INDIAN INSTITUTE OF TECHNOLOGY
BOMBAY

DEPARTMENT OF AEROSPACE ENGINEERING

Aircraft Structures Laboratory - AE 314

TENSILE TEST - COMPOSITE SPECIMEN

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Contents

1 Aim

1. Understand basic construction and operation of Universal Testing Machine (UTM).
2. Find the Tensile Strength, Strain and Modulus of Elasticity of the given FRP specimen.
3. Understand the ASTM E8/E8M Standard for Tensile test.

2 Equipment Used

- INSTRON 8800 Universal Testing Machine (UTM) WITH 100KN Load Capacity
- Flat rectangular Glass Fiber Reinforced Plastic (GFRP) composite specimens
- Micrometer Screw Gauge
- Vernier Calliper
- 30cm Ruler
- Ink Marker
- Strain Gauge

3 Results

The ability of a material to return to its original shape and size after removal of the deforming force is called Elasticity. The Young's Modulus or the Tensile Modulus of Elasticity is the ratio of the Stress to the Strain for the range of deformations over which the material shows linear elastic behaviour. The Ultimate Tensile Strength is the maximum Stress a material can withstand before fracturing. It is the value of the Stress at the highest point of the Stress vs. Strain curve. The corresponding Strain value is the Ultimate Tensile Strain.

Tensile tests were performed with the UTM using displacement control, by varying the the extension rate. For 5 different extension rates, the Load data in Newtons was stored over a range of extensions in millimeters until the specimen fractures.

Dimensions of the Composite Specimens

Gauge Length	81 mm
Width	12.6 mm
Thickness	2.9 mm

3.1 Load vs. Extension curves for various extension rates

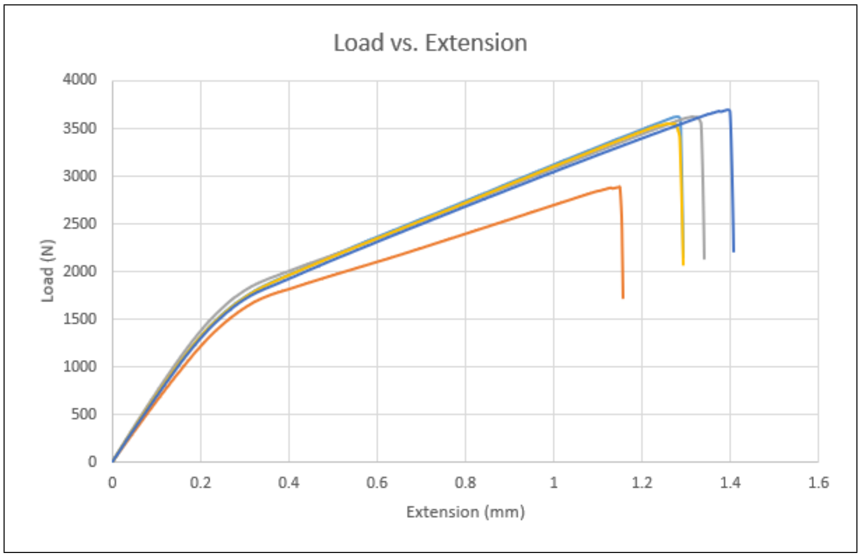


Figure 1: Load vs. Extension

From the Load and extensions data, the Stress and Strain values were determined using the specimen dimensions.

3.2 Stress vs. Strain curves for various extension rates

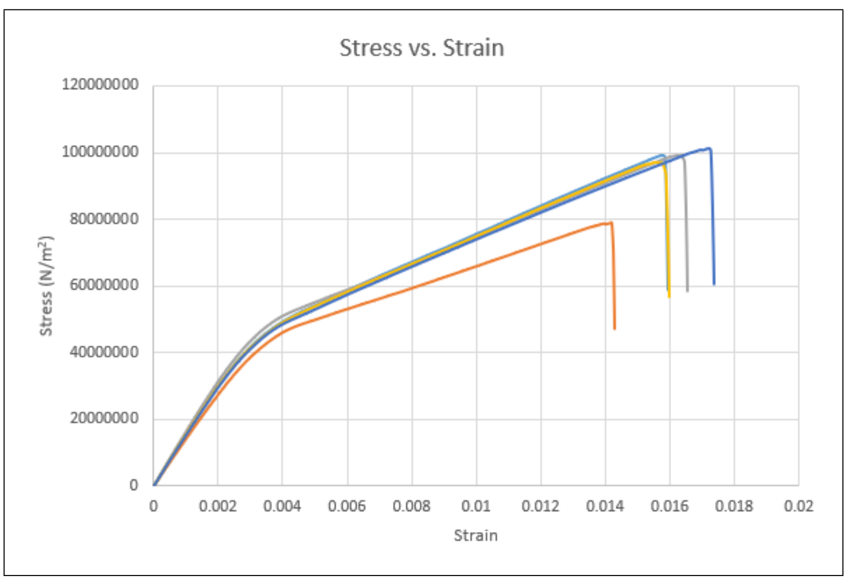
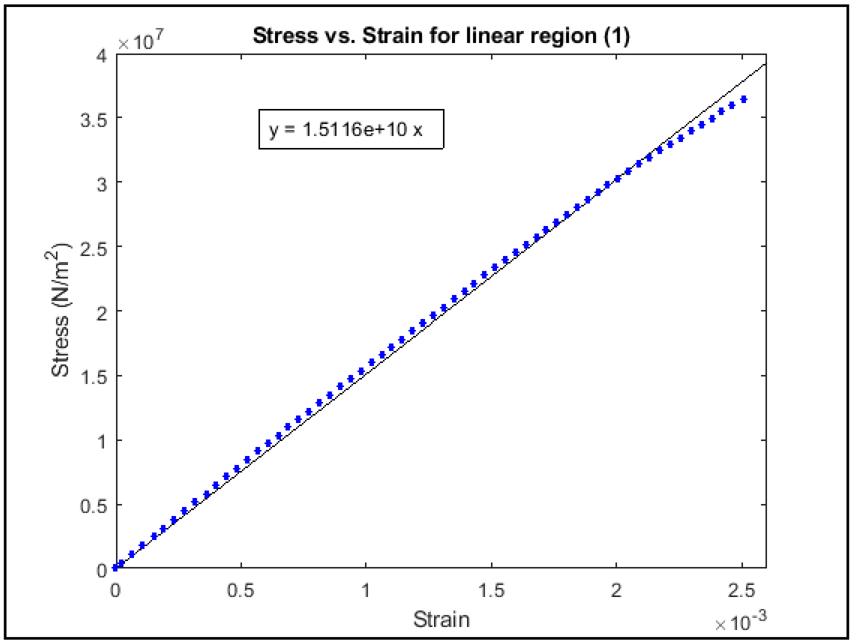


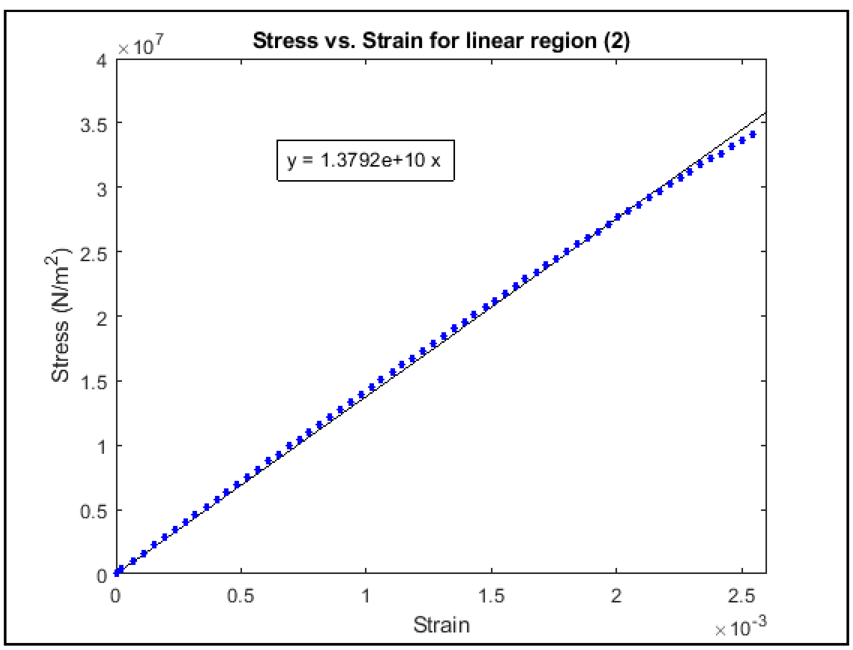
Figure 2: Stress vs. Strain

3.3 Determination of Tensile Modulus of Elasticity

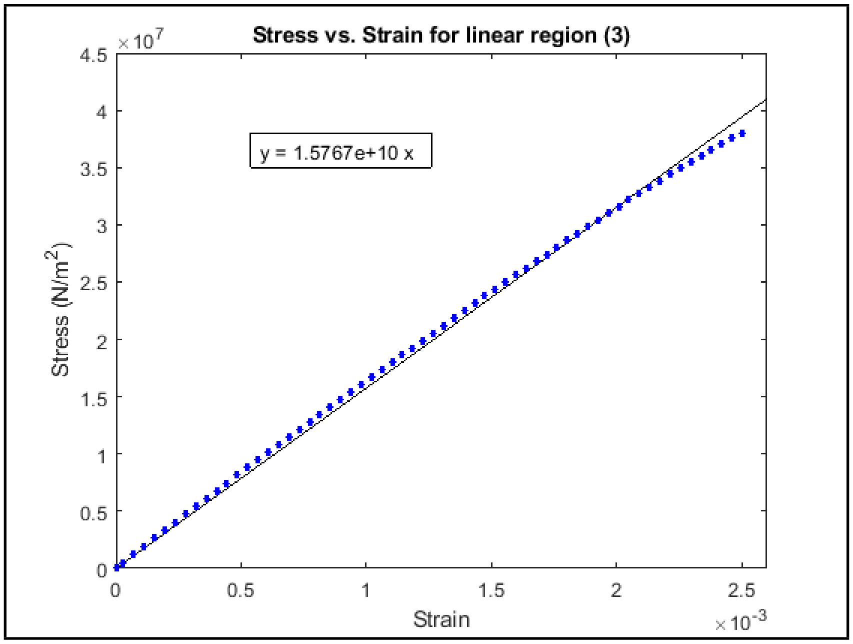
To determine the Tensile Modulus of Elasticity, the Stress vs. Strain curves were plotted for the 5 data samples over the range of linear elasticity and the slope of the linear best fit curve for each was obtained.



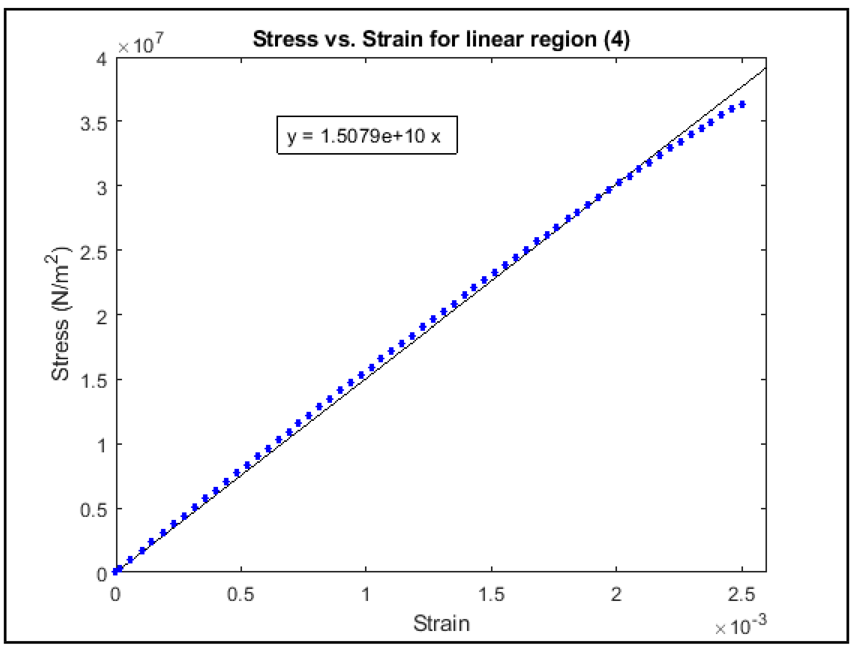
Slope $= E_1 = 1.5116 \times 10^{10}$



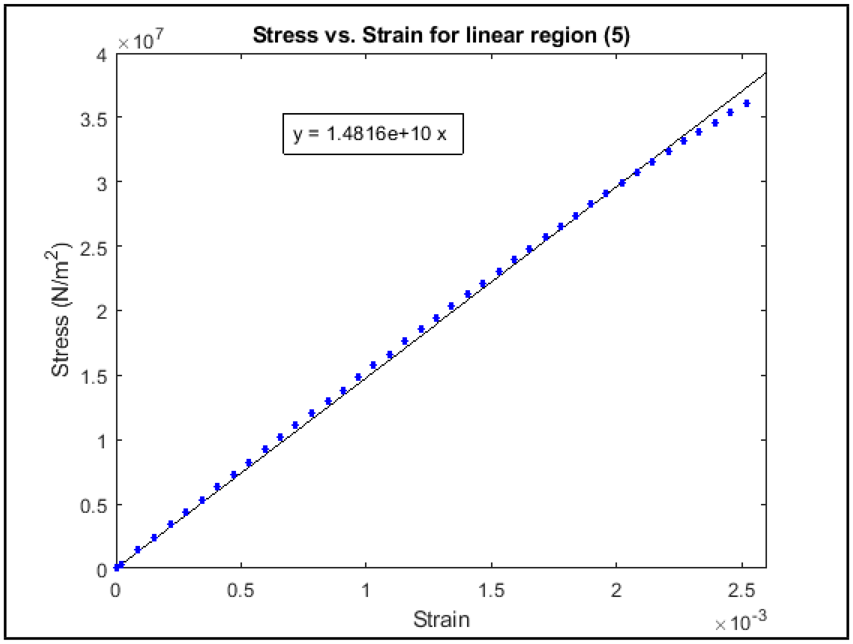
Slope $= E_2 = 1.3792 \times 10^{10}$



Slope $= E_3 = 1.5767 \times 10^{10}$



Slope $= E_4 = 1.5079 \times 10^{10}$



$$\text{Slope} = E_5 = 1.4816 \times 10^{10}$$

Mean Tensile Modulus of Elasticity :

$$\begin{aligned} E &= \frac{E_1 + E_2 + E_3 + E_4 + E_5}{5} \\ &= \frac{1.5116 + 1.3792 + 1.5767 + 1.5079 + 1.4816}{5} \times 10^{10} \\ &= 1.4914 \times 10^{10} \\ &= 14.914 \ \text{GPa} \end{aligned}$$

3.4 Determination of Ultimate Tensile Strength and Ultimate Tensile Strain

From the 5 data samples, the maximum value of Stress and the corresponding Strain value was noted.

