TÉCNICO LISBOA

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INSTITUTO SUPERIOR TECNICO

Ships in Composite Materials

ASTM D 790-03: *Standard Test Methods for Flexural Properties of Un-reinforced and Reinforced Plastics and Electrical Insulating Materials* – Task 1C

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1. Introduction

The goal of the project, as stated in the title, is to determine the flexural properties of various materials, such as unreinforced and reinforced plastics, to graphically represent the flexural stress-strain curve, and to estimate the flexural strength modulus and the amount of energy required to produce a specific deflection of the material. We'll gain some basic mechanical testing and data analysis experience this way. This test, in general, applies a load on a simply supported beam with two supports and a loading point in the center of the supports.

To get experimental data for the strength and stiffness of a laminate, flexural testing should be done following the standard ASTM D 790-03: "Standard Test Methods for Flexural Properties of Un-reinforced and Reinforced Plastics and Electrical Insulating Materials."

It is believed that the lamination is made of a balanced 0-90° cloth. There should be no variations in attributes between 0 and 90 degrees, in principle. The validity of this notion, however, will be established by analyzing specimens sliced from the laminate at various angles. At 0 and 90 degrees, flexural specimens are sliced.

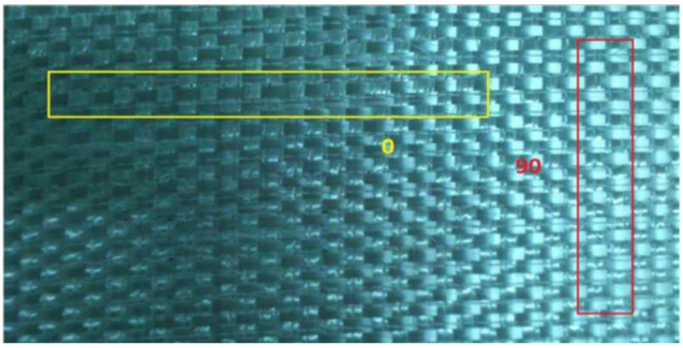


Fig.1 0 and 90° flexural specimens

2. Data measurement and initial dimensions

To do the necessary calculations, we will need the actual cut specimen measurements, thus the specimen thickness and breadth should be measured at three sites (in the middle and at both ends) and an average value utilized.

As a result, the starting dimensions for each specimen are as follows:

Sample		Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	AVG (mm)
0º	1	4.40	4.52	4.37	4.430
	2	4.30	4.55	4.57	4.473
90º	1	4.38	4.27	3.92	4.190
	2	4.05	4.24	4.23	4.173

Sample		Width 1 (mm)	Width 2 (mm)	Width 3 (mm)	AVG (mm)
0º	1	16.86	17.81	18.28	17.650
	2	18.10	17.60	17.39	17.697
90º	1	18.89	18.46	18.29	18.547
	2	17.95	17.54	17.21	17.567

Span	**[mm]**	90
Diam	**[mm]**	20
Nose	**[mm]**	20

Tab.1 Specimen dimensions

The force exerted in kg was reported in the data supplied. The first stage was to transform this force from kilograms to Newtons. In addition, the location was specified in millimeters. The deflection is merely a shift in coordinate references that results in a null deflection value at the start of the test when the first load is applied.

Flexural testing can be performed in two methods, as stated in the paper "ASTM-D790-03": Procedures A and B The first approach is suitable for materials that break at minor deformations and is used to test flexure characteristics, especially the flexural modulus, whereas the second procedure is suited for materials that achieve high degrees of deflection and is used to assess flexural modulus strenght. The concept of calculating the rate of crosshead motion and midspan deflection for each specimen and process is presented in an excel sheet.

Some parameters required to be discovered for each specimen in order to compare the qualities of the specimens. In terms of "strengths," like Strength at maximum load, σ_{fM}. That would be the maximum flexural stress that the test specimen can withstand during a bending test. However, in order to determine the'strength' at maximum load, the flexural stress must first be computed. Because the span-to-depth ratio is greater than 16:1, the flexural stress calculation for "Beams evaluated at Large Support Spans" will be utilized.

Sample		**Span to Depth Ratio**
0º	**1**	20.31602709
	2	20.11922504
90º	**1**	21.4797136
	2	21.56549521

Tab.2 Span-to-Depth ratio

All of the values are more than 16. The following formula was used to calculate flexural stress:

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

The 'break' strength, (σ_{fB}), must also be computed. This might be when an abrupt decline in load indicates that perhaps the load bearing capability of the beam has indeed been surpassed, or when the strain offset reaches 2%, whichever comes first.

