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TO: Dr. R (Boss)

FROM: Lily Badger and Leah Perkins

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TASK: Fiberglass Composite Sheet and Tube Layup

The task assigned was to properly design and lay up laminate composites of fiberglass in a sheet and in a tube. An additional aspect of this task is to choose the materials and design the methods so that the produced fiberglass composite is as strong as possible.

MATERIALS SELECTION:

Using the resources provided to us from the background reading, and understanding the accessibility of the different materials, the composite materials were chosen to be fiberglass reinforcement and epoxy resin matrix. Before selection, the safety training, hazards, and product SOPs for epoxy resin, E-glass, and the process of composite layups were researched. The 2120 Fibre Glast Epoxy Resin was chosen for the resin matrix because it has the highest comparative strength at room temperature compared to others, a 2 hour cure time, and can be used in structural applications [1]. The Style 120 E-Glass and 4 oz Fiberglass Fabric were chosen for the sheet lay up and the Style 120 E-Glass was chosen for the tube lay up because of their tight weave to contribute greater tensile strength than other fibers. [2,3]. The fiber for the tube weighed 30.35 g and the sheet fibers weighed 28.83 g all together.

The fiber to resin ratio was chosen to be 67% fiberglass to 33% total resin. This ratio gives a desired balance between strength and aesthetics, but will allow the composite to have the best performance.

Finally, the last material related selection made was in the specific layup orientation for the sheet composite. After choosing a variety of X-Y direction weave for the fabric, the layup orientation for the four sheets was decided as 0/90/45/-45 degrees. This allows the sheet layup to have the highest strength both in the axial and transverse loading directions, but also in off-axis loading (as shown in the figure below).

DOCUMENTATION OF METHODS:

To complete the sheet and tube layup, research was done for the sheet orientation, SOP of the materials being used, and how each procedure must be done. Using the DoItPoms simulation shown below in Figure 1 and composite theory, we decided to lay our fiber sheets with 0/90/45/-45 degree orientations. As we also used two different fiber weaves, we alternated the layers to prompt a more uniform composite. The fiberglass and epoxy resin SOPs were read for safety and research [4,5], as an SOP for each layup procedure was also written [6,7]. The procedures SOPs were used throughout our completion of the layups. The steps, materials, and safety precautions for the procedures were researched and documented in the procedure SOPs for our use. Additionally, we researched SOPs for formatting purposes.

WORKPLAN:

For the sheet lay up, we first cut the chosen fibers into 10 in squares and measured the ratio for fiberglass to resin by weight and then the ratio of epoxy resin to hardener. The next step is to assemble the composite in the wet lay up. We laid a sheet of mylar down, then laid one of the two Style 120 E-Glass fibers on top and applied enough epoxy resin to cover the sheet. We impregnated the resin matrix with the fibers by applying pressure with our hands, brushes, and a roller. After the first layer was entirely covered with resin, we laid the next fiber, 4 oz Fiberglass Fabric down 45 degrees in relation to the first layer. Like the first layer, the resin matrix aws impregnated with the fibers using the same tools. We continued this process for the next two layers, alternating the type of fiber used and rotating the layer 45° from the previous. The sheet lay up was left to dry for approximately 30 minutes before covering the top with mylar and cured completely.

For the tube layup, we also started by cutting the Style 120 E-Glass fiber into a 11.8 in by 20 in rectangle and carefully measuring the ratio for fiberglass to resin by weight and then the ratio of epoxy resin to hardener. Then, we assembled the workspace, with the mylar covered cylinder placed onto supports on either edge. To start, we applied a small amount of resin to the smaller edge of our fiber and laid it on the cylinder and wrapped the cylinder completely with the fiber, until mylar could not be seen. We then applied resin and impregnated it with the fiber by applying pressure with our hands. The fiber slowly continued to be wrapped around itself approximately 10 times, with resin being added and impregnated with each inch or so of rotation. Any excess resin was added and impregnated to the end of the fiber to prevent peeling. The entire tube was covered with mylar and left to cure.

DISCUSSION & RESULTS:

Defects

While observing the sheet composite lay up, there were air bubbles, dark-colored specks, misaligned or moved fiber strands, and a bubbly/blistery texture throughout (Fig. 3-6). The dark specks and misaligned fibers were likely due to the use of black foam brushes, as they made it hard to gauge the force needed to impregnate the matrix and broke apart in the process. Additionally, the bubbles and texture were likely caused by our application and impregnation, meaning we did not get the air bubbles out during our process. Overall, these defects are most likely due to our process and can be fixed with improvements made to it.

