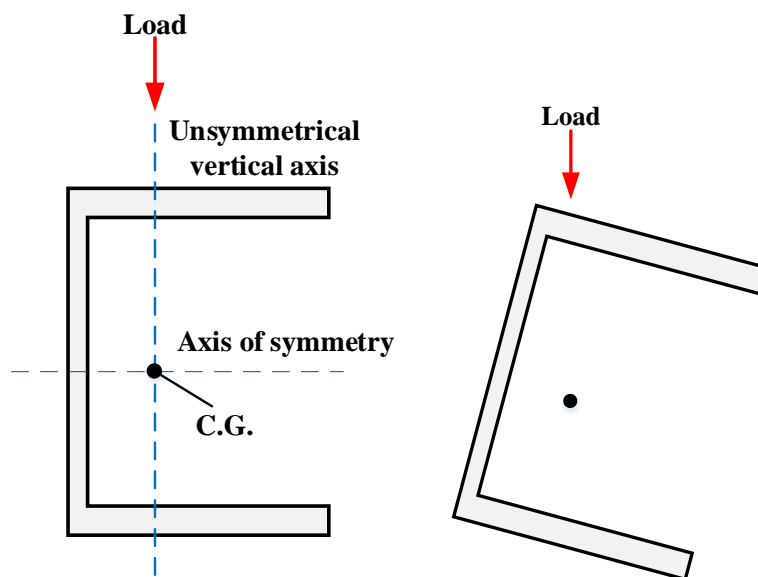


Figure 1: Twisting of unsymmetrical beam section induced by shear stresses

The shear center is always located on the axis of symmetry; therefore, if a member has two axes of symmetry, the shear center will be the intersection of the two axes. Channels have a shear center that is not located on the member

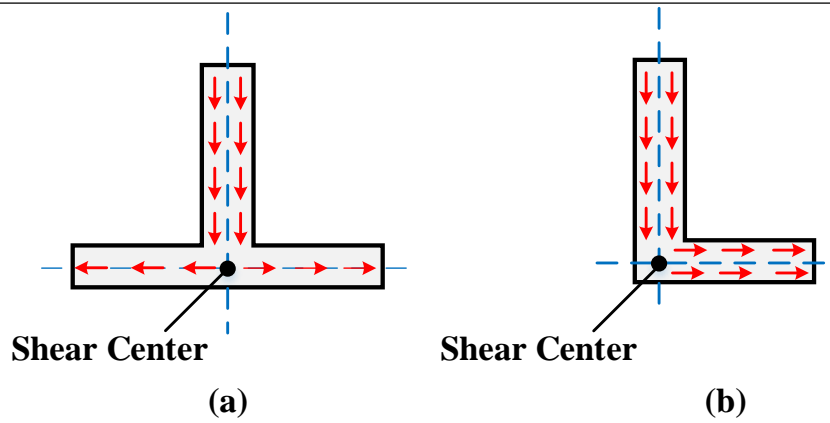


Figure 2: (a) and (b) Shear Centers on different sections

2. LOCATION OF SHEAR CENTRE IN CHANNEL SECTION

Consider a channel section as shown in figure 2. Now we shall find the position of the plane through which the vertical loads must act so as to produce simple bending, with the x-axis as neutral axis.

It may be assumed that the vertical shearing force, F at the section is taken up by the web alone. In the flanges, there will be horizontal shear stresses which will be denoted by q .