'Fortitude' at 'first failure': Since this material is a composite, just a few fibers or the resin may break before the entire beam collapses. A modest reduction in load or stiffness, for example, will indicate this. Because this relates to material damage, it is a significant strength which might or might not be included in design calculations, but should be calculated if it happens.

The Tangent Modulus of Elasticity should be determined in relation to the Modulus of Elasticity. The Tangent Modulus of Elasticity is the relation of stress to corresponding strain within the elastic limit. It may be computed by establishing a tangent to the sharpest initial straight-line segment of the load-strain curve and then using the following equation:

$$E_B = \frac{L^3 m}{4bd^3}$$

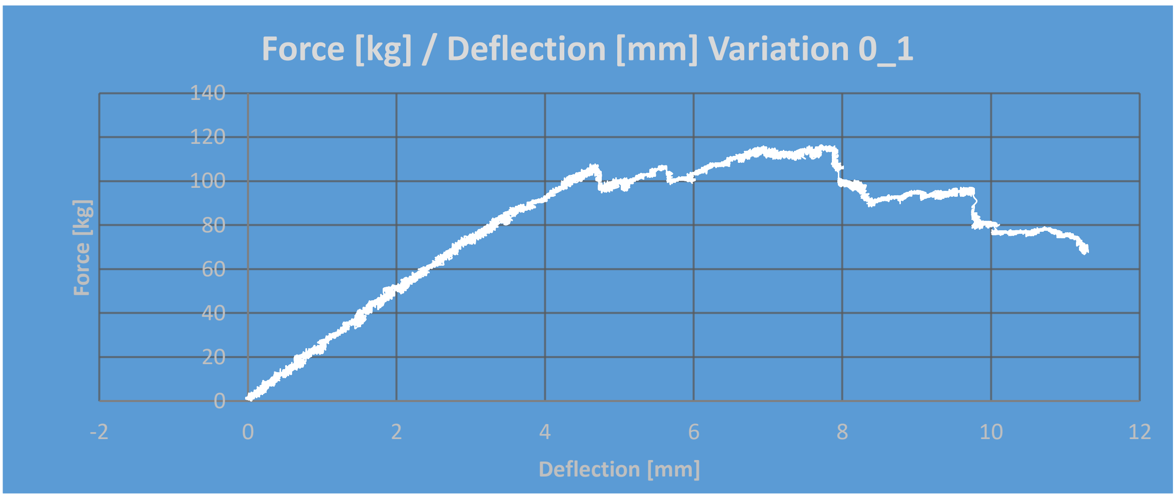
Since these tests should always be performed on multiple specimens, the arithmetic mean in each of the above-mentioned parameters should also be obtained to provide average values. The standard deviation needs also be calculated, which may be done using equations.

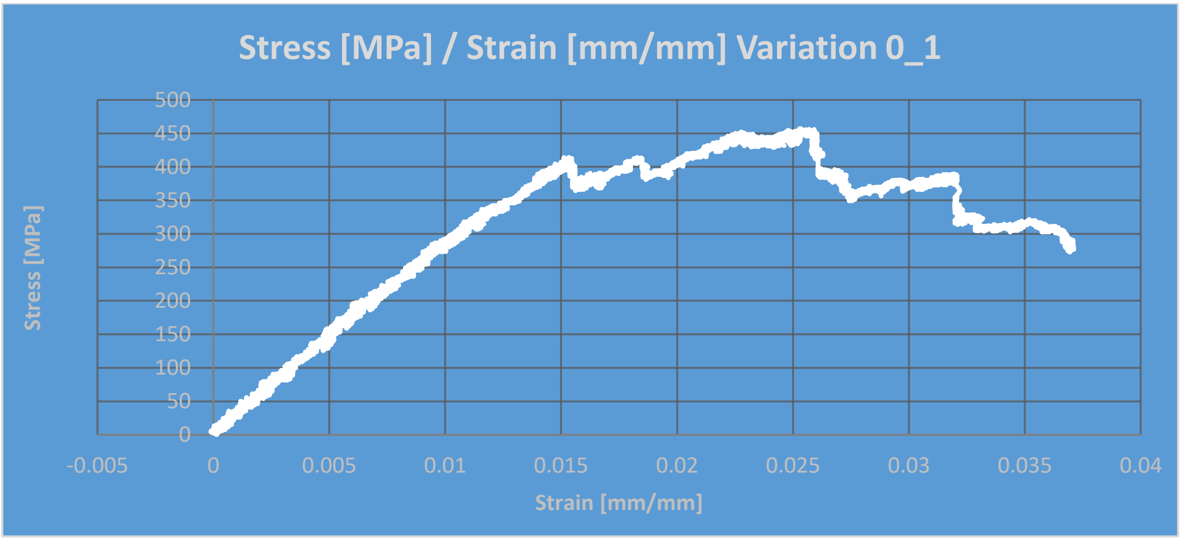
$$s = \sqrt{\frac{(\sum X^2 - n\overline{X^2})}{(n-1)}}$$