Data Set	Ultimate Tensile Strength σ_{max_i} (Pa)	Ultimate Tensile Strain ϵ_{max_i}
1	99065724.41	0.015793704
2	78940018.06	0.014148025
3	99118955.67	0.016205679
4	97245547.07	0.015547901
5	101245304.3	0.017208025

Mean Ultimate Tensile Strength :

$$\sigma_{max} = \frac{99065724.41 + 78940018.06 + 99118955.67 + 97245547.07 + 101245304.3}{5}$$
$$= 95123109.91 \text{ Pa}$$
$$= 95.123 \text{ MPa}$$

Mean Ultimate Tensile Stress :

$$\epsilon_{max} = \frac{0.015793704 + 0.014148025 + 0.016205679 + 0.015547901 + 0.017208025}{5}$$
$$= 0.0158$$

4 Error Analysis

Ultimate Tensile Strength

Mean = 95.123 MPa
Standard Deviation :

$$STD_{\sigma_{max}} = \sqrt{\frac{\sum(\sigma_{max_i} - \sigma_{max})^2}{5}}$$
$$= 9156820.656 \text{ Pa}$$
$$= 9.157 \text{ MPa}$$

Coefficient of Variation $= \frac{STD_{\sigma_{max}}}{\sigma_{max}} = 0.0963$

Ultimate Tensile Strain

Mean = 0.0158
Standard Deviation :

$$STD_{\epsilon_{max}} = \sqrt{\frac{\sum(\epsilon_{max_i} - \epsilon_{max})^2}{5}}$$
$$= 0.0011$$

Coefficient of Variation $= \frac{STD_{\epsilon_{max}}}{\epsilon_{max}} = 0.0704$

Tensile Modulus of Elasticity

Mean = 14.914 GPa
Standard Deviation :

$$STD_E = \sqrt{\frac{\sum(E_i - E)^2}{5}}$$
$$= 0.071835333 \text{ GPa}$$
$$= 71.835 \text{ MPa}$$

Coefficient of Variation $= \frac{STD_E}{E} = 0.0482$

5 Assignment Answers

1) What is the significance of the shape of the specimen?

- When the rupture of a sample occurs in the midsection it is attributed to the material reaching its maximum tensile strength, whereas if the sample ruptures at one of the ends or in the grip itself the failure may be attributed to improper loading or a pre-existing defect in the material.
- The specimens used are dogbone/dumbbell shaped, with more width at the ends where they are held and smaller width for the middle gauge length.
- The significance of this shape is that it ensures that failure will first occur in the gauge region due to higher stress as the force is same for all cross-sections but the central part has a smaller cross-section.

2) What is the significance of gauge length from stress point of view?

The gauge length is the one where the fracture will occur and is used for the calculations and determination of the material properties. The gauge length has uniform cross-section and thus will have uniform Stress throughout.

3) What is proportional limit, 0.2% proof stress? How will you calculate the yield stress for Aluminum?

- Proportional limit is the point on a stress-strain curve where the linear elastic region transitions into a non-linear plastic deformation region.
- For some materials like metals and plastics, the departure from the linear elastic region cannot be easily identified to determine the yield strength of the material. Therefore the offset method is used to determine the yield stress. According to ASTM E8/E8M standard, a line is drawn from 0.2% strain with slope equal to Young's Modulus and the Stress value at the point it intersects the Stress vs. Strain curve is the 0.2% Proof Stress.
- For Aluminium the yield stress is the 0.2% Proof Stress.

4) What is secant modulus?

The Secant Modulus is the slope of the line drawn from the origin of the Stress vs. Strain curve and intersecting the curve at the point of interest.

5) What is the effect of high strain rate on the properties of your specimen?

On increasing the strain rate, the Ultimate Tensile Strength of the material increases, elongation can both increase or decrease and Modulus of Elasticity increases.

6) What other devices are commonly used to measure extension?

Extensometer is a device which can be used to measure extension.

7) How can fatigue test be conducted using UTM?

For performing fatigue test using UTM, Cyclic or Periodic loading and unloading can be applied till the failure of the material.

6 Appendix

- Data set 1 : GFRP 1
- Data set 2 : GFRP 5
- Data set 3 : GFRP 6
- Data set 4 : GFRP 13
- Data set 5 : GFRP 14

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STRAIN MEASUREMENT

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Contents

1 Aim

1. To get familiar with commercially available strain gauges and associated instrumentation.
2. Understand the principle of operation of the Foil/Electric Resistance strain gauge, bridge circuits & effects of temperature on the performance of a strain gauge.
3. Measure the strain using strain gauges and calculate the young's modulus of the material.

2 Equipment Used

- Strain Gauges
- Aluminium specimen
- Steel Rule
- Clamp
- Vernier calipers
- Weights
- Pan

3 Observations

3.1 Specimen Geometric Measurements

Reading	**Gauge Length** l (mm)	**Breadth** b(mm)	**Thickness** t (mm)
1	448	31.79	6.21
2	448	31.83	6.26
Average	448	31.81	6.235

Table 1: Geometric measurements

3.2 Strain Gauge Measurements

Load	Strain ($\times 10^{-6}$)	
	Bridge circuit	
P (grams)	Quarter	Half
100	23	27
200	43	53
300	61	79
400	79	104
500	97	129
600	115	154
700	132	179
800	151	202
900	168	229
1000	181	253

Table 2: Strain and Load data

4 Calculations and Results

From Elementary Beam theory, the stress is calculated using the applied load and the dimensions of the specimen as-

$$\sigma = \frac{6Pl}{bt^2}$$

where,

$$P = \text{Applied Load in Newtons}$$
$$l = \text{Gauge Length}$$
$$b = \text{Breadth}$$
$$t = \text{Thickness}$$

The geometric measurements are done using ruler and vernier calipers and average of 2 readings is taken as shown in Table 1. The values of gauge length, breadth and thickness come out to be 448mm, 31.81mm, 6.235mm respectively. Using these values, and the expression given above, we calculate the stress for varying Loads.

Load	**Stress** (Pa)
100	2132365.695
200	4264731.389
300	6397097.084
400	8529462.779
500	10661828.47
600	12794194.17
700	14926559.86
800	17058925.56
900	19191291.25
1000	21323656.95

Table 3: Load and Stress data

4.1 Stress vs. Strain Curves

4.1.1 Quarter Bridge Configuration

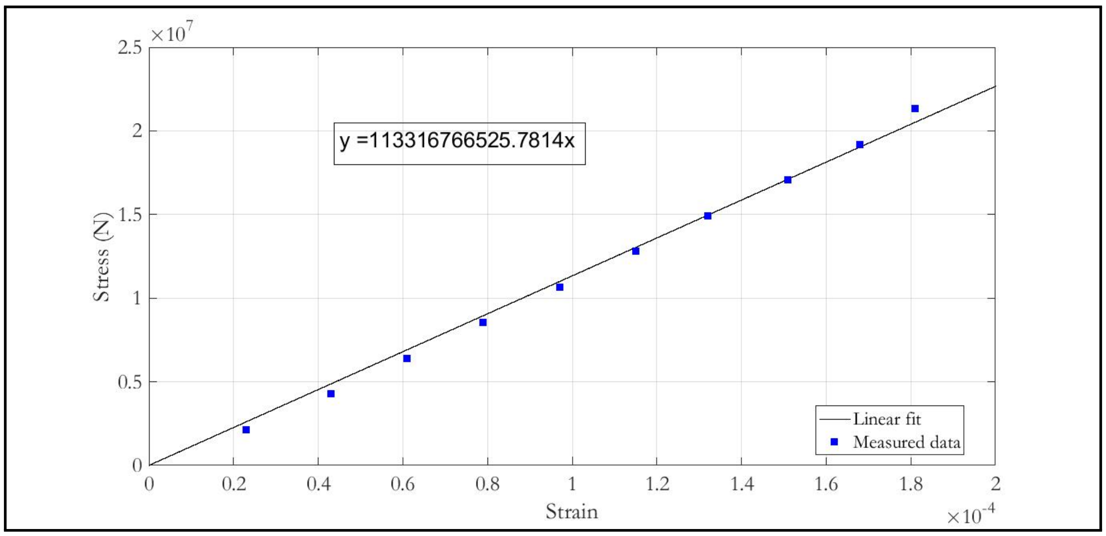


Figure 1: Stress vs. Strain - Quarter Bridge

Young's Modulus = Slope of stress-strain curve = $E_q = 113.32\ GPa$

4.1.2 Half Bridge Configuration

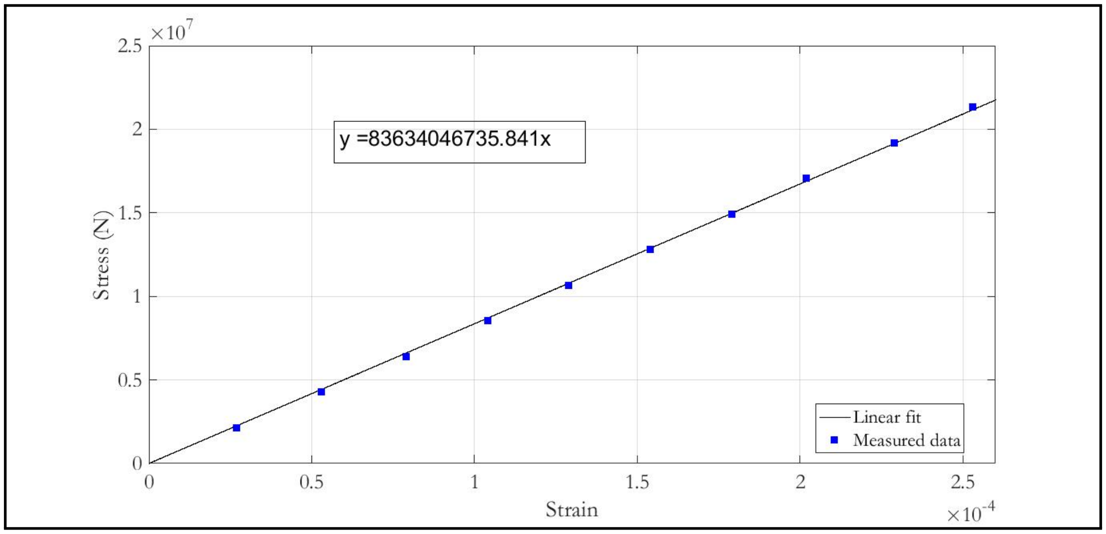


Figure 2: Stress vs. Strain - Half Bridge

$$\textbf{Young's Modulus} = \text{Slope of stress-strain curve} = E_h = 83.63\ GPa$$

We observe that the value of modulus obtained using the half bridge configuration is less than that obtained using quarter bridge configuration.

5 Error Analysis

The theoretical value of Young's Modulus for Aluminium is 70 GPa. Calculating the percentage errors for the obtained values for the modulus using the two configurations, wrt the theoretical value-

For quarter bridge configuration -

$$\begin{aligned}\%\ error &= \frac{113.32 - 70}{70} \times 100 \\ &= 61.89\%\end{aligned}$$

For half bridge configuration -

$$\begin{aligned}\%\ error &= \frac{83.63 - 70}{70} \times 100 \\ &= 19.47\%\end{aligned}$$

6 Assignment Answers

1) **Plot the stress vs strain graph for both the circuit configurations.**
The stress vs. strain curves for both the configurations are as shown in the Calculation and Results section.

2) **From the graph compute and compare the modulus of the aluminium specimen in quarter bridge and half bridge.**

Configuration	**Young's Modulus** (GPa)
Quarter bridge	113.32
Half bridge	83.63

3) **Find the percentage error from the theoretical modulus value (70GPa) for both the cases.**

Configuration	**% error from theoretical**
Quarter bridge	61.89
Half bridge	19.47

4) **Explain the significance of Gauge Factor.**
The Foil Strain Gauge is based on the principle that the induced strain leads to a change in resistance. The Gauge Factor is the relative change in the resistance for unit strain, thus signifying the strain sensitivity of the guage.

$$Gauge\ Factor = GF = \frac{\Delta R/R}{\epsilon}$$

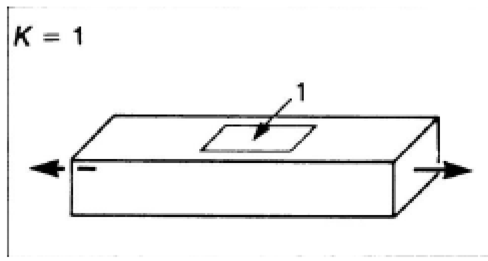
5) **What circuit is used in our experiment? Why?**
The **Wheatstone Bridge** circuit is used in performing the experiment. The wheatstone bridge converts the change in resistance to **change in potential** which can be measured with much **higher accuracy**. Also, we can compensate for the **effects due to temperature** using the wheatstone circuit.

