Two Ply Unidirectional Carbon Fiber Wet Layup; A Collection of Lessons Learned

Team 1

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1. Abstract

This report explains how to make a two-ply unidirectional carbon fiber wet layup, which involves laying carbon fibers in a certain direction with the use of wet epoxy resin and hardener. A layer of carbon fibers is first placed down in the desired direction, followed by a layer of wet epoxy resin and hardener mixture, and a second layer of carbon fibers laid down in the opposite or same direction. The layup is then left to cure under ambient conditions, producing a strong, light composite material. This procedure's outcomes are reviewed, along with the finished product's mechanical attributes and prospective applications.

The report will also go through the drawbacks and restrictions of this technique, like the requirement for exact fiber alignment, the potential for delamination if the layup is not done properly, dry spots, presence of voids and frayed carbon fiber strands at the boundary of the piece.

2. Background

Carbon fiber is a composite where the resin is the matrix that fibers exist in and bear most of the load. The orientation of fibers can be adjusted to meet the loading criteria of the component, therefore it is an extremely versatile material. Carbon fiber is available as dry sheets or pre impregnated (prepreg) with resin ready to be molded. Each form has its own merits and drawbacks.

For example, prepreg is stored at a low temperature requiring ample storage space. Wet layup is useful for small batch parts at any scale due to the ability for a technician to pull, mold and press the layers into the mold shape at will. Both methods can have fibers in any direction needed, creating strength in one direction or ‘all’ directions. Each final component is either cured under vacuum pressure or an autoclave for maximum strength.

Resin is the other half of the carbon fiber equation and requires the most attention during the layup process. Two types of resin are used: thermoset and thermoplastic. Thermoset resins need to be refrigerated and kept away from moisture. They can’t burn and cure to become a high strength rigid shape. Thermoplastic resins have an advantage of being incredibly stable and can be recycled. With each resin comes a MRCC or manufacturer recommended curing cycle. The MRCC instructs the technicians as to what temperatures and how long to cure the parts. The curing cycle differs for each resin on the market.

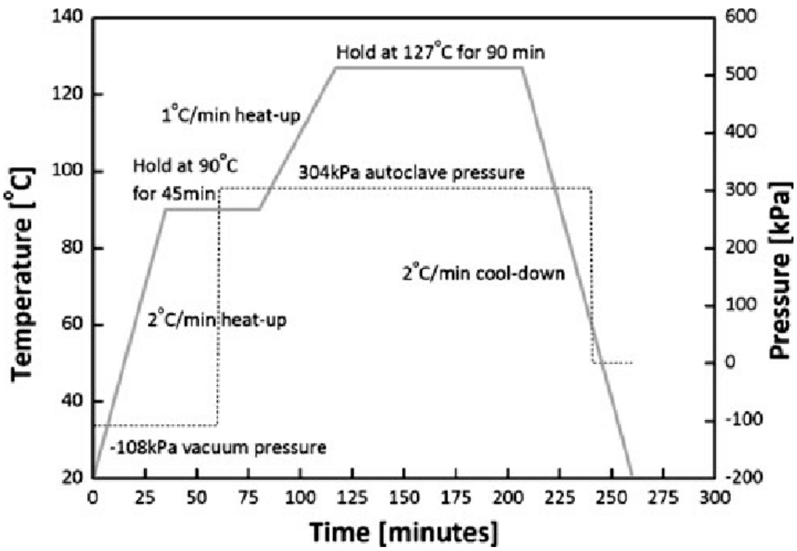

Figure 1: A graphical representation of the MRCC to be used in an autoclave. From Parket et. al.

In the above figure, the two ramp cycles and two curing times are plotted against temperature. Following this cure cycle will ensure the maximum strength of the finished part. The first ramp into the first holding time is the most important part of the cycle as the resin becomes less viscous and will be able to flow across and between layers with ease. The additional pressure helps force the resin throughout the part as well. Often a lower temperature is sought for curing times as it is easier for the autoclave to hold. Once the last hold time has passed the part can be removed from the autoclave and mold when cooled, then trimmed to specification.

3. Process

Wet layup is a basic process that involves laying down the reinforcement and applying the resin all by hand. The basic preparation for this process is the same as others.