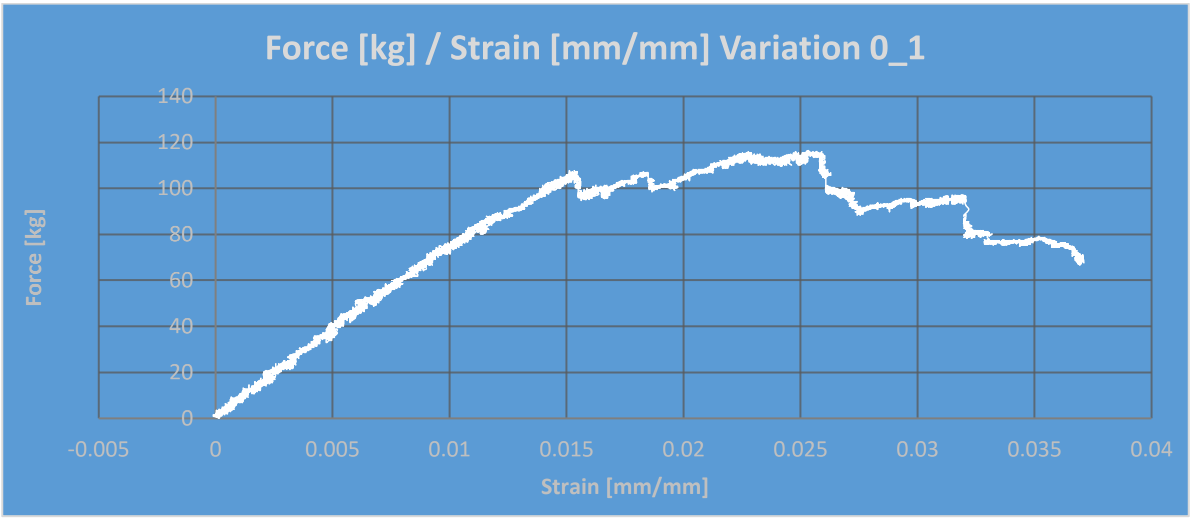
3. Graphs of results obtained

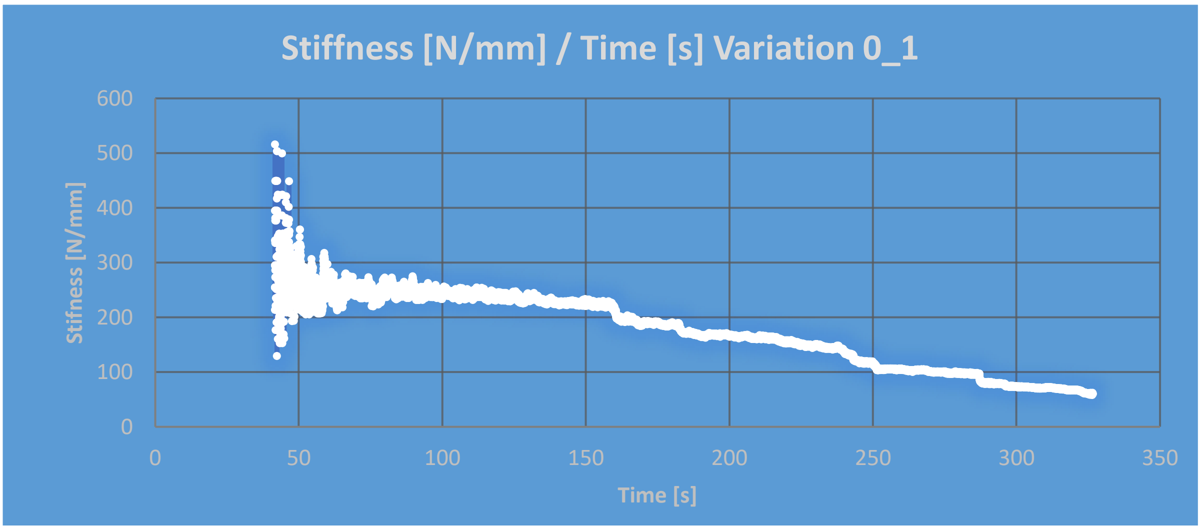
The acquired findings will be shown in this section of the study. To acquire the required data, the load, stress, deflection, flexural stress, and strain were first computed for each sample. Each sample's findings will be given. The load-deflection curve, as well as the force-deflection and flexural stress versus strain curves, will be given.