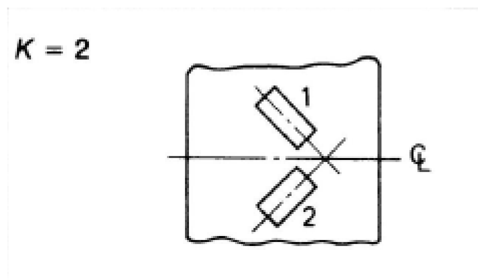
6) **What are different forms of electrical strain gauges available commercially?**
Commercially available strain gauges are-
   (a) **Linear Strain Gauges** - Record strain in the direction the grid is aligned.
   (b) **Shear Strain Gauges** - Mainly used to measure torque in a rotating object. Used in the construction of torque transducers or shear force transducers.
   (c) **Rosette Strain Gauges** - Suitable for applications where biaxial stress state is to be determined with unknown principle directions based on magnitude and direction.
   (d) **Chain Strain Gauges** - Measuring strain gradient i.e., the stress curve over a specific section.

7) What is the strain gauge configurations used for calculating bending stress, torsional stress?

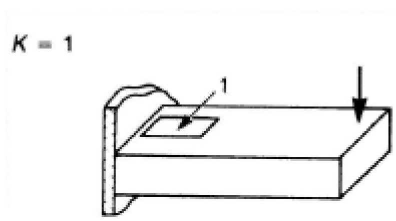
The following configurations of wheatstone bridge are used for calculating bending and torsional stress-

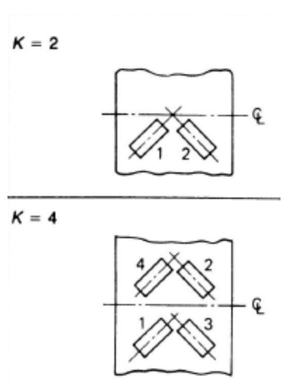
- Bending stress- one arm and two arm bridges





- Torsional stress- 2 arm and 4 arm bridges





8) **How are the strain gauges connected for compensating the effect of temperature?**
We use 2 strain gauges on the specimen in full bridge or half bridge configuration. Since the individual branches flow with different signs in the Wheatstone bridge circuit, there is a possibility for compensation. If temperature-dependent strain occurs, the strain appears to both strain gauges with the same sign and thus gets compensated due to the nature of the bridge.

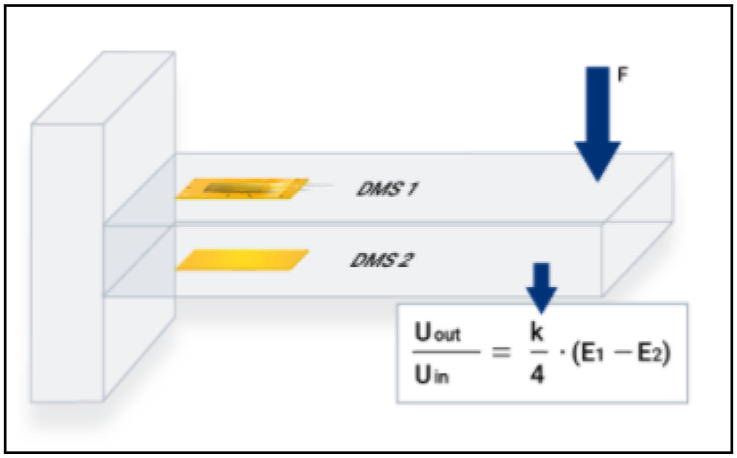


Figure 3: Example of temperature effect compensation

7 References

- Lab manual, Strain measurement, Department of Aerospace Engineering, IIT Bombay
- https://www.bestech.com.au/blogs/different-types-of-strain-gauge-geometries/
- https://www.hbm.com/en/6725/article-temperature-compensation-of-strain-gauges/
- Class Notes, AE242, Prof. Hemendra Arya, IIT Bombay

8 Appendix

MATLAB code for linear curve fit

```
clearvars

load strainh.txt;
load strainq.txt;
load stress1.txt;

f = strainh\stress1;

strain = 0:0.000005:0.0003;
stress = f*strain;

fh = figure('Name','Linear curve fitting');
plot(strain,stress,'LineWidth',1,'Color','k');
hold on;
plot(strainh,stress1,'Marker','s',...
                 'LineStyle','none',...
                 'MarkerSize',8,...
                 'MarkerFaceColor','blue',...
                 'MarkerEdgeColor','none');
xlim([0 0.00026]);
hold off; grid on; box on;
set(gcf,'Color',[0.7 1 1]); set(gca,'Color','w');
set(gca,'FontName','Garamond','FontSize',20);
annotation('textbox', [0.3, 0.7, 0.23, 0.08], 'String', "y
 ↪  ="+f+"x",'FontSize',20)
xlabel('Strain');
ylabel('Stress (N)');
legend('Linear fit','Measured data');
set(legend,'Location','best');
set(legend,'Orientation','Vertical');
set(legend,'Box','On');
```

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VIBRATIONS

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Contents

1 Aim

Estimation of elastic modulus of a given specimen by observing the vibration behaviour in first bending mode.

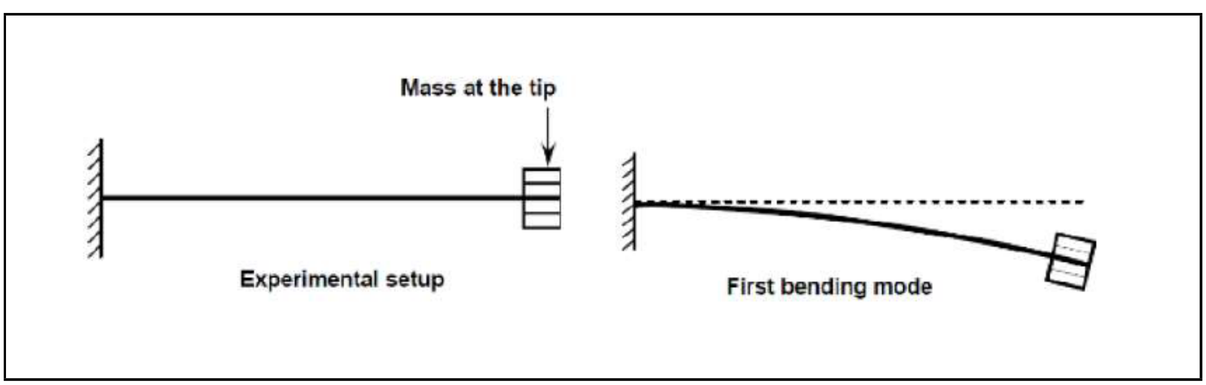
2 Objectives

1. To enhance understanding of natural vibrations of a system and to gain insight regarding experimental measurement of natural frequencies
2. To study the concept of making approximate engineering models
3. To calculate the desired material properties like Young's Modulus from the experiment
4. To perform error analysis and to identify reasons for the errors obtained

3 Equipment Used

- Steel rule
- Weights
- Bench Vice
- Stop Watch
- Rubber Bands
- Weighing Machine
- Vernier Calipers

4 Experimental Setup



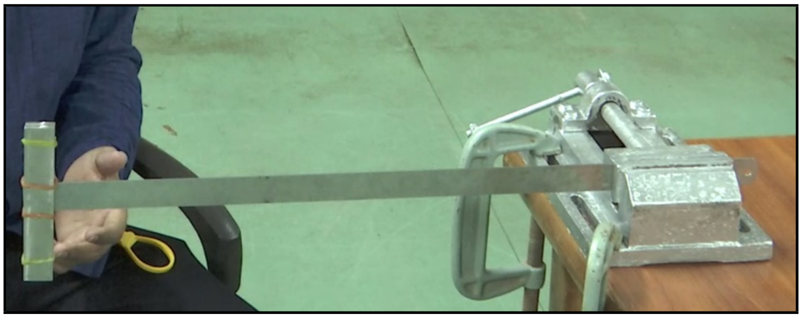


Figure 1: Experimental Setup

It consists of a cantilever specimen (steel ruler fixed at one end using bench vice). Masses are tied at the free end of the beam. A simple push on the mass produces initial condition sufficient to excite the first mode of the system. The time required for twenty oscillations is recorded for a given length of the beam.

5 Observations

5.1 Specimen Dimensions

Effective length is the length measured from the bench vice to the center of the attached weights. Thus it is the sum of the length from bench vice to point of load and the half width of the weights.
Two different cases are considered with different effective lengths.

Case 1

Specimen Width (mm)	30.51
Specimen Thickness (mm)	1.18
Length from bench vice to point of load (mm)	490
Half width of the weights (mm)	25.07
Effective Length (mm)	515.07

Table 1: Specimen Dimensions - Case 1

Case 2

Specimen Width (mm)	30.51
Specimen Thickness (mm)	1.18
Length from bench vice to point of load (mm)	492.5
Half width of the weights (mm)	25.07
Effective Length (mm)	517.57

Table 2: Specimen Dimensions - Case 2

5.2 Specimen Properties

The properties of stainless steel are-

- Density - $\rho = 7850\ kg/m^3$
- Young's Modulus - $E = 200\ GPa$

6 Calculations and Results

From the measured values for the time period for 20 oscillations, we can find the natural frequency as-

$$\omega_n = \frac{20}{T} \tag{1}$$

Using this, the Young's Modulus can be found out as-

$$E = \frac{4\pi^2\omega_n^2 \times m \times L_{eff}^3}{3 \times I} \tag{2}$$

Substituting for the natural frequency we get,

$$E = \frac{400 \times 16\pi^2 \times m \times L_{eff}^3}{b \times t^3 \times T^2} \tag{3}$$

We will calculate the Young's Modulus for each case of the observations first by neglecting the mass of the beam and later by accounting for it as follows-

$$M_b = \frac{33}{140}\rho A L_{eff} \tag{4}$$

6.1 Case 1: Effective Length = 515.07mm

Without M_b

Reading	Trials	Mass(g)	Time for 20 oscillations (sec)	ω_n	E (GPa)
1	1	273.3	16.71	1.196888091	168.5298636
	2	273.3	16.75	1.194029851	167.7259059
	3	273.3	16.73	1.195457262	168.1271639
				Average	168.1276445
2	1	546.6	23	0.869565217	177.9115292
	2	546.6	23.06	0.867302689	176.9869148
	3	546.6	23.04	0.868055556	177.2943171
				Average	177.397587
3	1	819.9	30.73	0.650829808	149.4947369
	2	819.9	30.95	0.646203554	147.3770018
	3	819.9	30.81	0.64913989	148.7194009
				Average	148.5303798

Table 3: Without considering Mass of beam M_b

With M_b

Reading	Trials	Mass(g)	Time for 20 oscillations (sec)	ω_n	E (GPa)
1	1	273.3	16.71	1.196888091	189.6882854
	2	273.3	16.75	1.194029851	188.7833932
	3	273.3	16.73	1.195457262	189.235028
				Average	189.2355689
2	1	546.6	23	0.869565217	189.0796602
	2	546.6	23.06	0.867302689	188.0970045
	3	546.6	23.04	0.868055556	188.4237035
				Average	188.5334561
3	1	819.9	30.73	0.650829808	155.7509431
	2	819.9	30.95	0.646203554	153.5445828
	3	819.9	30.81	0.64913989	154.9431599
				Average	154.7462286

Table 4: Considering Mass of beam M_b

6.2 Case 2: Effective Length = 517.57mm

Without M_b

Reading	Trials	Mass(g)	Time for 20 oscillations (sec)	ω_n	E (GPa)
1	1	273.3	16.2	1.234567901	181.9316506
	2	273.3	16.25	1.230769231	180.8137937
	3	273.3	16.22	1.233045623	181.4832672
				Average	181.4095705
2	1	546.6	23.73	0.842815002	169.5792882
	2	546.6	23.65	0.845665962	170.7284881
	3	546.6	23.7	0.843881857	170.0088746
				Average	170.1055503
3	1	819.9	29.63	0.674991563	163.1534421
	2	819.9	29.76	0.672043011	161.7311557
	3	819.9	29.7	0.673400673	162.3852749
				Average	162.4232909

Table 5: Without considering Mass of beam M_b

With M_b

Reading	Trials	Mass(g)	Time for 20 oscillations (sec)	ω_n	E (GPa)
1	1	273.3	16.2	1.234567901	204.88349
	2	273.3	16.25	1.230769231	203.6246082
	3	273.3	16.22	1.233045623	204.3785401
				Average	204.2955461
2	1	546.6	23.73	0.842815002	180.2760432
	2	546.6	23.65	0.845665962	181.4977325
	3	546.6	23.7	0.843881857	180.7327271
				Average	180.835501
3	1	819.9	29.63	0.674991563	170.0143916
	2	819.9	29.76	0.672043011	168.532295
	3	819.9	29.7	0.673400673	169.2139214
				Average	169.253536

Table 6: Considering Mass of beam M_b

7 Error Analysis

We now calculate the mean and standard deviation for the values of the Young's Modulus as found above. The theoretical value of Young's Modulus is given as 200 GPa.

7.1 Without M_b

Mean	167.9990495
Standard Deviation	10.99097113

Error wrt. the theoretical value:

$$\text{Error (\%)} = \frac{200 - 167.999}{200} \times 100 = \boxed{16.000\ \%}$$

7.2 With M_b

Mean	181.150022
Standard Deviation	15.39390259

Error wrt. the theoretical value:

$$\text{Error (\%)} = \frac{200 - 181.15}{200} \times 100 = \boxed{9.425\ \%}$$

8 Assignment Answers

1) Discuss about the errors which are associated with the current problem, find the possible reasons and make some conclusions from the same. Also suggest possible improvements in the experiment to minimize the errors.

- As we count the number of oscillations by directly observing the system, error can be induced based on our reaction time. This problem of human error can be solved by capturing the oscillations using a camera and using a computer program to count the number of oscillations.
- The motion of the ruler is not constrained in one plane and there can be coupling of bending in different directions. This may lead to incorrect calculation of Young's Modulus. There is also the force of gravity acting in the downward direction which is bound to affect the motion.
- The center of gravity of the attached masses at the end of the beam must pass through the shear center of the beam. This will ensure that the applied load will only lead to bending and there won't be any coupling with torsion. Thus we need to see if the loads are fitted properly at the end section, and the vibration is in the plane of the shear center.
- The masses attached to the end are considered as point masses for the sake of calculation. The motion will not be in the horizontal frame if their mass distribution is not uniform.