To start with, the resin (INF 114, A) and hardener (INF 212, B) are mixed together in a styrofoam cup in a ratio by its weight. We decided to go with 8.5g of Resin and 2.32g of hardener (ratio 3.65:1) as it would be sufficient enough to coat the carbon fiber samples. We mixed the resin and hardener using a wooden stick in a clockwise manner thoroughly for 10 minutes and set the cup down. We noted the time to make sure that we had only 70 minutes before the mixture started hardening.

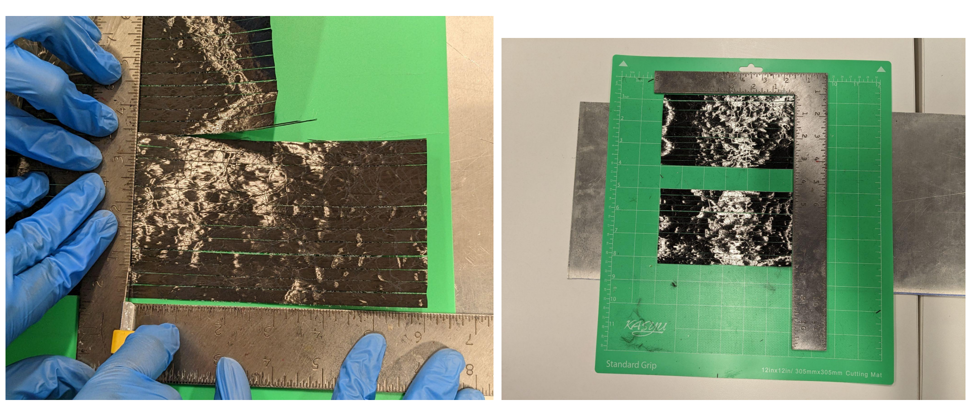

Figure 2 & 3: Cutting of Unidirectional Carbon fiber to the required dimensions

In figures 2 and 3 we can see that the carbon fiber is being cut to the required dimensions. While the mixture sat, we needed 2 sheets of unidirectional carbon fiber and got to cutting the carbon fiber sheets to the dimensions 3in x 6in. We used a specialized carbon fiber cutter intended to cut carbon fiber and with a shallow angle, we cut out the pieces we were going to use to create the 2 ply wet layup using the mixture.

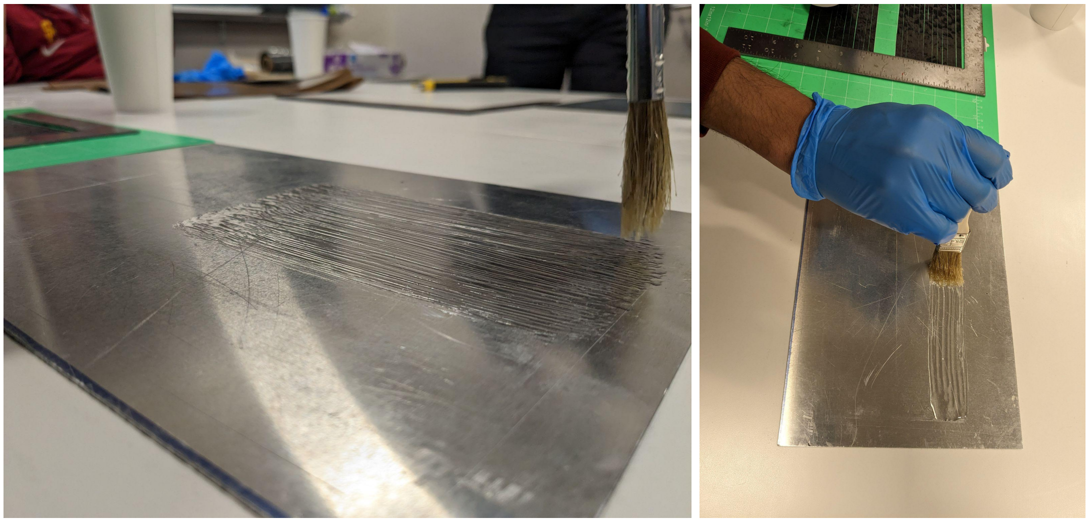

Figure 4 & 5: Coating/preparing of mold for the unidirectional carbon fiber sheets

In figure 4 and 5, the mold that we used is a flat steel plate, a few millimeters in thickness. We cleaned the surface of the mold where the wet layup will be performed with a paper towel but acetone would be prefered, thereafter, we coated the surface with the mixture using a brush for a couple of minutes in one direction.