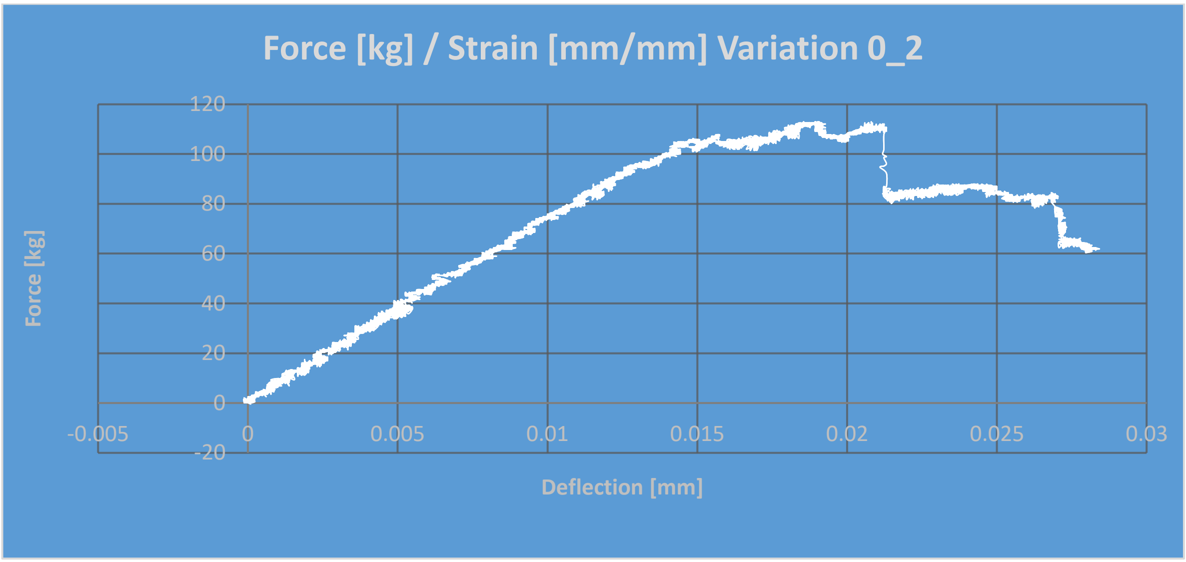
Sample one and two for 0°:




Stress [MPa] / Strain [mm/mm] Variation 0_1
Stress [MPa]
500
450
400
350
300
250
200
150
100
50
0
-0.005
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
Strain [mm/mm]


Force [kg] / Strain [mm/mm] Variation 0_1
Force [kg]
140
120
100
80
60
40
20
0
-0.005
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
Strain [mm/mm]


Stiffness [N/mm] / Time [s] Variation 0_1
Stifness [N/mm]
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
Time [s]