2) What is the effect of mass of the beam on system natural frequencies? How can we incorporate this in the model?
The Young's Modulus (E) of the beam is given by-

$$E = \frac{4 \times \pi^2 \times \omega_n^2 \times m \times L^3}{3I}$$

The value of the modulus will be constant for a material. Thus if we consider the mass of the beam as well and use it in the calculation, the m will increase and hence the natural frequency ω_n will decrease. The mass of the beam is accounted for by calculating the effective mass of the beam at the end point as-

$$M_b = \frac{33}{140}\rho A L_{eff}$$

where ρ is the beam material density, A is the cross-section area.

3) How can you simulate the free-free boundary condition for the specimen used?
The free-free boundary condition implies that both the ends of the beam should be free i.e. no external effects on the system. This can be simulated by suspending the beam between two springs, which have negligible masses and don't lead to any damping.

4) **What is the significance of this experiment?**
This experiment can be performed to find the value of the Young's Modulus of the specimen without subjecting it to any sort of extension or compression, thus there is no damage caused to the material as in the case of tensile test.

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Aircraft Structures Laboratory - AE 314

IZOD IMPACT TEST

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Contents

1 Aim

Determination of the impact strength of the fiber reinforced composite and aluminium specimens using Izod Impact Test.

2 Objectives

1. To understand the construction and working of the cantilever beam (Izod type) impact machine.
2. To determine the impact resistance of given specimens.

3 Equipment Used

- Cantilever beam (Izod type) impact machine
- Vernier Caliper
- Scale
- Fiber glass and aluminium specimens

4 Experimental Setup

Figure 1: Izod Impact Test Machine

The machine consists of a massive base on which a vise is mounted for holding the specimen. A pendulum type hammer is connected to the base through a rigid frame and bearings. The machine has a pendulum holding and releasing mechanism and a pointer and dial mechanism for indicating the excess energy remaining in the pendulum after breaking the specimen. The hammer at the end of the pendulum moves from the topmost position to the bottom most position. If the specimen is placed at the bottom then all the kinetic energy associated with the hammer is dissipated into the specimen. But not all energy of hammer is consumed to break the specimen. So, the hammer swings on the other side to certain height to convert the remaining kinetic energy into potential energy.

5 Observations and Calculations

The test was performed on 5 specimens each for fiber glass and aluminium. The width and the thickness measurements were performed first using vernier calipers and then the impact energy was noted for each after performing the test. The impact strength is given by-

$$\text{Impact Strength} = \frac{\text{Energy}}{\text{Cross-section Area}} = \frac{\text{Energy}}{\text{width} \times \text{thickness}}$$

Specimen Name	**Width** (mm)	**Thickness** (mm)	**Energy** (J)	**Impact Strength** (J/mm^2)	**Fracture Type**
Fiber Glass	10.48	3.04	1.50	0.047082161510647	brittle
	10.30	3.03	1.50	0.048063058733058	brittle
	10.19	3.14	1.10	0.034378652731853	brittle
	10.28	3.03	1.40	0.044946128854131	brittle
	10.35	3.05	1.60	0.050685039993664	brittle
Aluminium	10.19	3.09	15.25	0.484325326879897	ductile
	10.05	3.09	15.60	0.50234265565377	ductile
	10.09	3.05	14.50	0.471169312255276	ductile
	9.98	3.03	15.10	0.499348532047594	ductile
	10.94	3.03	14.40	0.434412728292939	ductile

Table 1: Izod Impact Test observations

The fiber glass specimen shears off without any plastic deformation and hence has a clean cut showing its brittle nature. On the other hand the aluminium specimen shows necking and does not break completely. It absorbs a larger amount of energy and hence is ductile.

6 Error Analysis

Let us now calculate the mean and the standard deviation values for the 5 trials performed on each specimen. For N observations $x_1, x_2, ..., x_N$,

$$\textbf{Mean} = \bar{x} = \frac{\sum_1^N x_i}{N}$$

$$\textbf{Standard Deviation} = std(x) = \sqrt{\frac{\sum_1^N (\bar{x} - x_i)^2}{N}}$$

Fiber Glass

Mean	0.045031 J/mm^2
Standard Deviation	0.006302 J/mm^2

Aluminium

Mean	0.4783197 J/mm^2
Standard Deviation	0.027542 J/mm^2

It is seen that the fiber glass has a low impact strength being brittle and the ductile aluminium has higher impact strength. The standard deviation for fiber glass is less than that for aluminium specimen.

7 Assignment Answers

1) **Why do we need to do an Impact test?**
The impact test is used to observe the fracture mechanics of a material. It gives us the amount of energy the material absorbs during deformation or complete rupture which is a measure of the material's toughness. It is also useful in determining the material behaviour at higher deformation rates. This helps us in knowing whether a material is brittle or ductile in nature and thus identify the various fields of application for that material.

2) **Can we find fracture toughness using stress-strain curve?**
Toughness refers to the capacity of a material to absorb energy prior to failure. Fracture toughness is the mechanical energy absorbed by a unit volume of a material prior to the occurrence of fracture. The fracture toughness is given by the area under the stress vs. strain curve till the point of fracture.

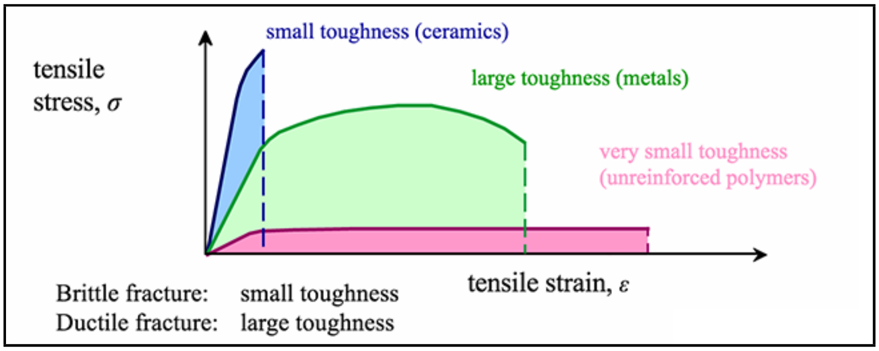

Figure 2: Fracture toughness

3) **Note your observation about the scale of impact testing machine.**
The dial has a marker which indicates the starting position of the pendulum hammer. If we mark a point at the mirror image location of the starting position marker with the vertical axis, we get the zero marker of the scale. This means that the hammer will reach this point after one free swing in the absence of any energy loss or friction between the components. The extreme point of the scale is the bottom most point of the dial. The different scales on the dial are-
    - Degree scale which gives a measurement of the angle traversed by the hammer.
    - There are 4 different energy scales based on the hammer energy. (Note that the calibration is done in terms of the hammer energies and not the weight)

4) **Name some applications of impact test.**
    - The impact test is used to measure a material's toughness, which is a measure of the energy absorbed by the material before fracturing.
    - We can also measure the variation of the material's toughness with the temperature. Generally, at lower temperatures, the impact energy of a material is decreased.
    - The impact test also helps to determine the other material parameters like impact strength, fracture resistance, impact resistance or fracture resistance, temperature-dependent ductile-brittle transition and so on based on the test performed.

8 References

- `https://www.wmtr.com/en.impact-testing.html`

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DETERMINATION OF POISSON'S RATIO

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Contents

1 Title

Determination of Poisson's Ratio of the specimen using a unique setup which requires minimum sophistication and minimum instrumentation.

2 Objectives

The objective of this experiment is to determine the Poisson's Ratio using the elementary theories.

3 Equipment Used

- Specimen mounted as a cantilever beam (mild steel)
- Scale
- Glass plate with chalk coating
- Weights
- Pan
- Adjustable stand

4 Experimental Setup

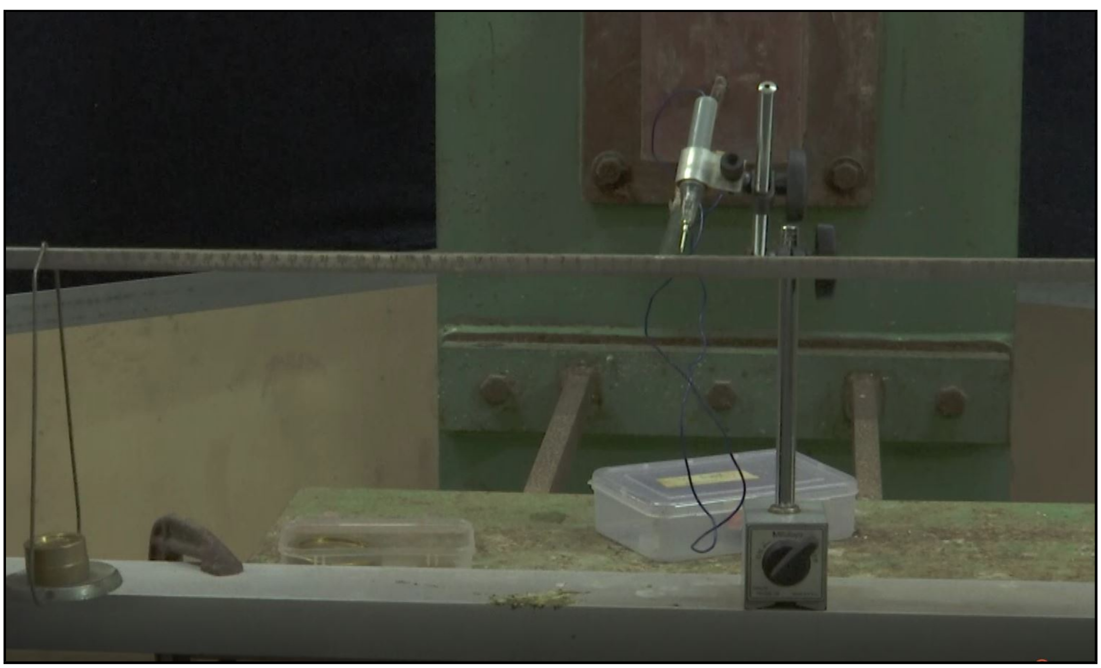

Figure 1: Experimental Setup for Poisson's Ratio Determination

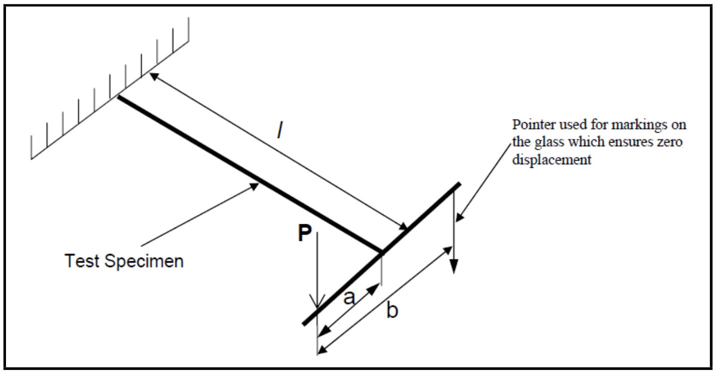

Figure 2: Schematic of general arrangement used in the experiment

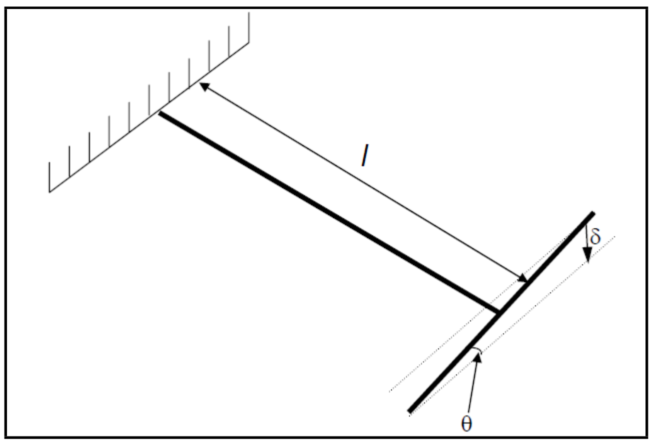

Figure 3: Deformed shape under the applied load

5 Observations and Calculations

The length of the cantilever beam, l is 75 cm. Based on our experimental setup, the Poisson's ratio of the specimen of the cantilever beam, here mild steel, is given by-

$$\nu = \frac{l^2}{3ab} - 1$$

Please note in the expression that, Poisson's ratio is dependent on dimensions l, a and b and it is independent of the load applied. As per the figure (2), a is the distance of applied load from center of bar and b is distance between the point of applied load and the point where the measuring pointer touches the bar on the other side of the cantilever beam.

Based on the measured data for a and b, we calculate the Poisson's ratio for each case using the above mentioned formula. We take the mod of the values obtained from the above formula.

a (cm)	**b** (cm)	**Poisson's ratio** ν
40	77.3	0.393596378
44.5	76.7	0.450654088
43.5	82.5	0.47753396
44	78.5	0.457151129
41.5	79.3	0.430255701

Table 1: Observations and Calculations

6 Error Analysis

Let us now calculate the mean and the standard deviation values for the 5 trials performed on the specimen. For N observations $x_1, x_2, ..., x_N$,

$$\textbf{Mean} = \bar{x} = \frac{\sum_1^N x_i}{N}$$

$$\textbf{Standard Deviation} = std(x) = \sqrt{\frac{\sum_1^N (\bar{x} - x_i)^2}{N}}$$

Mean	0.441838251
Standard Deviation	0.031811243

From literature, we know that the Poisson's ratio for mild steel is somewhere in the range of 0.26 to 0.33. The difference in the experimental and literature values may be because of probable human errors or faulty instruments while performing the experiment.

7 Assignment Answers

1) **Give examples of materials with extreme values of Poisson's ratio.**
For most common materials, the Poisson's ratio is between 0-0.5.