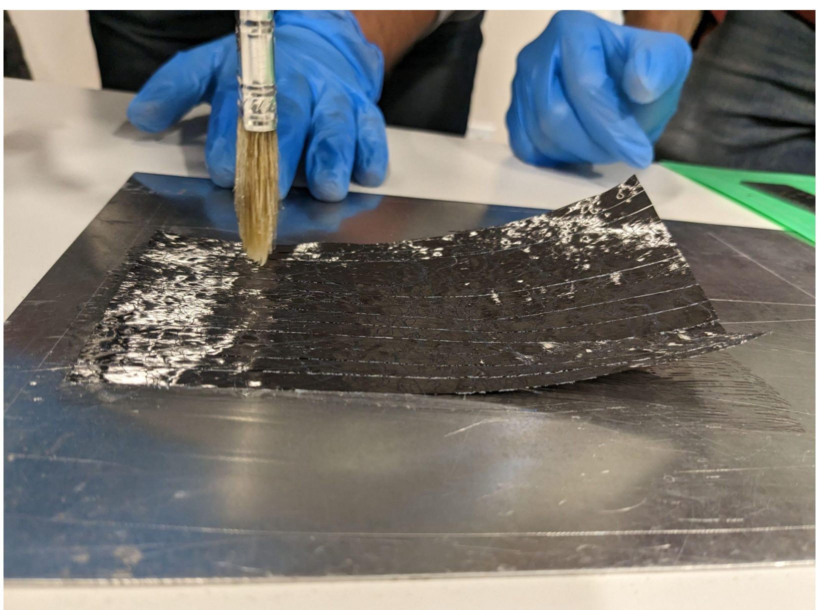

Figure 6: Placing the first carbon fiber layer

In figure 6, the first unidirectional carbon fiber cut sheet was placed on top of the resin that was applied to the mold carefully. We applied gradual pressure through brush to remove trapped air bubbles for several minutes until satisfied.

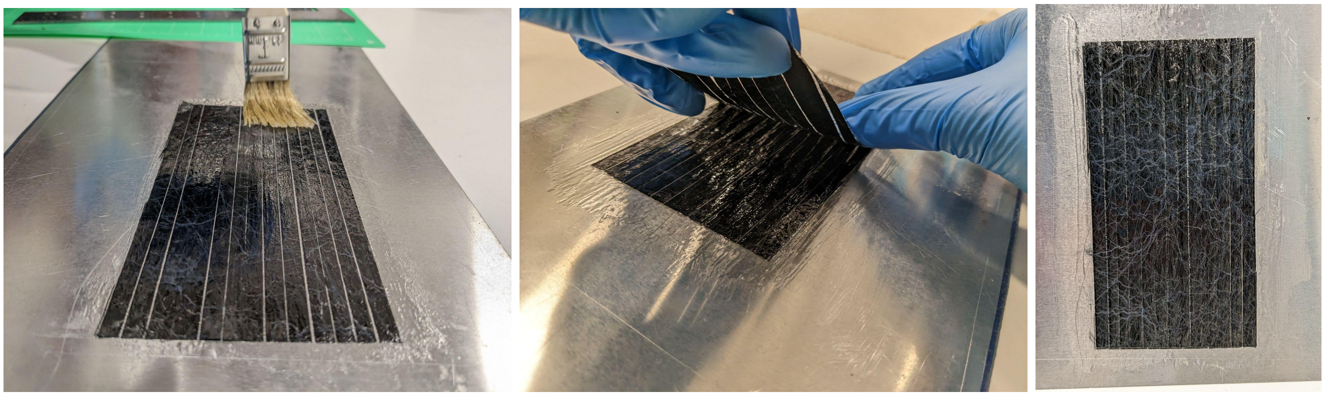

Figure 7, 8 & 9: Second layer being applied and brushed on

In figures 7 and 8, we applied a second layer of mixture and thereafter placed the second carbon fiber on top of the first one in the same direction. For the second carbon fiber again we applied gradual pressure to remove trapped air bubbles for a couple of minutes. We cured the part by simply leaving the part out dry. In figure 9, we can see that the unidirectional 2 ply wet layup is set for curing under ambient conditions and will harden up and ready to remove in about 70 minutes from time of resin and hardener mixing.