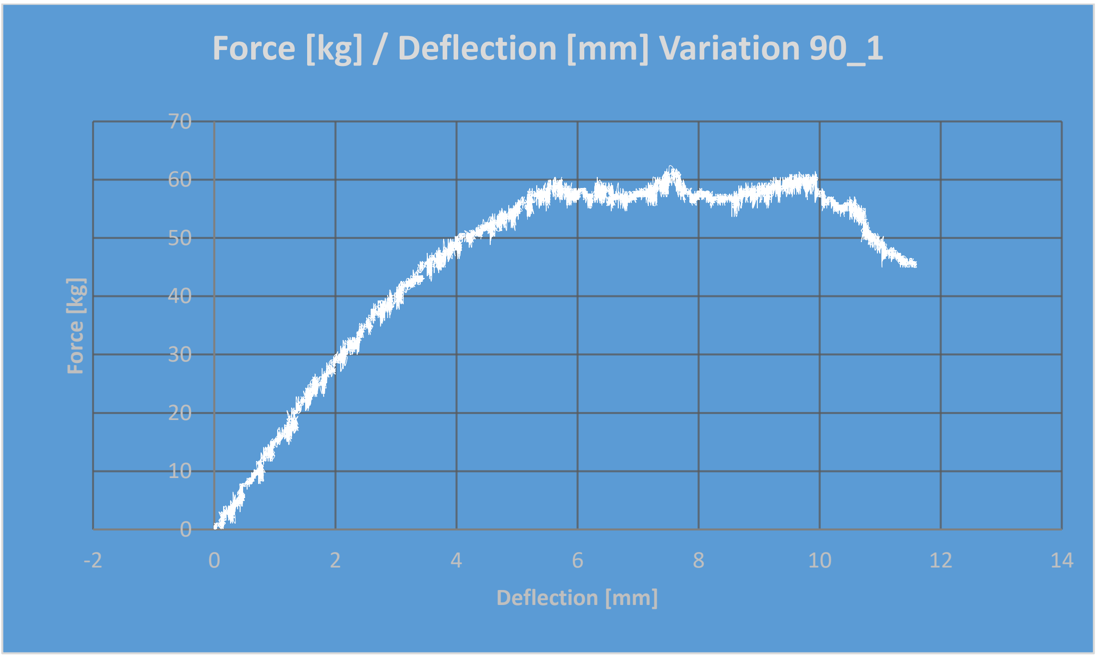


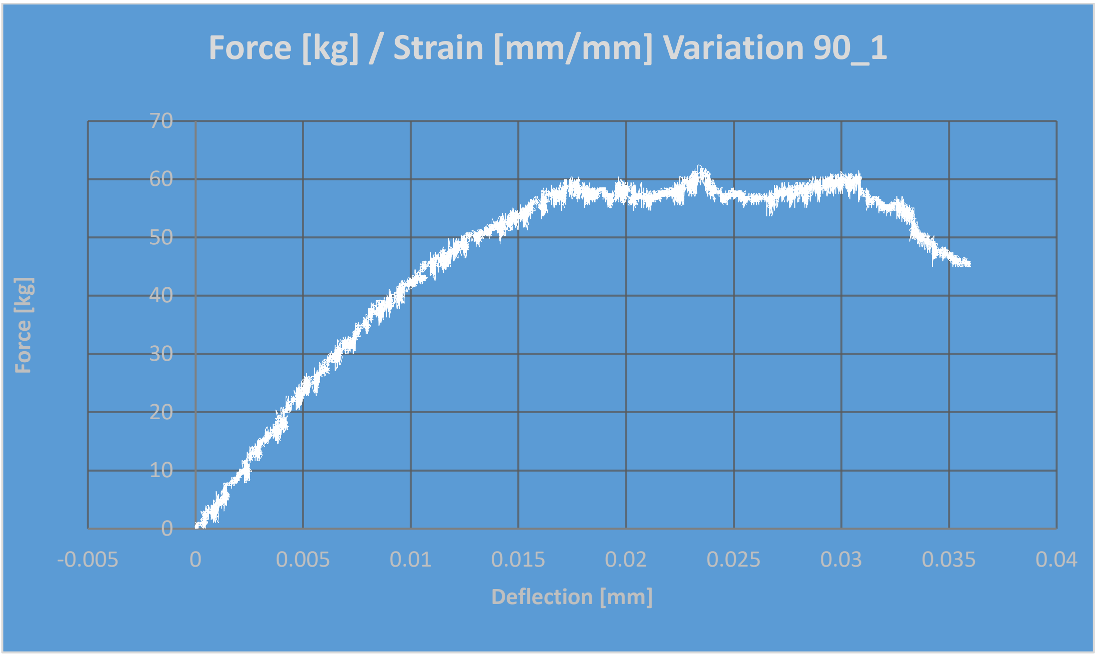
The results obtained for this procedure are summarised in the following table:

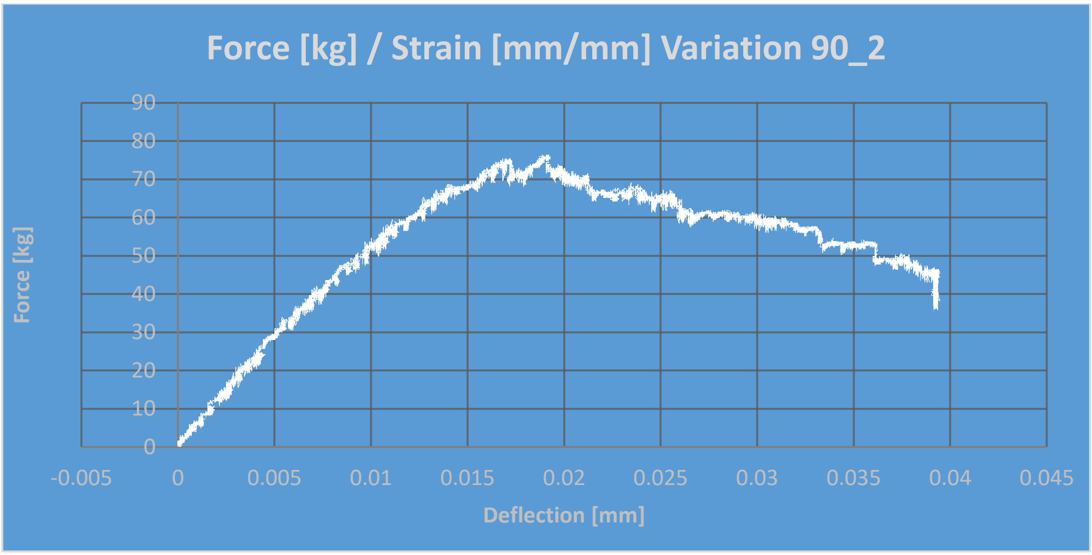
Sample 0º - 1					
Tangent Modulus of Elasticity [MPa]	**l [mm]**	**b [mm]**	**d [mm]**	**m [N/mm]**	
26162.03219	90	17.65	4.43	220.2722699	
Strength at First Failure (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
379.8614674	928.8120888	90	17.65	4.43	9.770524013
Strength at Maximum Load (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
447.7391848	1141.795032	90	17.65	4.43	4.710851887
Strength at Break (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
404.5514234	1023.471175	90	17.65	4.43	6.094910681

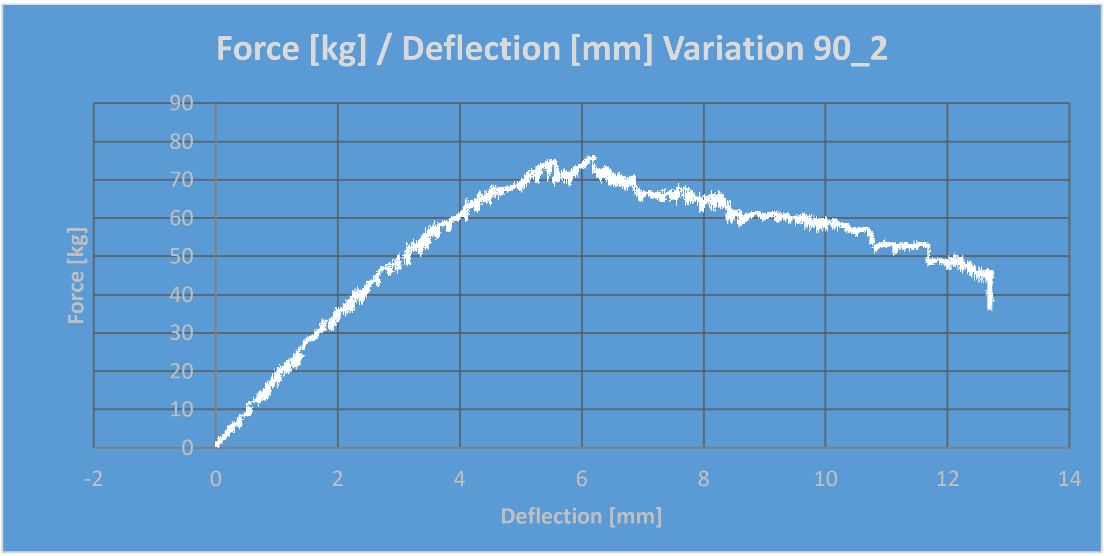
Sample 0º - 2					
Tangent Modulus of Elasticity [MPa]	l [mm]	b [mm]	d [mm]	m [N/mm]	
26507.2719	90	17.65	4.43	223.1790293	
Strength at First Failure (MPa)	Force (N)	l (mm)	b (mm)	d (mm)	Deflection at midpoint (mm)
412.2776474	1051.363	90	17.65	4.43	4.710851887
Strength at Maximum Load (MPa)	Force (N)	l (mm)	b (mm)	d (mm)	Deflection at midpoint (mm)
444.6478839	1108.664	90	17.65	4.43	7.910316358
Strength at Break (MPa)	Force (N)	l (mm)	b (mm)	d (mm)	Deflection at midpoint (mm)
417.5152345	1056.602	90	17.65	4.43	6.047863311