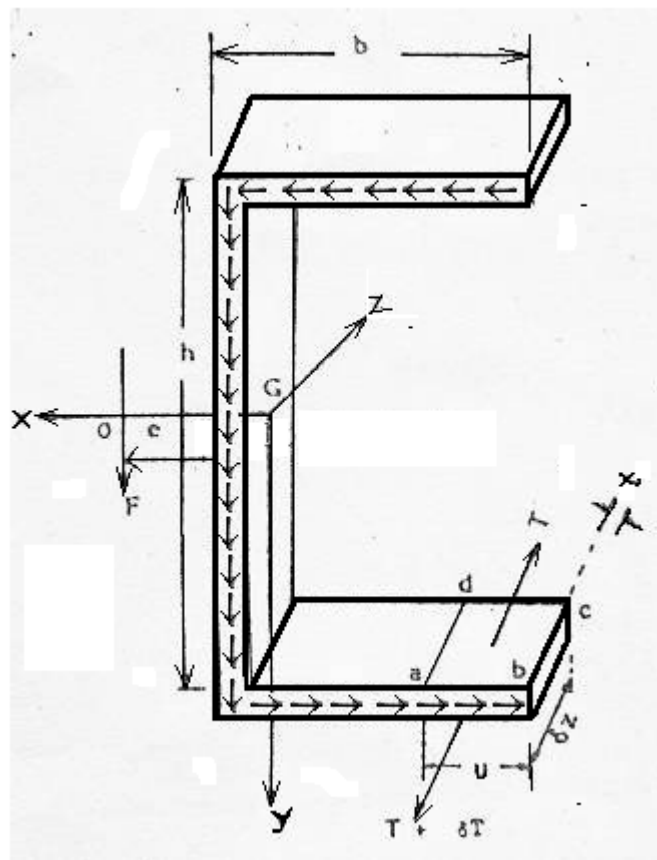


Figure 2: Shear Centre in Channel Section

Let us consider an element 'abcd' cut from the lower flange by two adjacent cross-

sections ∂z apart and by a vertical plane parallel to the web and at distance 'u' (which is variable) from the free end of the lower flange. The difference in tensile forces T and $T + \partial T$ must be equal to the shear force on the side 'ad' of the element. Assuming a uniform distribution of shear stress (since the thickness is small) over the thickness, we have,

$$qt \cdot \partial z = \partial T = \frac{\partial M}{I_x} \int y \cdot dA$$

The integration being carried out over the portion 'ab' of the flange.

The stress per unit length of the center line of the section,

$$qt = \frac{\partial M}{\partial z} \cdot \frac{I}{I_x} \int y \cdot dA$$

$$\therefore q = \frac{F}{t \cdot I_x} \int y \cdot dA = \frac{F \times u \times t \times \left(\frac{h}{2}\right)}{t \cdot I_x} = \frac{Fuh}{2I_x}$$

Therefore, it is seen that q is proportional to u.

The maximum value of

$$q = \frac{Fbh}{2I_x}$$

At the junction of the flange and web, the distribution of the shear stress is complicated, so we may assume that the equation

$$q = \frac{Fuh}{2I_x}$$

holds good for $u = 0$ and $u = b$.

$$\text{The average shear stress} = \frac{Fbh}{4I_x}$$

$$\text{The longitudinal shear force in the top and bottom of the flange} = \frac{Fb^2th}{4I}$$

$$\text{The couple about the z-axis of these shear forces} = \frac{Fb^2h^2t}{4I_x}$$

Let us assume that the vertical shear force F acts through point 'o', the shear center at a distance c from O on the center line of the web.