4. Discussion

One of the possible disadvantages of hand lay-up using wet resins is the lack of control of the initial resin content applied to the fibers. Although the resulting resin bleed-out was very different in each case, the resin remaining in the cured laminates was the same. Another parameter which was considered to be a possible factor in controlling resin bleed-out and therefore the quality of the laminate was the bleeder/ absorption arrangement adopted in the vacuum bagging procedure. Control of the amount of resin bleed-out can be achieved simply by varying the arrangement of the vacuum bleed-out or absorption pack.

Since the procedure is mostly manual, safety is crucial. Rubber gloves must be worn while handling the resin and all other components involved in the procedure; eye protection glasses are recommended. Wrist watches and bracelets must be removed and long hair must be tied in a bun. Any cuts being made must have a motion away from the body. The cuts must be strong as light cuts will not cut through and will leave strands of fibers which may cause further problems. Frayed carbon fiber strands can come at the cost of decrease in structural integrity and the voids not being able to flow out of the system. The voids will eventually grow and propagate into cracks destroying the product. It is possible that we may not be able to spread the mixture evenly throughout the ply, and because we cannot, we get something called dry spots on the finished dried up ply; it is common and cosmetic. Proper care must be taken while mixing the resin and the hardener. The appropriate mixture ratio must be checked before actually mixing the parts. If the mixture ratio is done by weight, a reliable and calibrated scale must be used. The mixture must not contain any bubbles or air pockets. This also goes to say while laying or brushing the resin on the composite sheet. Bubbles, air pockets or voids propagate cracks and lead to fractures and critical failure. The lab set up must contain a spill area (with Teflon) where in an event of emergency, the resin can be spilled over a large surface area. Resin MUST not be disposed off in a sink. If done so, the resin hardens in the pipes causing a blockage in the plumbing. The spill area facilitates for a quicker cooling time.

Due to the cost effectiveness of the process, wet layup is a go-to option for amateur rocketry and aircraft builders. It's a quick and fairly reliable method to produce strong and lightweight composite components. For example, amateur rocketeers use the process from building fins to entire airframes for high powered model rockets. RC aircraft builders also use the process to make components like ailerons, elevators and rudders. This process can also be used to repair and reinforce composite structure and components.

5. Conclusion

Epoxy resins are strong and expensive. The reinforcements, such as carbon fiber, help to take loads, making the entire part extremely strong while keeping the weight low. Parts can be designed to resist forces in different directions by orienting the fibers to take those loads in our case it was unidirectional. The manufacturing process includes combining materials to make composite parts. The materials are combined in a layup process, and then are cured, where they are fused together. Other materials that could be researched for further discussion might include aramid fibers, or any of the many other forms of matrices.

6. References

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Four Layer Unidirectional Carbon Fiber Tube Layup

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1. Abstract

The Four Layer Unidirectional Carbon Fiber Tube Layup is a design for the manufacture of composite tubes made from carbon fiber. The layup refers to the arrangement of carbon fiber layers within the tube, with each layer oriented in single or multiple directions. The four layers are positioned perpendicular to one another, creating a structure that is strong in all directions. This design approach results in a composite tube that is lightweight, stiff, and durable, making it well-suited for a variety of applications such as aerospace, automotive, and sports equipment. The use of unidirectional carbon fiber enhances the mechanical properties of the composite material, allowing for optimized strength and stiffness-to-weight ratios. Additionally, the use of carbon fiber offers advantages in terms of resistance to environmental factors such as moisture and temperature changes, further increasing the durability and reliability of the composite tube. Overall, the Four Layer Unidirectional Carbon Fiber Tube Layup is a cost-effective and reliable solution for various engineering applications.

2. Background

Carbon fiber tubing is an excellent alternative to metal tubing in structural applications due to its lightweight and resistance to many chemicals, such as jet fuel. Carbon fiber tubes can be manufactured in various ways from hand layup layer by layer to filament winding when molding tubes in this way aluminum pipes are used as the mold and machined to have a smooth surface finish when used for aerospace applications to reduce the possible number of defects. Once the carbon fiber is laid up, shrink tape is wrapped around the component. Shrink tape provides the pressure uniformly needed for the component when curing in the oven. Once the part is cured, in order to de-mold the tube, the differing coefficients of thermal expansion of carbon fiber and aluminum aid in this process. By freezing the mold and component, the metal will shrink, and the tube will expand until it is slid off easily. Additionally, extra strips of carbon fiber are applied at the ends of the tube to provide a grip when demolding the part, which is then trimmed away. An Even number of layers must be used on each tube. Tubes are often loaded in bending, so fiber must go along the length of the tube (0° relative to the length of the tube), and only a few layers need to be applied perpendicular to the length of the tube.