Sample one and two for 90°:




Force [kg] / Strain [mm/mm] Variation 90_1
Force [kg]
Deflection [mm]
0
10
20
30
40
50
60
70
-0.005
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04


Force [kg] / Strain [mm/mm] Variation 90_2
Force [kg]
Deflection [mm]
0
10
20
30
40
50
60
70
80
90
-0.005
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045


Force [kg] / Deflection [mm] Variation 90_2
Force [kg]
Deflection [mm]
0
10
20
30
40
50
60
70
80
90
-2
0
2
4
6
8
10
12
14

The results obtained for this procedure are summarised in the following table:

Sample 90º - 1					
Tangent Modulus of Elasticity [MPa]	**l [mm]**	**b [mm]**	**d [mm]**	**m [N/mm]**	
12253.44983	90	17.65	4.43	103.1684078	
Strength at First Failure (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
231.8435565	588.039379	90	17.65	4.43	5.699800854
Strength at Maximum Load (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
244.347642	611.411343	90	17.65	4.43	7.515683058
Strength at Break (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
223.666151	564.374608	90	17.65	4.43	6.467661042

Sample 90º - 2					
Tangent Modulus of Elasticity [MPa]	**l [mm]**	**b [mm]**	**d [mm]**	**m [N/mm]**	
15699.35762	90	17.65	4.43	132.1813654	
Strength at First Failure (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
289.4422686	734.761	90	17.65	4.43	5.558733337
Strength at Maximum Load (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
296.2811007	748.9598	90	17.65	4.43	6.212016154
Strength at Break (MPa)	**Force (N)**	**l (mm)**	**b (mm)**	**d (mm)**	**Deflection at midpoint (mm)**
272.460644	687.4314	90	17.65	4.43	6.480817861

The flexural strain was calculated for each sample using all of the data for all of the samples shown.

The next step is to compare the samples' results. The stress at the time of the first fail, the highest stress recorded, and the flexural stress at break will be compared. The Tangent Modulus of Elasticity between the samples will then be compared, as will the strain at the time of each stress. The force at the initial fracture as well as when the specimen breaks will be shown.

Since no errors were made during the experimental test, the findings for the first sample at 0 degrees are comparable between samples. However, the findings are not particularly consistent between samples since the graphics in the 90° samples are not very exact, most likely owing to errors made during the experimental test. Furthermore, because the specimens were chopped in different orientations, varied findings were predicted.
As can be observed, the maximum stress and break tension reported in the 0o samples are much higher than those reported in the 90° samples. The values in the 0o samples are likewise greater than the values in the 90° samples for the first failure stress.

Sample		Tangent Modulus of Elasticity [MPa]	Strength at First Failure (MPa)	Strength at Maximum Load (MPa)	Strength at Break (MPa)
0º	1	26162.032	379.861	447.739	404.551
	2	26507.272	412.278	412.278	412.278
90º	1	12253.450	231.844	231.844	231.844
	2	15699.358	289.442	289.442	289.442
Avg		20155.528	328.356	345.326	334.529
Std Deviation		6179.124	67.713	84.683	73.886

In terms of deflections, the values of the first failure and break are not statistically different between the 0° samples, but the maximum stress deflection is. The 90° samples' results are more comparable to the 0° samples' values.
The first failure and break, as seen, occur with a lesser deflection in the 0° samples than in the 90o samples. These results are not especially accurate since, as previously stated, it was not able to pinpoint the specific moment of the first fail and break in 90° samples.
When the first fail occurs, the strain values between 0° samples are highly comparable. Furthermore, the readings are comparable amongst the 90° samples.