High Poisson's ratio materials-

Rubber	0.499
Saturated Clay	0.4-0.49

Cork has 0 value of Poisson's ratio. Some materials with negative values for Poisson's ratio are-

α-Cristobalite	-0.16
Rippled Graphene	-0.38

There are some materials which are exceptions and show a large range of Poisson's ratio values-

Material	$\nu_{\max}$	$\nu_{\min}$
Cesium Dihydrogen Phosphate	2.7	-1.93
Lanthanum niobate	3.95	-3.01

2) **What are Auxetic Materials? Give some examples.**
Auxetic materials are those that exhibit an unexpected behaviour when they are subjected to mechanical stresses and strains. For example, if we stretch the material in the longitudinal direction, one may expect it to become thin whereas they tend to become thicker in one or several perpendicular directions. This implies that these materials have negative Poisson's ratio.

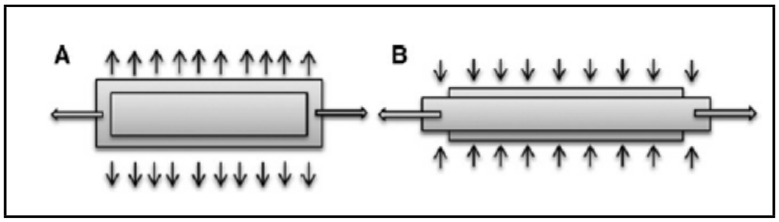

Figure 4: (A) Auxetic vs. (B) Non-auxetic

Examples of such materials include Polyurethane Foam, α-Cristobalite, and some crystalline materials like Lithium, Sodium, Silver, Cobalt etc.

3) **Explain and justify the uses of cork.**
Cork has an almost zero Poisson's ratio, which means the radius of a cork does not change significantly when squeezed or pulled. The major applications of cork are stoppers and plugs, like bottle stoppers for wine bottles. It is also used in making the head of badminton shuttlecocks and as the core of both baseballs and cricket balls. Cork also has application in thermal insulation for house walls, floors and ceilings.

4) **What is a honey-comb structure? List the possible applications.**
Honeycomb structures are the ones that resemble the geometry of a honeycomb, which allows the minimization of the material used for manufacture thereby reducing the weight and the cost. The primary structure consists of cells which are columnar or hexagonal in shape arranged in an array between thin walls. Such a structure also provides a minimal density. The honeycomb exhibits a Poisson's ratio of -1 for in plane deformations. Some applications are mentioned below-

- Aerospace Industry - manufacture of helicopters, gliders and jet aircrafts
- Lighting Industry - LED technology
- Woodworking in furniture
- Sports Industry - manufacture of snowboards, racing shells

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DETERMINATION OF SHEAR CENTER

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Contents

1 Title

Determination of the shear center of a given cross section of a beam mounted as a cantilever.

2 Objectives

- Understand the concept of **shear center** and **center of twist**
- Identify the shear center of the given cross section
- To cross check the results with theoretical calculations; and compare the two methods of measuring shear center.

3 Equipment Used

- Steel Rule
- Two dial gauges of same accuracy, range.
- Vernier Calipers
- Weights

4 Experimental Setup

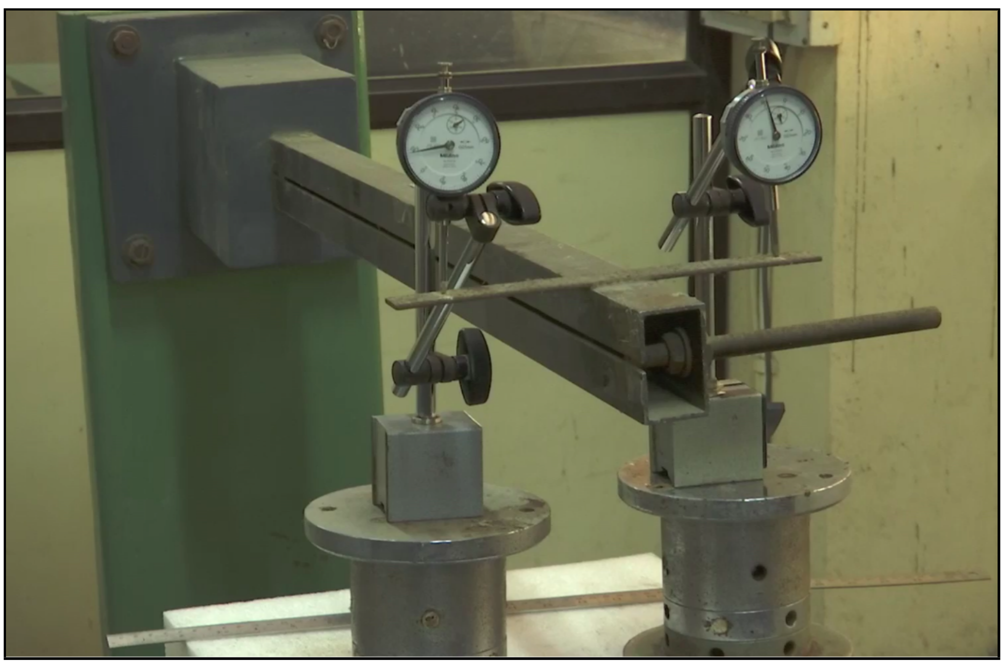


Figure 1: Setup for shear center experiment

5 Observations and Calculations

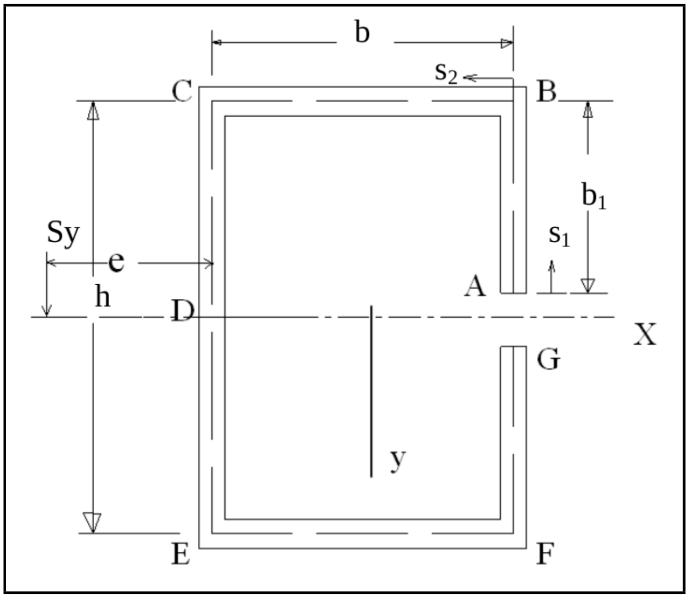


Figure 2: Beam cross section

For the beam cross section shown above, the theoretical value of the location of shear center, **e**, in terms of the lengths marked in the above diagram is-

$$e = \frac{b(3h^2b + 6h^2b_1 - 8b_1^3)}{h^3 + 6h^2b + 6h^2b_1 + 8b_1^3 - 12hb_1^2} \tag{1}$$

Based on the measurements, the values obtained are-

h	62.85 mm
b	38.136 mm
h_1	28.6 mm
h_2	29.53 mm
t	3.083 mm

Table 1: Beam measurements

The value of b_1 is taken as the average of h_1 and h_2.

$$b_1 = \frac{h_1 + h_2}{2} = 29.065\ mm$$

Substituting h, b, b_1 in the above formula, we get the theoretical value of the shear center location e as **25.7193 mm** from the midline of the flange. (as per fig. 2)

5.1 Dial Gauge Method

The observations for the Dial Gauge method are tabulated below-

Dial gauge method				
Distance of weight from the outer edge of the beam, e (mm)	Deflection measured in the left dial gauge (mm)	Deflection measured in the right dial gauge (mm)	Difference between dial gauge readings (mm)	Theta
98	0.095	0.030	0.1250	0.0008116883117
72	0.070	0.000	0.0700	0.0004545454545
51	0.065	0.000	0.0650	0.0004220779221
36	0.060	-0.015	0.0450	0.0002922077922
27	0.060	-0.020	0.0400	0.0002597402597
22	0.060	-0.020	0.0400	0.0002597402597
18	0.045	-0.035	0.0100	0.00006493506494
16	0.045	-0.055	-0.0100	-0.00006493506494

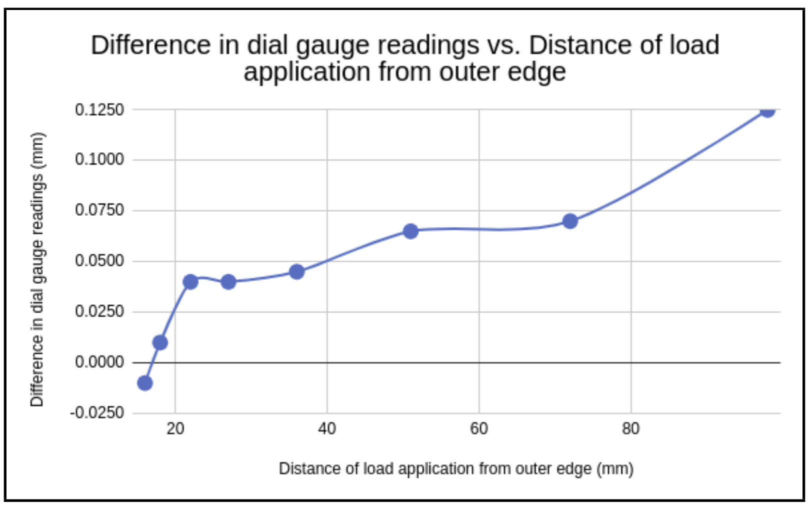
Figure 3: Dial gauge method observations

Here, the difference between the dial gauge readings is obtained by adding the deflection measurements of the left and right dial gauges, as the dial gauges also account for negative values. The net rotation of the cross section, θ, is obtained as-

$$\theta = \frac{\text{Difference in dial gauge readings}}{\text{Distance between dial gauges}}$$

The distance between the dial gauges is 154 mm.

Now to find the location of the shear center, we need to estimate the location from where the load acting gives us a difference of zero in the readings of the 2 dial gauges. We plot the difference in dial gauge readings vs. the distance of application of load from the outer edge.



We see that the plot crosses the 0 value between 16 to 18 mm distance from the outer edge. Thus the shear center has to lie in between these locations. Taking linear variation in between 16 and 18 mm, we get the location of shear center as **17 mm** from the outer edge.

6 Error Analysis

Experimental location of the shear center from the midline will be-

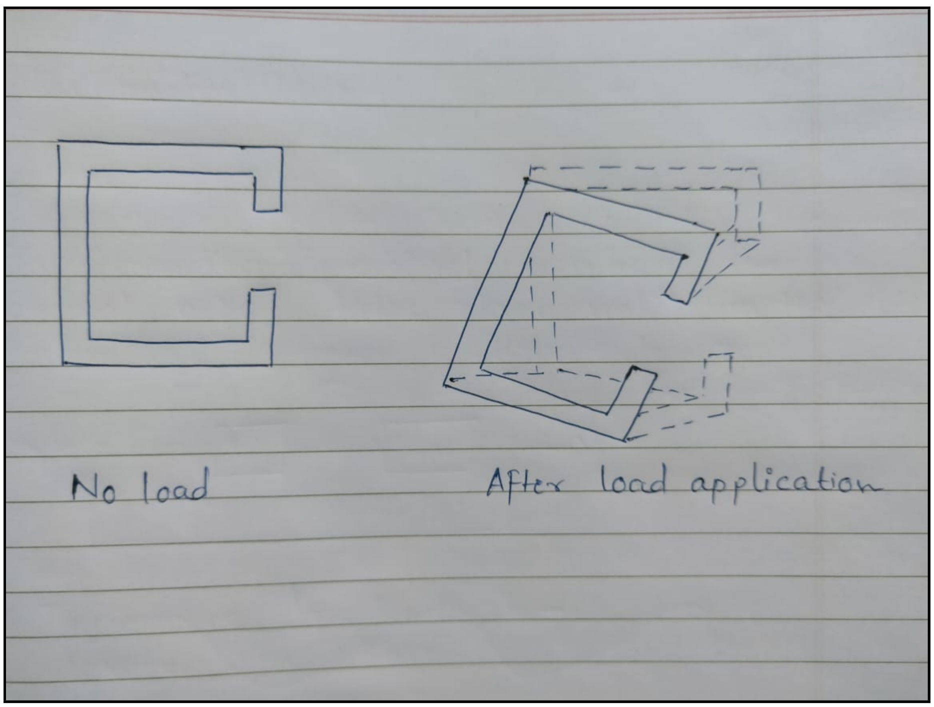
$$e = 17 + t/2 = 17 + 3.083/2 = \mathbf{18.5415\ mm}$$

where t is the thickness. The percent error wrt the theoretical value will be-

$$\%\ \text{error} = \frac{25.7193 - 18.5415}{25.7193} = \mathbf{27.908}\%$$

7 Assignment Answers

1) **Sketch the diagram for axial deformations over the cross section at the tip of the above beam.**



2) **What is Neuber beam? Give three examples of Neuber beam.**
In the presence of transverse loads, beams undergo unusual distortion i.e. nonuniform out-of-plane displacements due to torsional effects, known as warping. The warping stays constant for different distances from base of specimen. The beams which do not warp under pure torsion are known as Neuber beams. The property of these beams is $p_R G t = \frac{2A}{\delta}$ = constant, where p_R is the shortest distance between the center of twist R and the line tangential to some part ds of the beam, G is the shear modulus, t is the thickness. Examples-

- Circular section beam with constant cross section
- Triangular section beam of constant thickness

- Rectangular section beam for which $at_b = bt_a$

3) What are the possible applications of the concept of shear center?