3. Process

To start with the process we will need a pair of scissors, an aluminum mold of an inner diameter of 1 inch, Unidirectional Carbon Fiber sheets, a composite cutter, shrink tape, and high heat-resistant duct tape.

Figure 1:(A) Cutting the square to make right angles. (B): Cutting one of the marked squares

Firstly, we planned and designed the number of layers, the dimensions, and the flange strip dimensions. The layer dimensions were decided to be 4 squares of side 3.5in and 2 flange strip dimensions of 8in x 0.4in. The prepreg Carbon Fiber squares were cut using scissors (see Figure 1 (A) and (B)), and each corner was cut to a right angle using an angle ruler to make sure the sheets line up perfectly when the layup is performed on the tube.

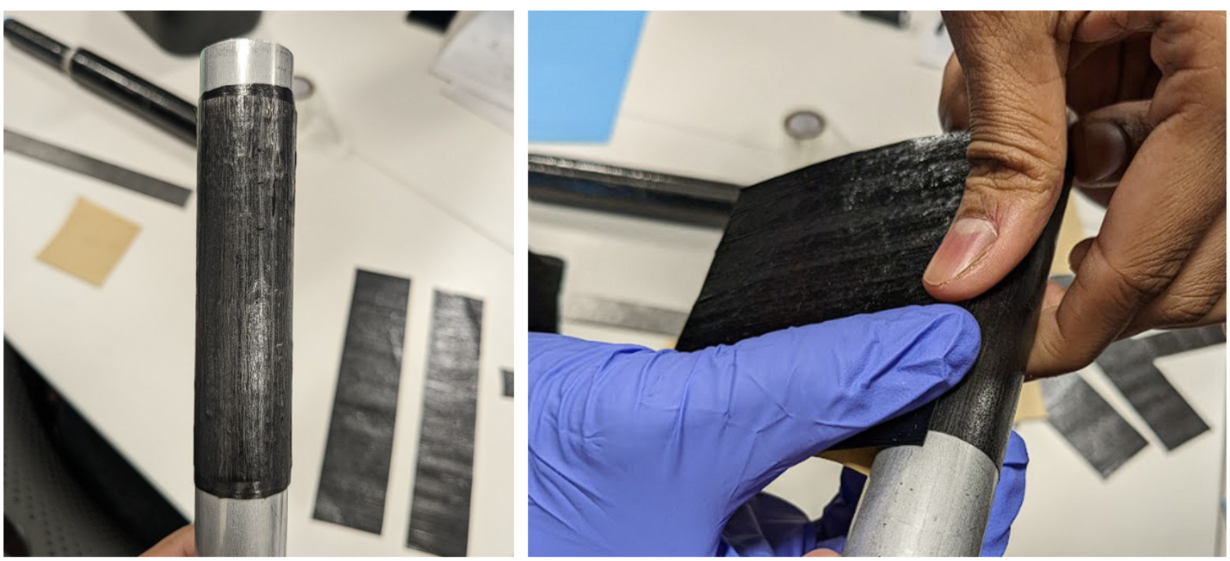

Figure 2:(A) 0-degree layer applied on the mold. (B): 90 degrees later applied on the mold

Before applying the layer to the mold (aluminum tube) we decided to wrap the layers in alternating directions; one 0^o orientation (along the axis of the tube) and 90^o (perpendicular to the axis of the tube). Once this was decided, we peeled off the plastic from the pre-preg carbon fiber and wrapped it around the aluminum tube. Once the first layer was applied, the mold was rolled on the scrap plastic covering to make sure that the layer sticks properly. (See Figure 2 (A) and (B))