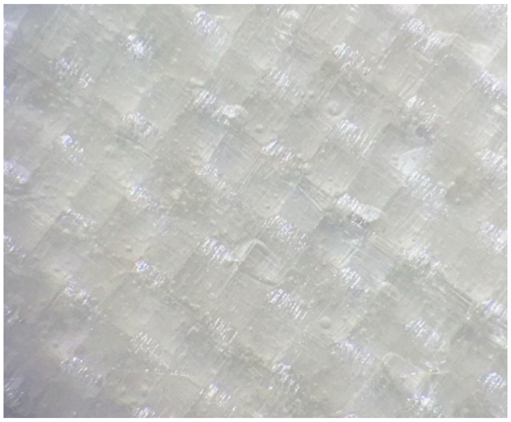

Figure 3:Air bubbles and bubbly texture in the sheet layup

Figure 4: A dark-colored speck and misaligned fiber in the sheet layup

Figure 5: The bubbly texture and misaligned fibers in the sheet layup

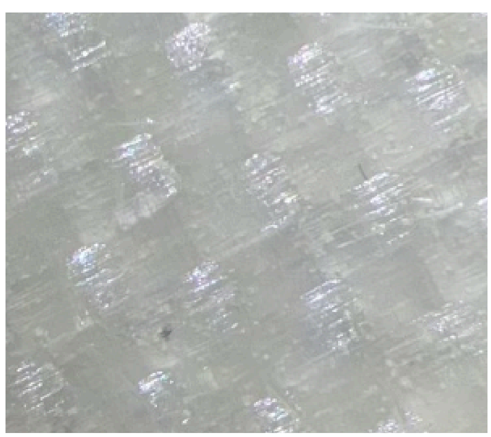

Figure 6: A dark-colored speck and the bubbly texture in the sheet layup

The surface of the tube lay up also contained bubbles, but none of the other defects of the sheet lay up (Fig. 7-8). Again, this is likely due to the bubbles not being removed in the application process. However, the tube lay up also had some discoloration, possibly due to the mixing and/or application of resin and fibers not being uniform.