The twisting of this section is avoided if

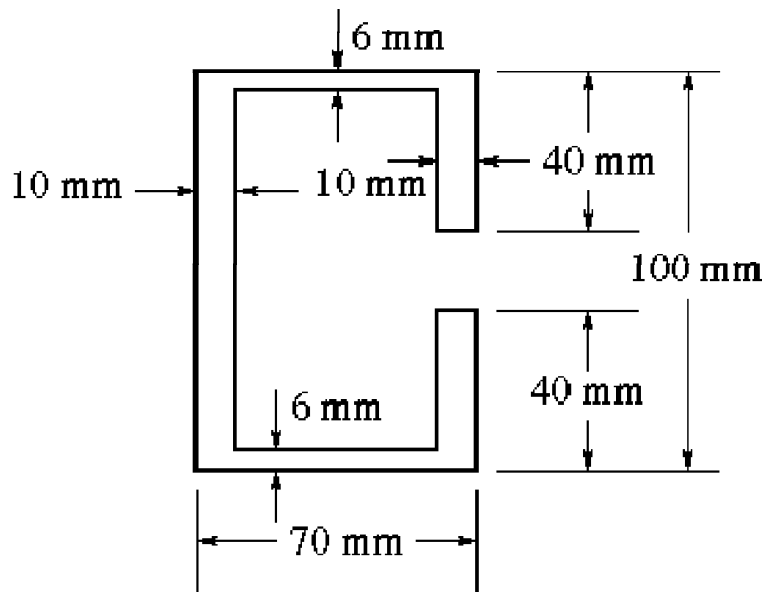
$$F \times c = \frac{Fb^2h^2t}{4I_x}$$

$$c = \frac{b^2h^2t}{4I_x}$$

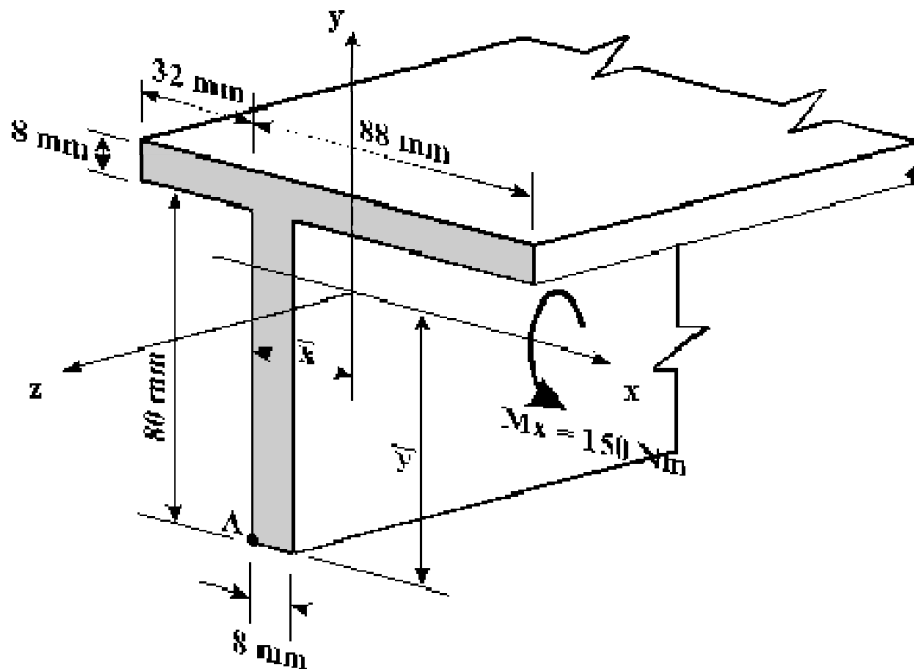
which gives the position of the shear center.

3. ASSIGNMENTS

1. What is the significance of shear centre of a structural component?
2. Determine the Shear centre for the following sections shown in figures below.



(a)



(b)

Figure 5: (a) and (b) typical section for shear centre calculation.

ACKNOWLEDGEMENT

The preparer would like to acknowledge the support of Ms. Zasiah Tafheem, Assistant Professor, Mr. Md. Golam Rashed, Assistant Professor and Mr. Debasish Sen, Assistant Professor, for their contribution in successful completion of the lab manual. The editor also expresses his thanks to Mr. Rasel Reza, Lab in Charge, Strength of Materials Lab, for his contribution in typing of different parts of the manual.

REFERENCES

1. Dr. Ishtiaque Ahmed, Mechanics of Solids Sessional Manual, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET).
2. Md. Ruhul Amin, Mechanics of Solids Sessional Manual, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET).
3. ASTM E8 / E8M-13a, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International, West Conshohocken, PA, 2016, www.astm.org
4. ASTM A370-07a, Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM International, West Conshohocken, PA, 2017, www.astm.org
5. ASTM A48 / A48M, Standard Specification for Gray Iron Castings, ASTM International, West Conshohocken, PA, 2016, www.astm.org
6. ASTM E18-15, Standard Test Methods for Rockwell Hardness of Metallic Materials, ASTM International, West Conshohocken, PA, 2017, www.astm.org
7. ASTM D143-09, Standard Test Methods for Small Clear Specimens of Timber, ASTM International, West Conshohocken, PA, 2009, www.astm.org
8. ASTM E 23-16b, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, ASTM International, West Conshohocken, PA, 2017, www.astm.org

APPENDIX

Lab Report Format

**AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING**



**COURSE NO: CE 212
COURSE TITLE: MECHANICS OF SOLIDS SESSIONAL**

SPRING 2016

NAME:

ROLL: (IN BOLD)

YEAR/SEMESTER:

SECTION: (IN BOLD)

GROUP:

Figure A1: Sample of Cover Page



INDEX

NAME:
ROLL:
GROUP:

EXP. NO.	EXPERIMENT NAME	DATE OF PERF.	DATE OF SUB.	REMARKS	SIGNATURE

Figure A2: Sample of Index Page

<p><u>COURSE NO:</u> CE 212</p> <p><u>COURSE TITLE:</u> MECHANICS OF SOLIDS SESSIONAL</p>	<p><u>SECTION:</u></p> <p><u>GROUP:</u></p>
<p><u>EXPERIMENT NO.:</u></p> <p><u>EXPERIMENT NAME:</u></p>	
<p><u>DATE OF PERFORMANCE:</u></p> <p><u>DATE OF SUBMISSION:</u></p>	<p><u>NAME:</u></p> <p><u>ROLL:</u></p> <p><u>YEAR/SEMESTER:</u></p> <p><u>DEPARTMENT:</u></p>

Figure A3: Sample of Front Page of Experiments