- More load can be applied at the shear center instead of the center of specimen before buckling, as compared to other locations.
- The Shear Stress can be used to calculate the torque acting on a specimen.
- This concept can be used in the construction of purlins, which are logitudinal horizontal structural members of a roof.
- Since thin walled open steel sections are weak in resisting torsion, the concept of shear center is useful in its design.
- We can use this to plan floors and walls of houses to make them earthquake resitant.
- It also has application is aircraft structures such as wings. It is important for the center of pressure to coincide with the shear center, else we can have extreme structural damage to wings in case of extreme maneuvers in fighter jets

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COMPOSITE FABRICATION

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Contents

1 Aim

Fabrication of **E-glass Fibre/Epoxy Composite** by **Hand lay-up** process.

2 Equipment Used

- Metal mould
- Rotary cutter
- Weighing pan
- Screw gauge
- Marker pen
- Mixing pan for resin
- Stirrer
- Brush

3 Materials Used

- Fibres: Plain weave E-glass fabric
- Resin (Matrix): Epoxy (LY 556)
- Hardener (also called catalyst): HY 951
- Mould Releasing Agent: Wax (shine all)

4 Assignment Answers

1) **List and explain the function of all the material components involved in the fabrication of composites.**

   (a) **Fibres**: Fibres, also known as reinforcement is the component that plays the role of withstanding the maximum load. The tensile strength, stiffness and other performance properties of the composite is a result of the fibres used in the manufacture process.
   Examples: Carbon, Fiberglass, E-glass

   (b) **Matrix**: Matrix, or the resin acts as a glue and has the function of holding and binding the fibres together. Resins also play the role of distributing and transferring the stresses throughout the composite material and thus contribute to the strength and durability of the composite. Resins help to protect the fibres from mechanical and environmental damage. Typically we use 60% fibre and 40% resin by weight.
   Examples: Epoxies, Phenolics, Polyimides

(c) **Hardener**: Hardeners act as curing agents in the fabrication process by helping in the formation of cross-links between the reacting chemicals, thus increasing the cohesive strength of the adhesive layer. They can also act as catalysts by initiating and controlling the process of cross-linking. Typically for 10 parts of resin, 1 part by weight of hardener is used.
Examples: Aromatic diamino compounds

(d) **Mould Releasing agent**: This is a material which is applied on the surface on the mould to prevent the bonding between the composite which is being fabricated and the moulding surface. Mould release agents facilitate easy separation of the composite. Thus, they help in enhancing the productivity and increasing the life of the mould.
Examples: Wax, Polyvinyl alcohol (PVA)

2) **Describe/explain any one process of fabrication of FRP composites other than Hand lay-up process with the help of a neat schematic diagram of the process. Explain its advantages and disadvantages of your selected process. What component(s) can be manufactured using your selected process?**

<u>FILAMENT WINDING PROCESS</u>

Filament winding is an automated open mould process for composite fabrication using a rotating component as the mould, used in the manufacture of open cylindrical objects.

Equipments used:

- Filament winding machine - consists of a rotating mandrel having internal shape of the desired FRP product
- Creel - continuous rovings
- Resin bath
- Rollers and pulleys

Procedure:

(a) Continuous fibre strand roving is wound onto a rotating mandrel, fed through a resin bath. The rovings can be in a variety of orientations.
(b) The roving feed runs on a trolley that travels the length of the mandrel.
(c) The rotation rate of the mandrel and the fibre feeding mechanism can be controlled externally.
(d) The filament is laid down in a predetermined geometric pattern like longitudinal, circumferential, helical or polar to provide maximum strength in the directions as desired.
(e) When sufficient layers have been applied and desired part thickness is obtained, the laminate is cured on the mandrel.
(f) The molded part is then stripped from the mandrel. For some products, the mandrel is left as a part of the finished product.

Filament winding processes can be either continuous or discontinuous type. The continuous process is used for manufacturing low pressure parts while the other is for high pressure ones.

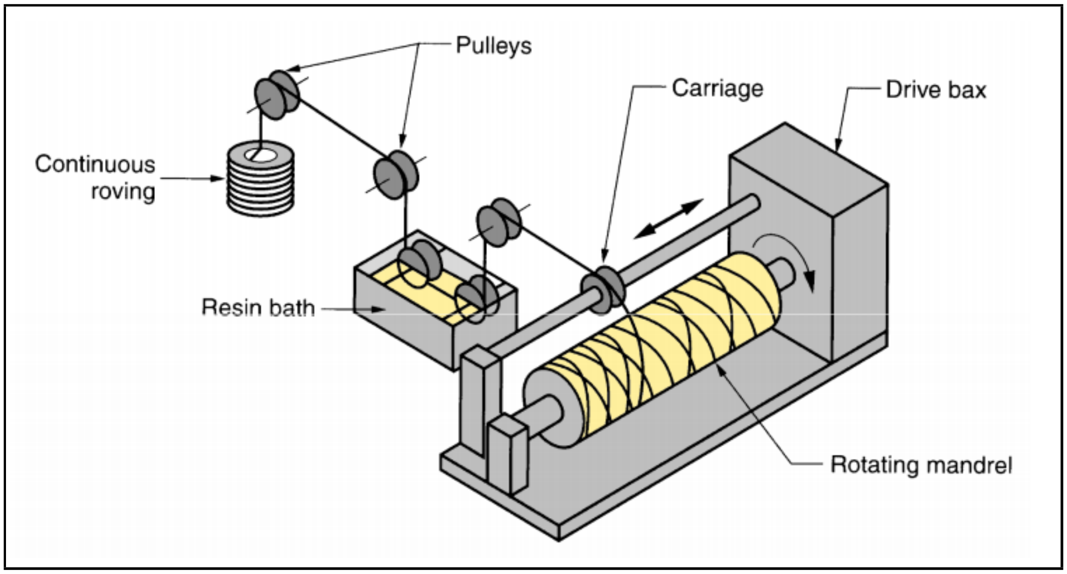

Figure 1: Filament winding schematic diagram

Advantages:

- Fast and economic
- Control over resin content being used with the help of nips and dies
- Minimization of cost as no secondary process involved for conversion of fibre to fabric, which happens while winding
- Desired patterns can be used for laying the fibres to obtain the desired structural properties to match applied loads

Disadvantages:

- Limited application, only for manufacture of convex, cylindrical shaped components
- Increased cost of mandrel for manufacture of larger components
- Difficulty in laying the fibres exactly as desired on the component, accurate functioning of pulleys and carriage required
- External surface of the mould remains unmolded, hence cosmetically unattractive
- Low viscosity resins need to be used considering their health and safety properties

Materials manufactured:
Glass fibre pipes, sailboard masts, golf clubs, bicycle rims, aircraft fuselages

5 References

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FLEXURE TEST

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Contents

1 Title

Determination of the **Modulus of Elasticity** and the **Flexural Strength** of E-glass epoxy woven composites using three point bending method as per ASTM D790.

2 Objectives

This experiment is modeled to-

- Understand the construction and operation of a **Universal Testing Machine** (UTM).
- Compare the **three point bending** and **four point bending** tests.
- Finding the **Flexural Strength and Modulus of Elasticity** of the composites.

3 Equipment Used

- Steel Rule
- Vernier Calipers
- Commercial UTM of 50 kN capacity with maximum 1% loading and displacement error

4 Test Specimens

- E-glass epoxy woven composite samples

5 Experimental Setup

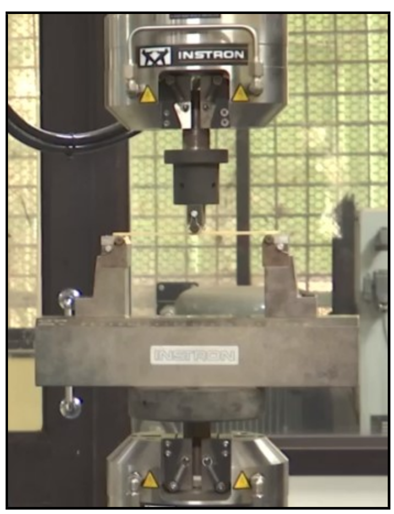

Figure 1: Flexure Tests Experimental Setup

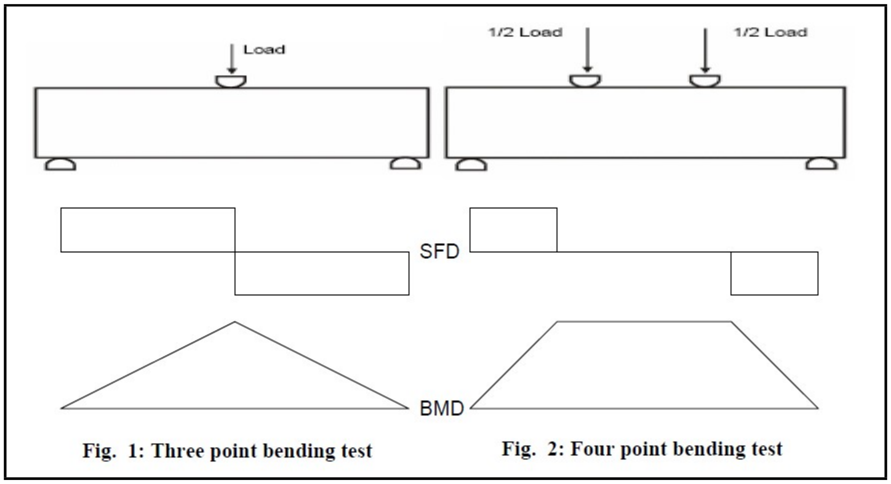

Figure 2: Flexure Tests Schematic

6 Observations and Calculations

6.1 Specimen Dimensions

Width, b	27.06 mm
Thickness, d	2.9 mm
Length, L	162 mm

Table 1: Specimen Dimensions

Based on the data obtained from the UTM, we plot the load vs. deflections plots for each sample to determine the Flexural Strength. Along with these, we also plot the same graphs for the linear region in each case for determination of the Modulus of Elasticity.