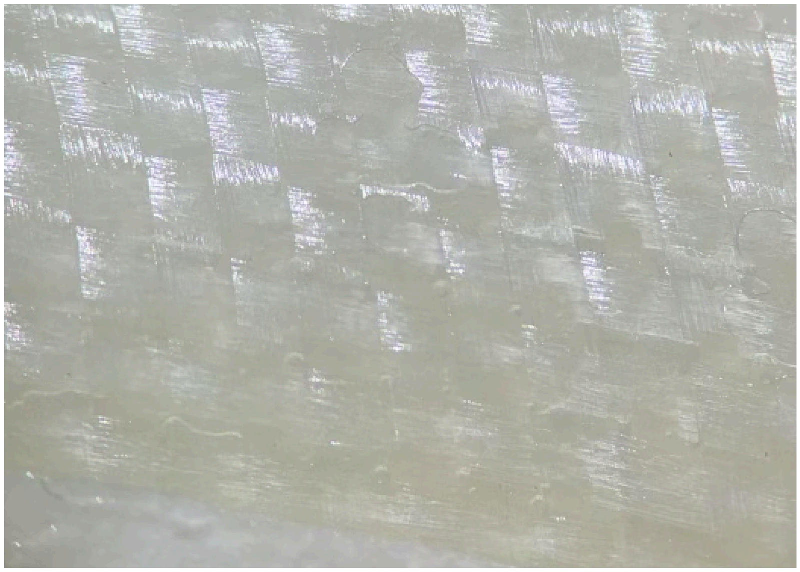

Figure 7: Air bubbles in the tube layup

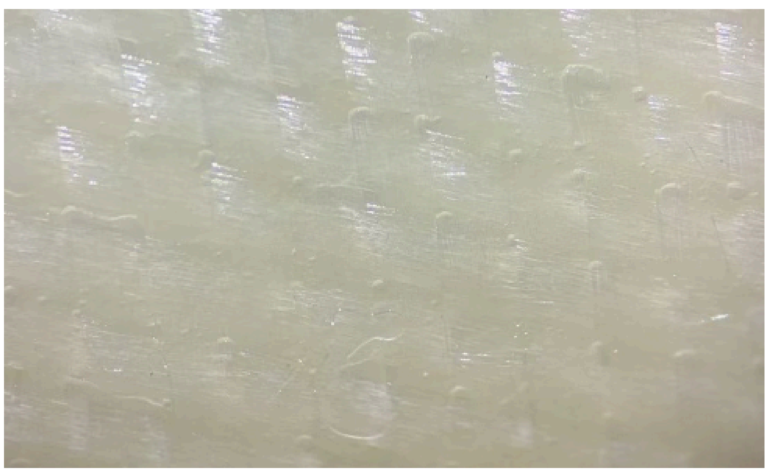

Figure 8: Air bubbles and discoloration in the tube layup

Mechanical Testing

Sheet:

Tensile Test:

The standard number for the tensile test is the ASTM E8/E8M-24, and the test is conducted using an Instron machine. After cutting the sheet composite to the proper dogbone sizes, they were loaded into the tensile grips and tested. Mostly, the tests were consistent and that is reflected in the stress-strain curves; however, some samples slipped from the grips because it was not tight enough. Finding the right balance between tightening the grips to hold and not slip, but not too much as to crack the composite was tricky and could be improved upon. The results of this test are the ultimate strength and strain of the material, the elastic modulus, a yield strength, and an analytical toughness.

Table 1: Calculation of the Theoretical Young's Modulus

Sheet	Fiberglass Weight (g)(±0.01)	Epoxy Weight (g)(±0.01)	Total(± 0.02)	Weight for each fiber layer(±0.01)	Volume Fraction 1(±1.5)	Volume Fraction 2(±1.5)	Volume Fraction Epoxy (±1.5)	Elastic Modulus Composite (MPa)(±13.4)
	28.83	14.2	43.03	14.415	0.334998838	0.334998838	0.330002324	5733.777898

Table 2: Young's Modulus and Ultimate Tensile Strength Comparison of Samples:

Sample	Young's Modulus Calculated (MPa)	Ultimate Tensile Strength (MPa)	Young's Modulus Literature (MPa)
1	5.2932x10^3	174.6949	5.73378x10^3
2	5.6107x10^3	223.0259	5.73378x10^3
3	3.3863x10^3	106.9094	5.73378x10^3
4	5.5335x10^3	195.3543	5.73378x10^3
5	5.6926x10^3	233.7458	5.73378x10^3
Average	5.10326x10^3	186.74606	5.73378x10^3
Error			-10.99655%

The average Young's Modulus of the composite samples tested was 5103.26 MPa. When compared to the literature or expected value of 5733.78 MPa, there was a -10.997% error. This means that the tested value was smaller than expected by about 11%. Unfortunately, the goal for alternating the layup angle of the sheets was to increase the overall strength of the composite, so for the experimental composite to have decreased values is not ideal. In calculating the theoretical value for the Young's Modulus, the volume fraction of the fiber layer was divided between two layers of each kind of fiber; however, there could be errors in the exact division of that volume. Due to the way the fiber sheets were angled and laid up, there could be more of one kind of fiber per volume than the other. If the lower modulus sheet composed more of the fiber volume fraction for the sheet layup, then that could cause the decrease in modulus from the expected value. The cause of this is definitely in the layup procedure and the amount of defects imposed on the composite. Looking at the stress-strain curves, there were also issues with gripping the samples properly and there being some slip (which is especially evident in sample 3). Additionally, the stress-strain curves were difficult to fit with proper linear relationships, and had to be over-approximated. This over-approximation of the elastic region directly alters the calculation of the elastic modulus, and could be another explanation for error between the measurements. Overall, the mechanical behavior of the sheet layup performed closely to the expected properties of the ideal composite, but there could be future improvements in the layup process to reduce defects.

Tube:

Three Point Bending Test:

The standard number for the tensile test is the ASTM D790-17, and the test is conducted using an Instron machine with different grips. We chose one of our cut tube samples for this test, and loaded it into the Instron three point bending grip. The data could be affected by the sample slipping from the bottom grip while the test was occurring, and causing us to restart the test. In the future, ensuring the proper measurements for the sample is vital to the success and accuracy of the test. This test can give the tensile strength and flexural (or bending) modulus of the material.

Charpy Impact Toughness Test:

The standard number for the tensile test is the ASTM E23-23a, and the test is conducted using an Instron Satec impact tester. The test is used to determine the amount of energy absorbed by the hammer/pendulum mechanism, which can give data for the impact toughness of the material. The best of the four cut samples were chosen and were loaded into the impact tester, and tested with the hammer. There were no observable errors in the testing process that could have caused inaccuracies in the measurements.