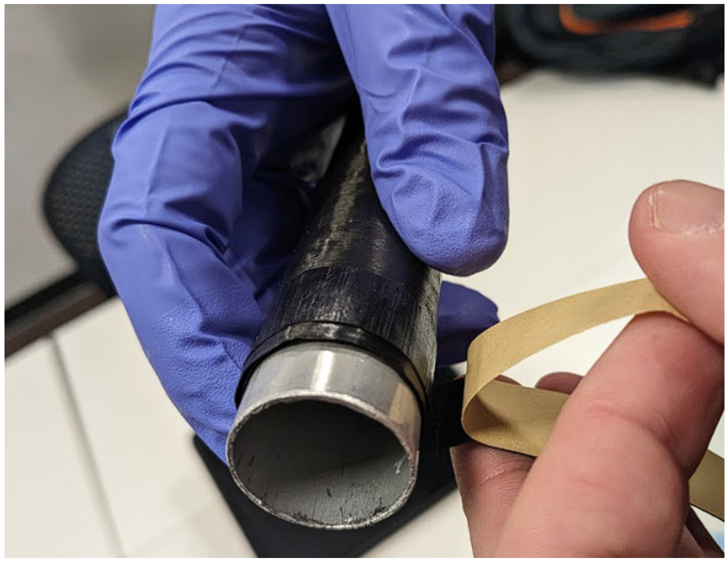

Figure 3: The flange strip being added to the CFRP mold

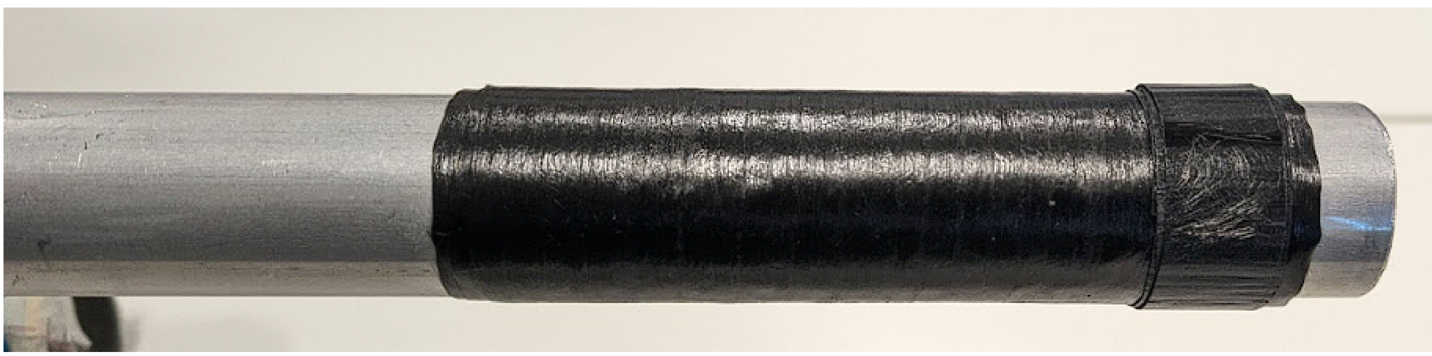

Figure 4: Completed CFRP tube structure on mold

After the 4 layers were applied in alternating orientations, we moved forward in deciding where to apply the flange strips and ultimately the section of the CFRP tube that would be cut off. The strips were applied toward the end of the mold so that it is easier to pull the mold out once it has been cured under high pressure and temperature (see Figures 3 and 4).

Figure 5:(A) wrapping shrink tape on the prepreg layers on the mold. (B): The shrink tape wrapped around and ready to be put in the oven

As the final step, once all 4 prepreg layers and the flange strips were applied, we wrapped the CFRP structure with shrink tape at an angle of approximately 15° so that it overlaps which when heated under high temperature and pressure will compress the mold and the prepreg carbon fiber layers with tremendous amounts of force evenly along the circumference. (see Figure 5 (A) and (B)).

4. Discussion

One of the main benefits of the unidirectional carbon fiber tube prepreg layup is its high strength-to-weight ratio. Another advantage of the unidirectional carbon fiber tube prepreg layup is its versatility. The material can be easily formed into complex shapes and can be used to create structures with different mechanical properties in different directions, allowing for the optimization of the composite structure to meet specific design requirements.

However, there are also some limitations to the unidirectional carbon fiber tube prepreg layup. The prepreg material is sensitive to temperature and moisture, which can impact its mechanical properties. In addition, the layup process can be time-consuming and labor-intensive, and there may be difficulties in obtaining consistent results, which in other words is called the Coefficient of Variation, and we will most likely see a 20% difference between 2 similar manufactured CFRP tubes in strength and not stiffness as strength is a structure dominant property and stiffness is a material dominant property.