When the strain at maximum stress and break stress are compared, the results change somewhat between the 0° and 90° samples, as well as between each other. The same holds true for the stresses, as previously stated. In the 0 degrees samples, the forces for the initial fail and the break are greater than in the 90 degrees data.
The standard deviation for stress and strain was computed after obtaining and comparing all of the above values.
The qualities of laminates with 0° directions differ from laminates with 90o directions, according to all of the results.
One of the most essential aspects of composites is their mechanical strength, which is controlled by the number of layers, the angle of application of the fibers, and the material used. Furthermore, curing temperature and matrix type will influence its characteristics.
Even when the first break occurs, the remaining fibers manage to hold and have greater displacement and even more stress, because all of the maximum stresses were greater than the stresses at first failure with the exception of the second sample of 90o direction, which probably happened due to the reason explained earlier, where the curve is not very accurate and the results obtained are not very precise.

Another conceivable, but less likely, explanation for why this material has different qualities in various directions is that, assuming the specimen in investigation was made utilizing a Hand Lay-up technique with unidirectional reinforcing. This approach has various drawbacks, including inferior product quality due to less dependable equipment. It is vital to be able to laminate the reinforcement and matrix, which includes resin mixing, laminate resin amounts, and laminate quality. Because it is so reliant on human talents, it is difficult to assure consistency throughout the process, and as a result, product quality may suffer.
Furthermore, it is apparent that the characteristics of the specimens would alter when sliced in different orientations 0 and 90 degrees

This is because they were made of an orthotropic material, which means their qualities will change depending on the orientation. The material's characteristics will be better with a 0° direction than with a 90° direction in this situation since the Tangent Modulus of Elasticity as the Flexural Strength and Flexural Stress at Break have greater values. The construction of a composite laminate made up of numerous laminates oriented in various directions.

4. A comparison of experimental and theoretical results

The experimental data seen above will be compared to relevant literature values in this part, and possible causes for the discrepancy will be investigated.
Based on the data shown in the table below, it was determined that the laminate in issue was made utilizing a Hand Lay-up procedure with unidirectional reinforcement and that it included E-glass fiber. The following table, which featured typical mechanical parameters of Fibre Reinforced Plastic laminates, was obtained from the papers given.
In addition, the Young Modulus and Tensile Strength were determined using values obtained from the Rule of Mixtures.

Values from E-Glass Polyester (Unidirectional) and the Rule of Mixtures are more similar to the ones obtained. So, when we compare the values, we get the following results:

	Experimental	Theoretical (Literature)	Theoretical (ROM)
Young Modulus [GPa]	20.156	15.000	38.053
Specific Young Modulus	10.664	8.800	20.188
Tensile Strength [MPa]	345.326	250.000	634.220
Specific Tensile Strength	182.705	147.000	336.463
Shear Modulus [GPa]	8.398	3.500	
Specific Gravity [g/cm3]	1.890	1.700	1.885
Fibre Volume Fraction	0.504	0.340	0.504

When the experimental results are compared to both theoretical values, the values differ. One possible explanation is that the resin effects the composite properties, and the resin employed in the specimen is unknown. Furthermore, the lamination technique, as well as material quality and man skill, may have an effect on the outcomes achieved. Furthermore, the tests may contain experimental errors that arise during the flexural test, which is why reading the graphs in the 90o samples was challenging.

Furthermore, as previously noted, if the specimens were manufactured using a Hand Lay-up procedure, which greatly relies on the technician's ability, it's likely that the lamination of each specimen occurred under varied conditions in which some layers were not exactly at 0 or 90 degrees, potentially having been shifted during the resin application. As a result, flaws in the fabric might be to blame for the disparities in outcomes. This is less likely if the fabrication process is automated.

5. Conclusion

Since a study of the fabrication technique was undertaken in order to discover likely causes for the disparities in test findings, which demonstrated that direction might alter specimen qualities, the major goals of this assignment were met. It was able to process the flexural test data and calculate the deflection and stress values required to evaluate the tested specimens without having to perform the test itself, providing basic experience in mechanical testing of composites and applying what was learned about standard composite testing practices.

Knowing the manufacturing procedures and probable anomalies during the lamination technique, the most likely case scenarios may be anticipated to explain the disparity between theoretical and experimental results.

6. References

- Documents sent to help the projects
- Slide lectures
- ASTM D790-03: Standard Test Methods for Flexural Properties of Un-Reinforced and Reinforced Plastics and Electrical Insulating Materials