6.2 Load vs. Deflection

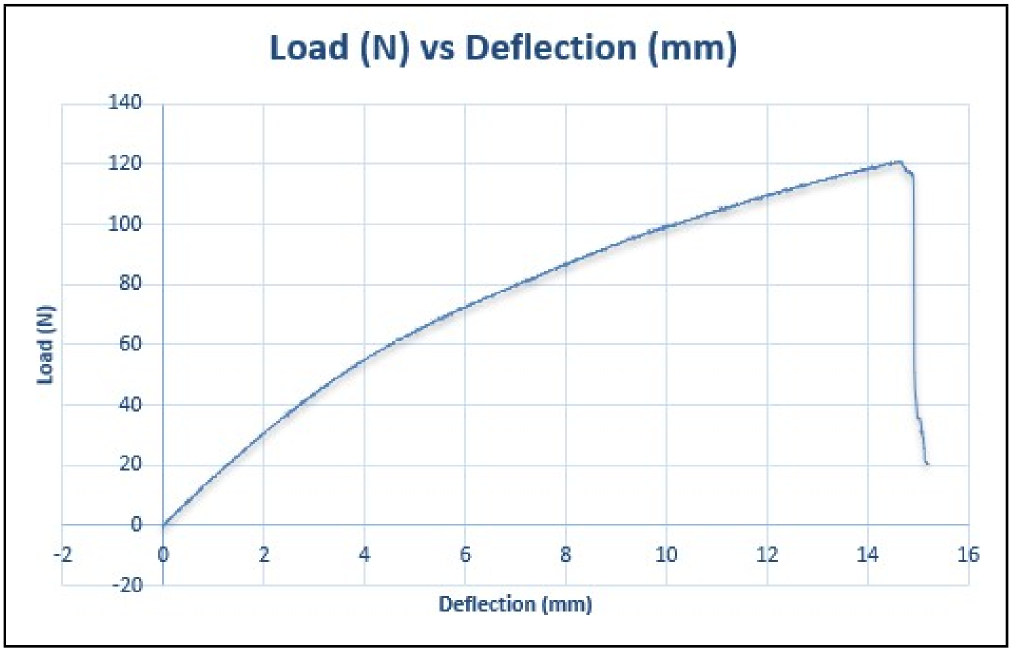

Figure 3: Sample 1

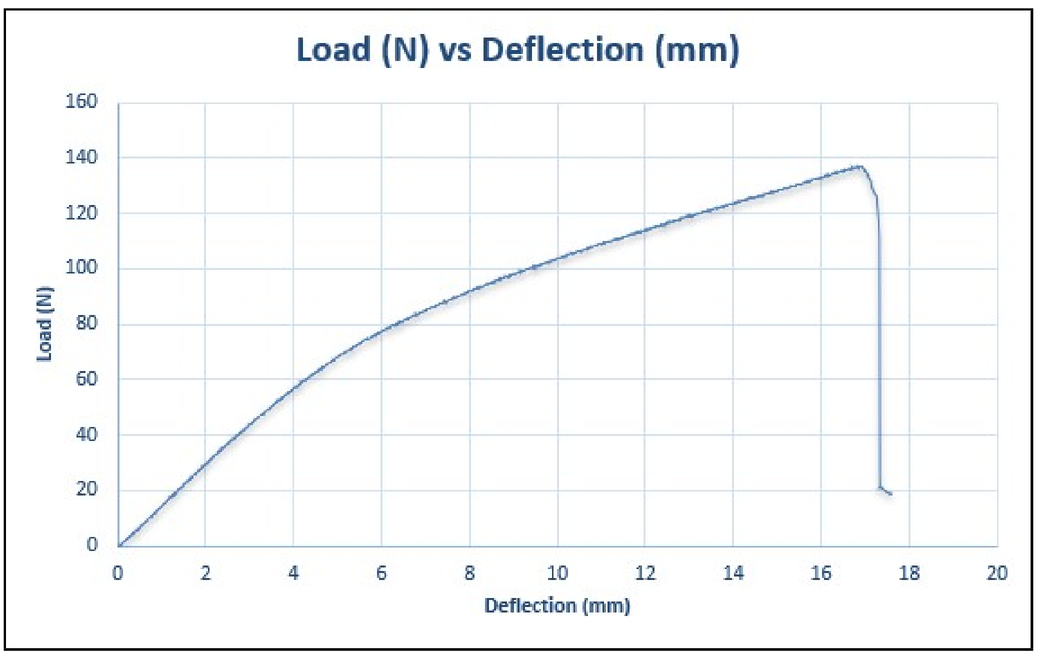

Figure 4: Sample 2

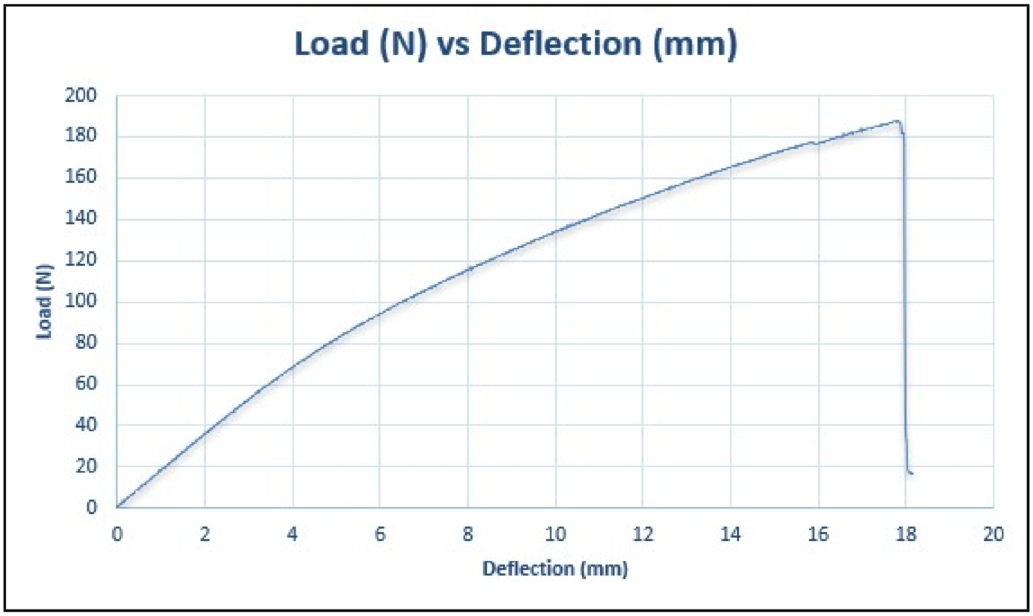

Figure 5: Sample 3

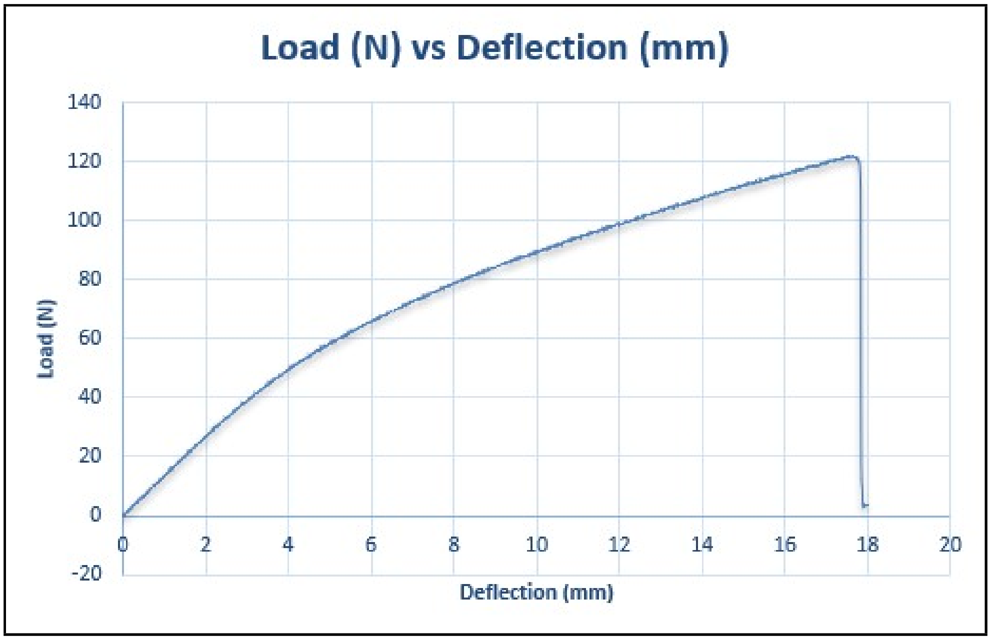

Figure 6: Sample 4

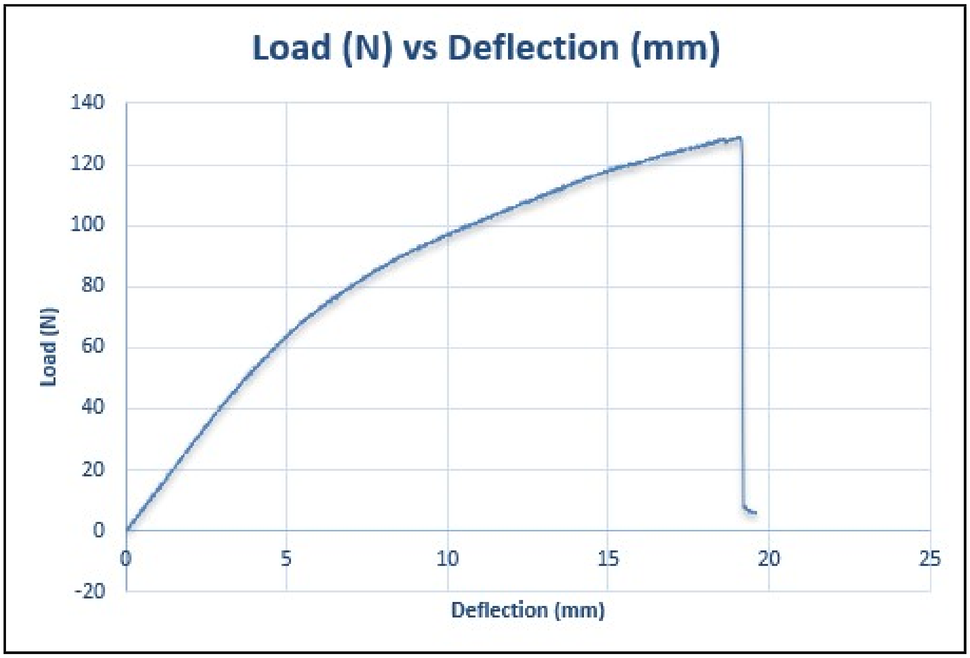

Figure 7: Sample 5

6.3 Load vs. Deflection for linear region

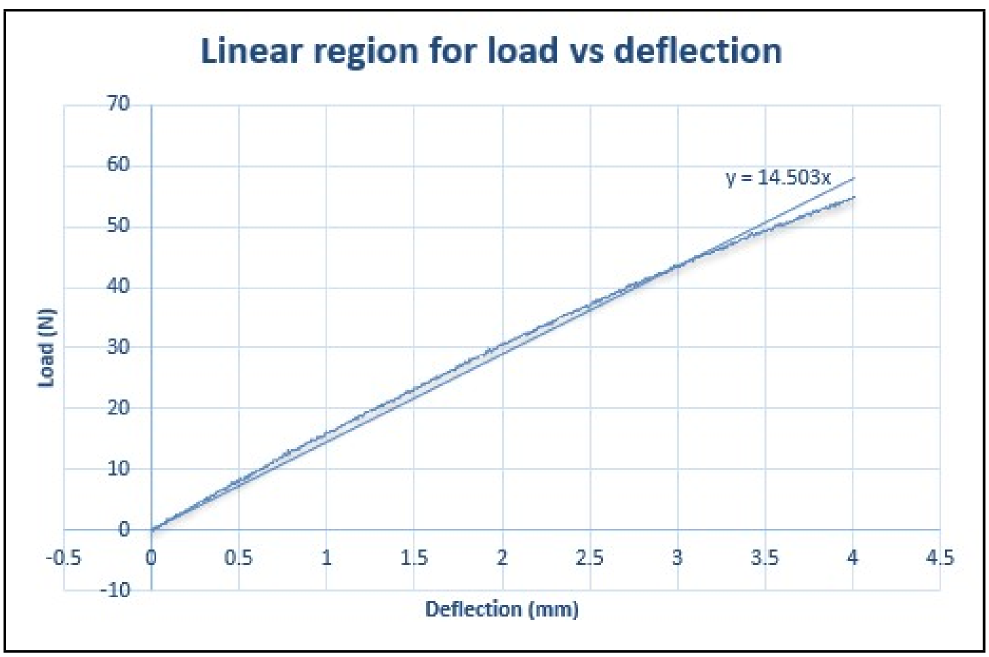

Figure 8: Sample 1

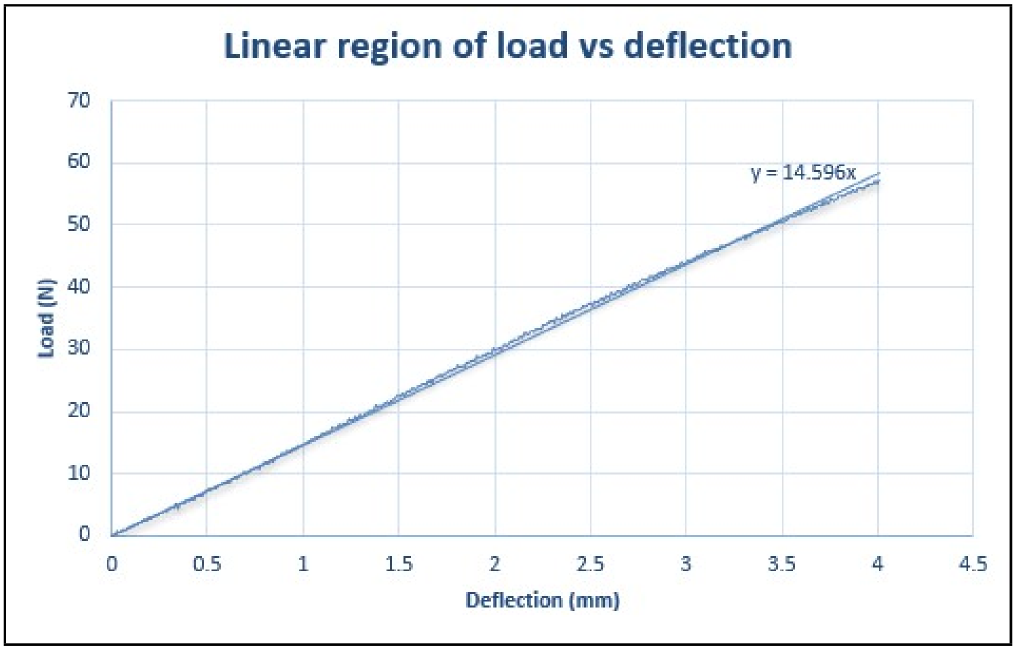

Figure 9: Sample 2

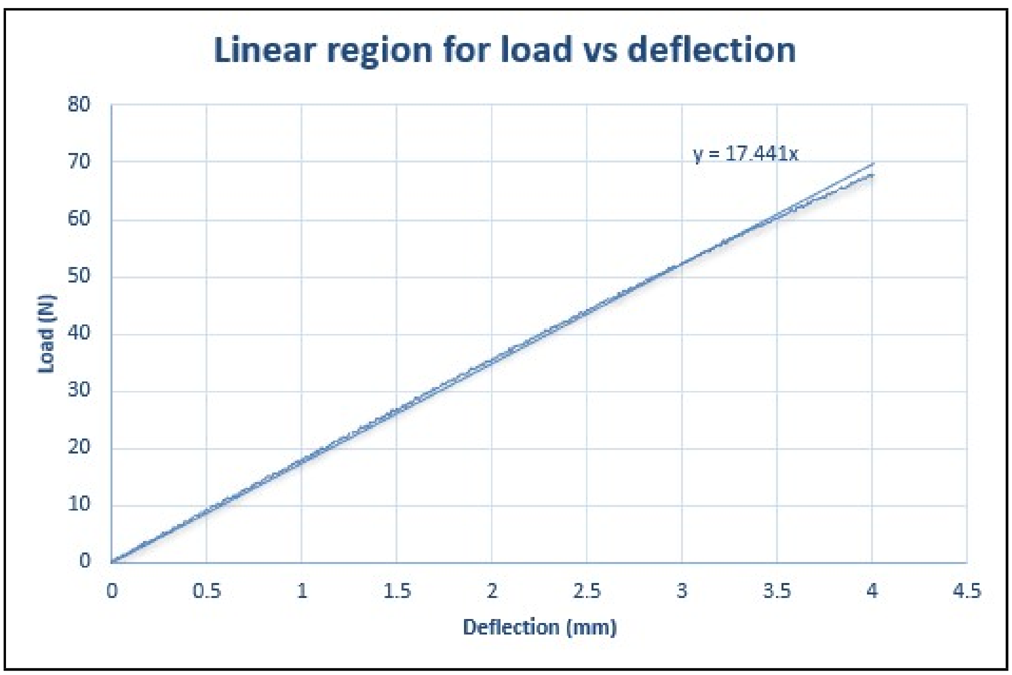

Figure 10: Sample 3

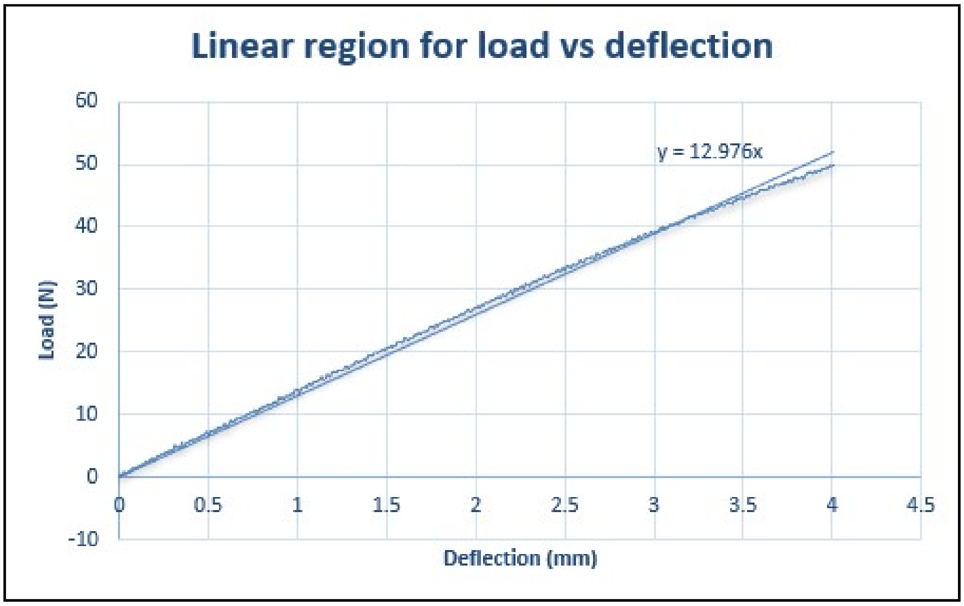

Figure 11: Sample 4

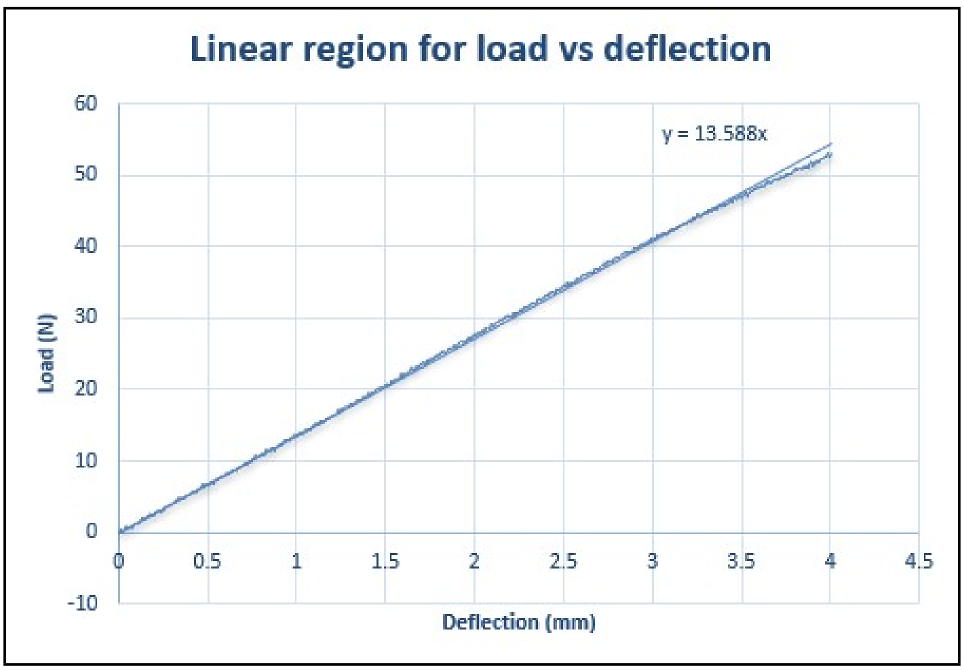

Figure 12: Sample 5

The Flexural Strength of the specimen is given by-

$$\sigma_f = \frac{3PL}{2bd^2} \tag{1}$$

The Modulus of Elasticity of the specimen is given by-

$$E_B = \frac{mL^3}{4bd^3} \tag{2}$$

Where,

- P: max load before failure on load vs. deflection curve (N)
- L: Length of the beam (mm)
- b: Width of the beam (mm)
- d: Thickness of the specimen (mm)
- m: Slope of load vs. central deflection curve (N/mm^2)

All the calculated values are tabulated below-

Sample	**Max Load** (N)	**Max Deflection** (mm)	**Slope** (N/mm^2)	**Flexural Strength** (MPa)	**Modulus of Elasticity** (MPa)
1	120.56519	14.60493	14.503	128.7373071	23357.21795
2	136.58759	16.81143	14.596	145.8457331	23506.99533
3	187.7049	17.75854	17.441	200.4278628	28088.8946
4	122.14981	17.67857	12.976	130.4293354	20897.97009
5	128.71585	19.05195	13.588	137.4404329	21883.60185

7 Error Analysis

Let us now calculate the mean, variance and the standard deviation values of the flexural strength and elasticity modulus for the 5 samples. For N observations $x_1, x_2, ..., x_N$,

$$\textbf{Mean} = \bar{x} = \frac{\sum_1^N x_i}{N}$$

$$\textbf{Variance} = var(x) = \frac{\sum_1^N (\bar{x} - x_i)^2}{N}$$

$$\textbf{Standard Deviation} = std(x) = \sqrt{var(x)}$$

7.1 Flexural Strength

Mean	148.5761343 MPa
Variance	885.7365141 $(MPa)^2$
Standard Deviation	29.76132581 MPa

7.2 Modulus of Elasticity

Mean	23546.93596 MPa
Variance	7612669.252 $(MPa)^2$
Standard Deviation	2759.106604 MPa

8 Assignment Answers

1) What are the different fixtures used in an UTM (Flexure and tension test)?

- **Flexure Test**: 3 point bending method is applied. The fixture commonly used is **ASTM C1161**.
- Tensile Test: Wedge action with self tightening grip is applied. The fixture commonly used is **ASTM C469**.

2) Why is the overhang required in the specimen?
Overhang is mainly required to ensure that the specimen does not slip through the supports while performing the flexure test. For safety purposes, the specimen should be long enough to **allow overhanging by about 10%** on each end.

3) What if S/d ratio is > 16?
S/d is known as the **Span-to-Depth ratio** for a specimen. For Flexure tests, we prefer a $S/d < 16$ to ensure that the **failure occurs only due to the bending moment**. In case $S/d > 16$, there is contribution of shear as well in the failure, and hence the formula $\sigma_f = \frac{3PL}{2bd^2}$ will not give us an accurate result for the Flexure Strength. For this, the following relation has to be used-

$$\sigma_f = \frac{3PL}{2bd^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{d}{L}\right)\left(\frac{D}{L}\right)\right] \tag{3}$$

In the equation above, D is the deflection of the specimen centerline at the middle location.

4) What are the limitations on the crosshead motion speed?
The UTM can be operated over the range of crosshead motion speed where in the error in the load measuring system **does not exceed by 1%** of the maximum load that is expected to be measured.

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