Charpy Toughness Comparison:

Table 2: Charpy Data

Sample	Weight (g)(±0.01)	Energy (J)(±0.05)	Friction (J)(±0.5)	Energy Absorbed (J)(±0.5)	J/g(±0.98)
2	7.46	41	2.75	38.25	5.12734584
3	7.87	50	2.75	47.25	6.00381194
4	7.5	40	2.75	37.25	4.96666667
Average	7.61	43.666667	2.75	40.916667	5.36594148333
Error	0.173333	4.222	0	4.2222	0.42524697111

The original Charpy data was not very accurate, but it was dependent on the variable weight of the samples cut. The calculation of the toughness from the expected elastic modulus yielded two different results: one based on the elastic modulus of the ideal composite, and one based on the tensile strength from the three point bending test. Either way, the results of the analysis are orders of magnitude off of the tested data. This could suggest that there was a large error from the formation of the tube composite, or that there was an issue with the precision of the Charpy test machine. The theoretical toughness was determined through unit analysis, and was found by multiplying the modulus by the volume of the tube sample, and then dividing it by the mass to obtain toughness in J/g. A possible error in the calculations would be in the volume of the tube, as even though the rod diameter was subtracted, the delamination in the tube was not. The volume was approximated to be a solid cylindrical tube, when in reality it is much more porous and layered which would result in lower toughness from the impact test. Moreover, because the basis data for this theoretical calculation originated from the 3 point bending test and the flexural modulus, any error in that test would alter the toughness results.

CHANGES:

Our proposed layup was not successful because the sheet layup did decrease in stiffness, or the Young's Modulusdid not decrease, as well as the tube's toughness being far from expected from literature reviews. Some things we would change to improve both the sheet and tube layups are using gloved hands rather than a brush because it helped work in the resin better without damaging the weave, losing resin to absorption, or leaving brush debris. As the lowered strength could be due to defects, using gloved hands would prevent their formation. Additionally, the tube's toughness could have been due to the nonuniform resin distribution, where gloved hands would improve this process.

We also would have left the sheet and tube layups to dry longer before covering them with mylar to decrease the amount of mylar that sticks to the resin during the curing process, as this limits the ability to analyze the sample in certain areas using methods like microscopy but ultimately does not impact the stiffness or toughness. Another change, specifically for the sheet layup, would be to cut the fabric for the sheets at a 45 degree angle for the two corresponding sheets. This will utilize all the fiber cut, producing the most samples and least waste.

In terms of our proposed layups orientations, the pattern still would be a successful design as calculated in Figure 1. However, our choice to alternate the orientation and fiberglass type simultaneously may have caused weak points instead of increasing the overall strength. Furthermore, blocking the fiberglass types (AA-BB) and alternating orientations in the same way as before may yield a different response, one closer to what we planned for.

ATTACHMENTS:

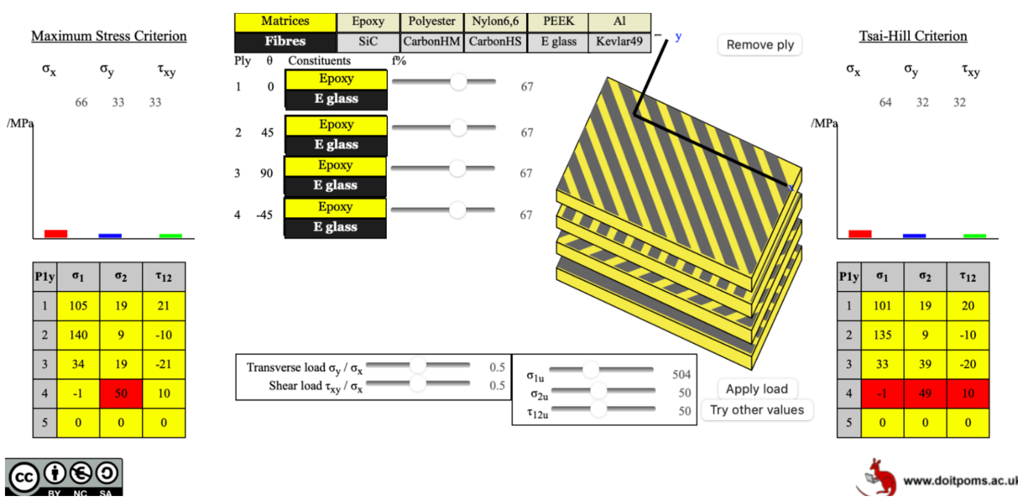

Figure 1: Simulation of sheet layup orientation with theta as 0, 45, -45, and 90 degrees, an epoxy matrix, fiberglass fibers, and transverse and shear loads of 0.5.

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Figure 2: Sheet Layup

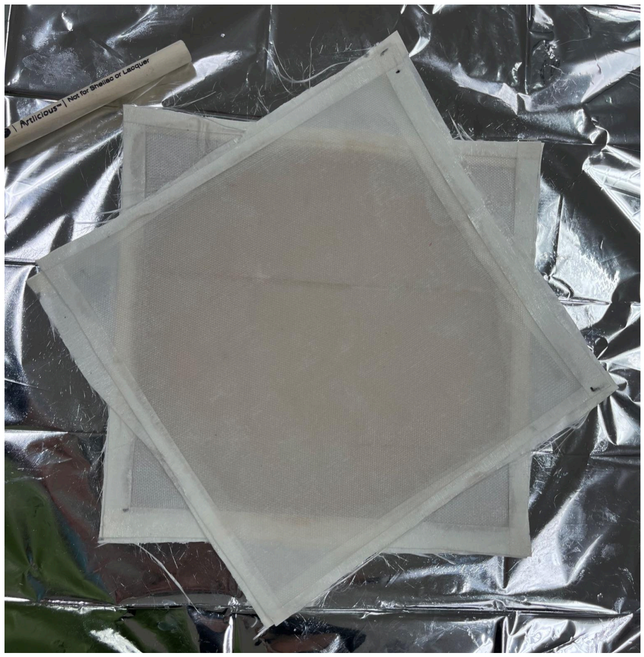


Figure 2: Sheet layup with two of the four sheets added. The first layer of Style 120 E-Glass with 0 degree orientation and the second layer of 4 oz. Fiberglass Fabric with a 45 degree orientation.

Figures 9-13: Stress-Strain graphs of the Tensile Test for Sheet Composite Dogbones:

Figure 9:

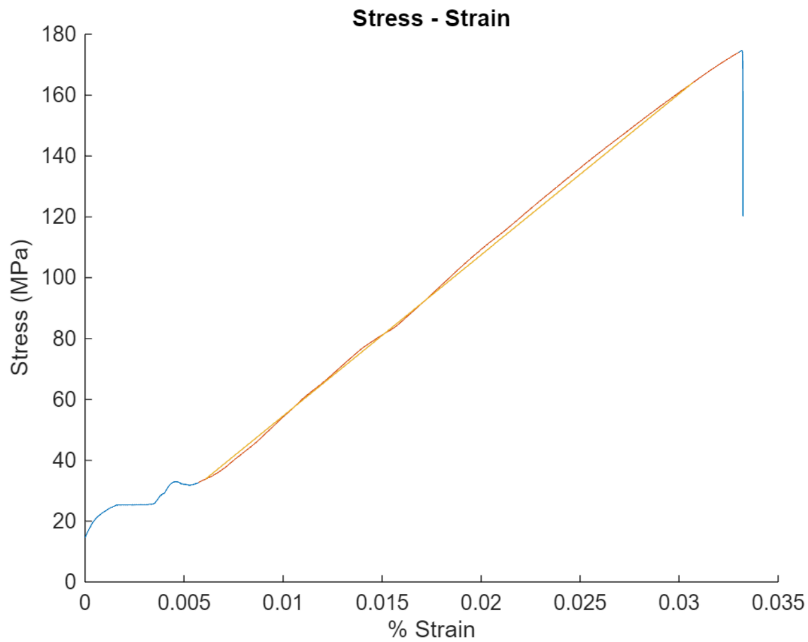


Figure 10:

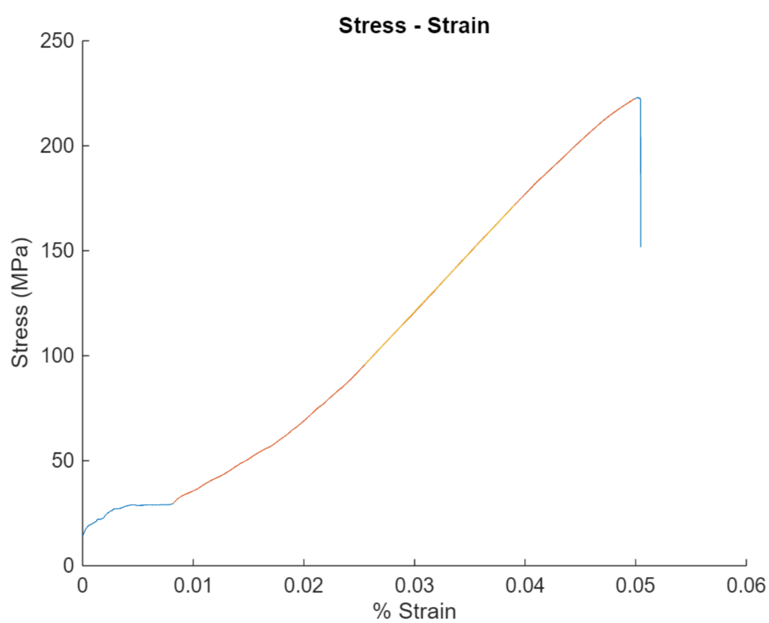


Figure 11:

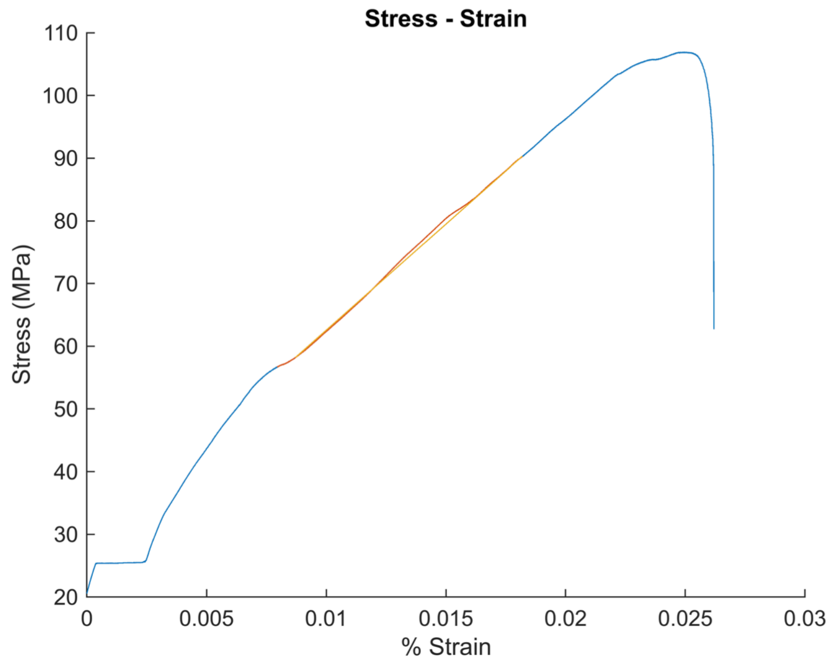

Stress - Strain
Stress (MPa)
% Strain
110
100
90
80
70
60
50
40
30
20
0
0.005
0.01
0.015
0.02
0.025
0.03

Figure 12:

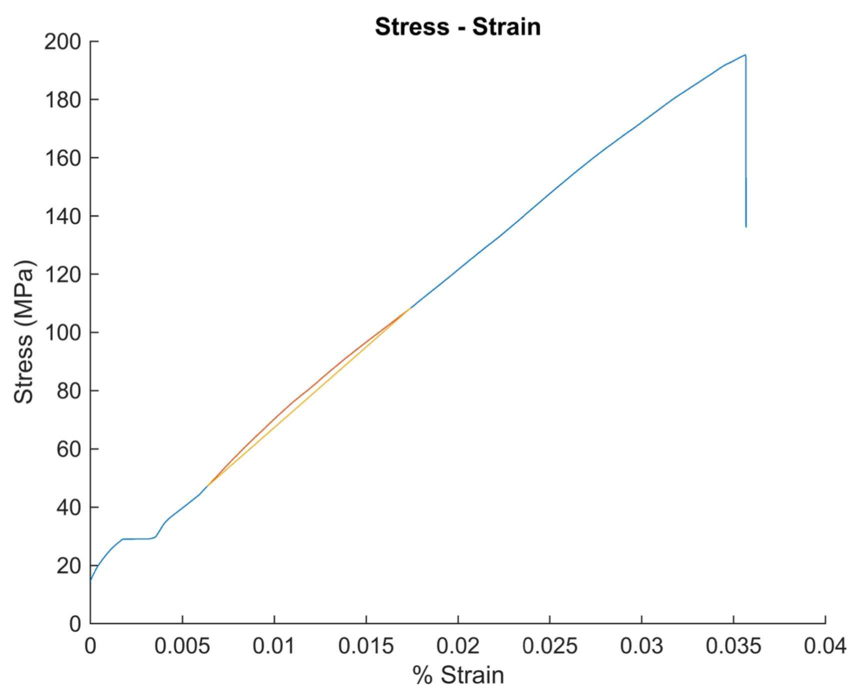
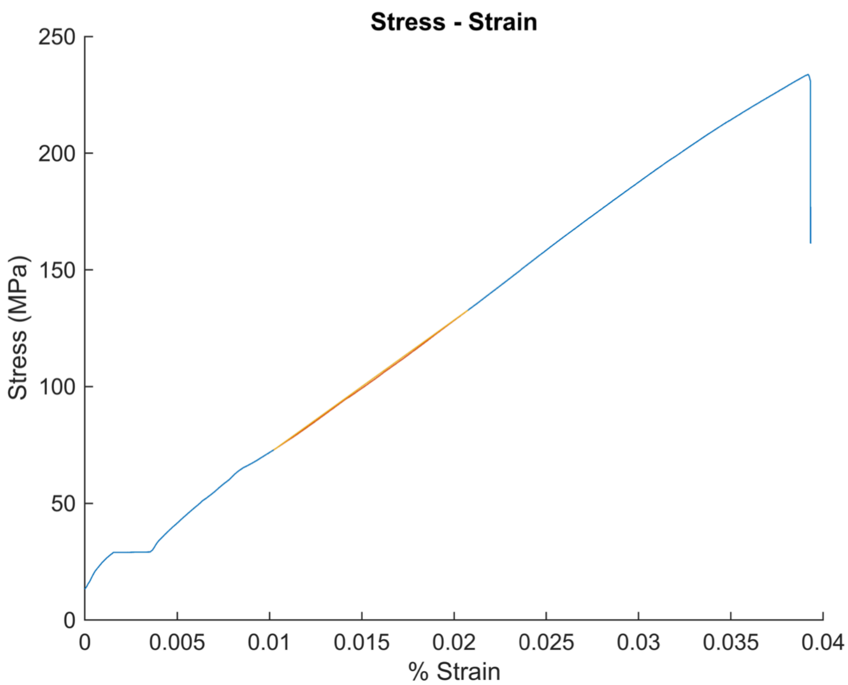

Stress - Strain
Stress (MPa)
% Strain
200
180
160
140
120
100
80
60
40
20
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04

Figure 13:



Tube:

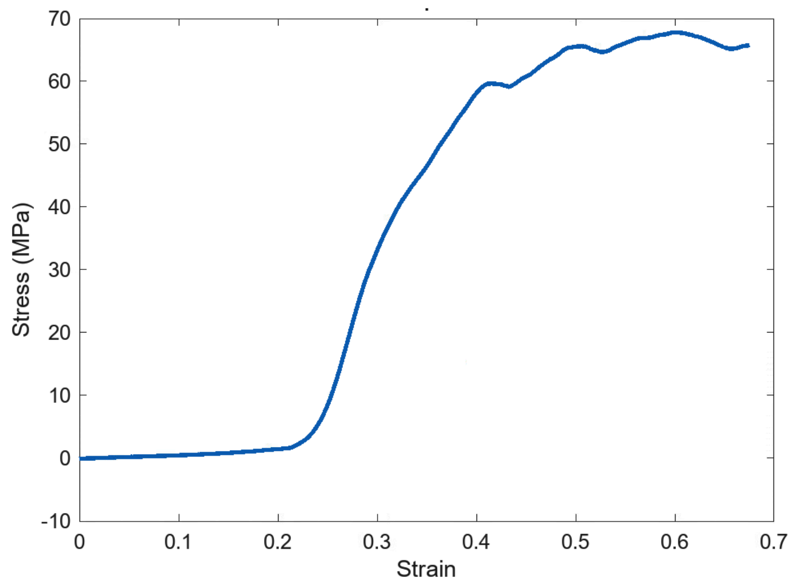


Fig 14. Stress (MPa) - Strain graph of Tube Composite Layup.

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