DEPARTMENT OF AEROSPACE ENGINEERING

Aircraft Structures Laboratory - AE 314

INTER - LAMINAR SHEAR STRENGTH TEST

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Contents

1 Aim

To determine the **inter-laminar shear strength** of woven E-Glass Epoxy composites using the **D3846 double notched shear test**.

2 Equipment Used

- Universal testing machine (UTM) of 100 kN capacity with maximum 1% loading and displacement error
- Vernier Calipers

3 Materials Used

The test specimen is made up of

- E-Glass fiber
- Epoxy Resin (LY 556)
- Hardener (HY 951)

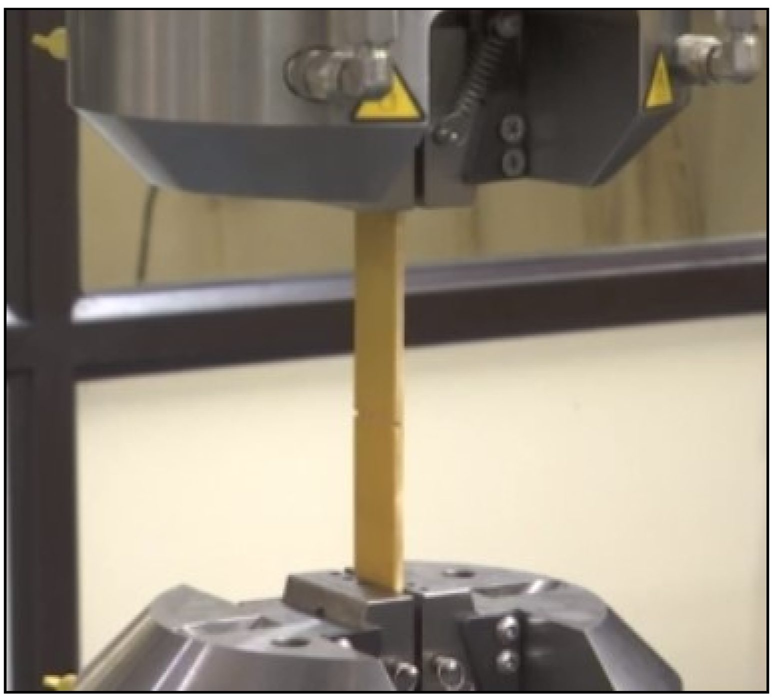

Figure 1: Sample mounted on UTM for ILSS test

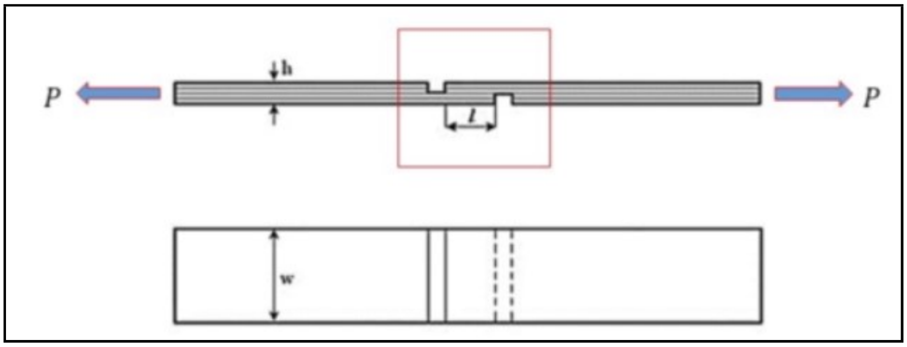

Figure 2: Double notched shear test

4 Observations and Calculations

4.1 Specimen Dimensions

Using Vernier calipers, we measure the specimen dimensions required for estimating the inter-laminar shear strength of the specimen.

Width (mm)	26
Distance between notches (mm)	14

Table 1: Specimen Average Dimensions

The test rate applied using the UTM was 0.5 mm/min.

4.2 Calculations

$$S = \frac{P}{ad} \tag{1}$$

$$\begin{aligned} S &= \text{In plane shear strength} \\ P &= \text{Maximum load at the time of breaking } (N) \\ a &= \text{Distance between the notches } (mm) \\ b &= \text{Width of the specimen } (mm) \end{aligned}$$

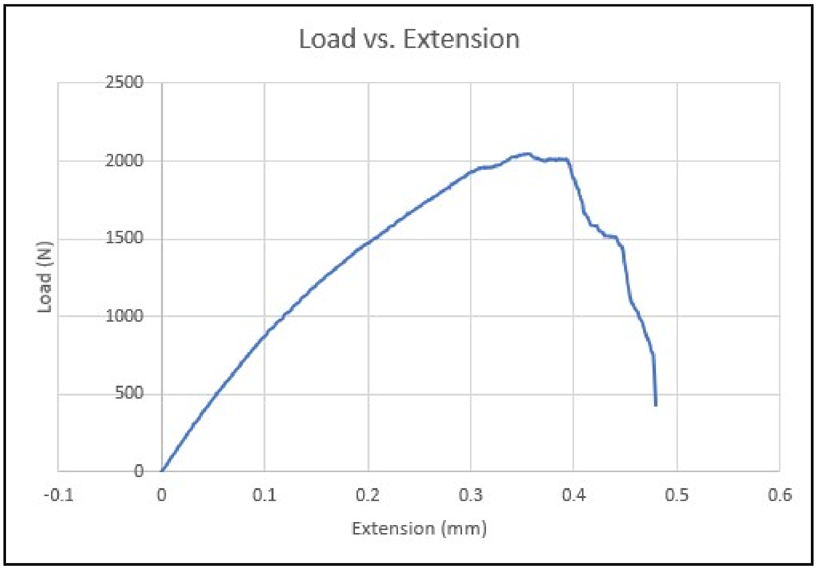

Figure 3: Load vs. Extension

From the data obtained using the UTM, the maximum load comes out to be **2041.668 N**.

$$S = \frac{2041.668}{26 \times 14} = \mathbf{5.608979\ MPa}$$

Width (mm)	Distance between notches (mm)	Max Load (N)	ILSS (MPa)
26	14	2041.668	5.608979

5 Assignment Answers

1) **What is inter-laminar shear strength? What is the importance of ILSS?**
Laminated composites consist of multiple lamina stacked over each other to form a laminate. Inter-laminar shear strength (ILSS) in the **shear strength measured at the time of failure** in which the plane of fracture is along the **interface between two lamina**. ILSS is an important property in design of laminates subjected to transverse loads. **Delamination** is a critical failure mechanism observed for laminates, which is the failure at the interface between different layers. The resistance against delamination is characterized by the inter-laminar shear strength of the composite.

2) **What are possible sources of error in the experiment and what can be done to eliminate them?**
   - The specimen should be mounted on the UTM such that the **notches are at the center**, i.e. equidistant from the two ends of the holder. If a notch is placed very near to a holder, the shear stress induced will not be linear which will lead to errors in the measurements.

- The specimen must also be mounted **perfectly vertical** to avoid non-uniform loading which may again lead to measurement errors.
- The **fixture grips** used for mounting the specimen must be **identical**, otherwise error may be induced due to different grips at the 2 ends.

3) **How is the distance between two notches influencing your experiment?**
Inter-laminar shear strength along the midplane between the notches is non uniform, but becomes uniform as the distance between the notches is reduced.

$$S = \frac{P}{ad}$$

here a is the distance between the two notches, which when reduced will lead to a lower value of the failure load. Thus the inter-laminar shear strength measured will **almost remain constant** with decrease in notch separation. It is better to perform the test with lesser distance between the notches to keep the failure load low.

6 References

- ASTM D790-99 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

- Engineering Mechanics of Composite Materials by Daniel, Ishai.