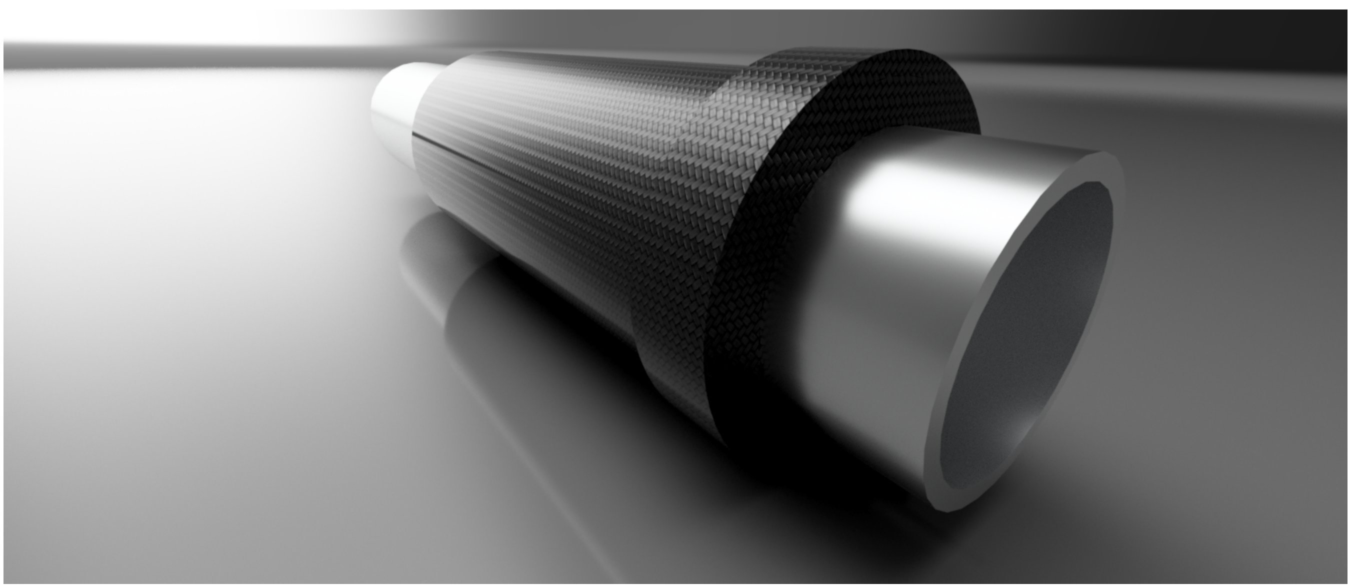

Figure 6: A 3D CAD rendition of the CFRP tube around the mold with its flange

Some important considerations while making a carbon fiber tube layup are the precautions taken during the procedure. The fiber wrap is exceeded at the ends purposely so as to face off the edges and have a smooth finished end. Additionally, fiber is wrapped either at one or both ends of the tube to create a small flange (see Figure 6). This flange helps in attaining some leverage to perform the de-molding or removal of the mold. The duct tape and shrink tapes used are to be of high thermal grades. The shrink tape applied over the tube prior to the curing process is made up of a chemical that when heated under high temperatures and pressure, contracts and wraps itself around the CFRP tube applying a large amount of uniform pressure around the tube. The fiber-wrapped tube is preserved in a refrigerator to facilitate the right amount of thermal expansion as we know that the thermal coefficient of expansion of aluminum is close to 24 x 10^{-6} (1/C°) and that of carbon fiber is negative or close to 0, which means it expands when cooled and the aluminum mold contracts. The demolding or removal of the mold is strictly to be done inside the refrigerator so as to avoid any unwanted thermal expansions. The underlying mold should have a smooth surface and no scratches. This is important as any surface defect will directly be translated into the final cured CFRP part.

Multiple layers are used in the layup and a seam can be observed. No angle is needed while layering the layup, however, the orientation of the fibers is crucial. The fibers must go along the length of the tube as they bear most of the loads in most commonly observed cases in pipes: bending, torsion, and fatigue.

The applications of prepreg unidirectional carbon fiber tubes are abundant, some of which are used to transport fuel in pipelines made of CFRP as the tubes are corrosion-resistant, lightweight, easy to replace, and do not melt under high operating temperatures. Another use of the tube is in aerospace where it is used as a sleeve joint or as tubings.

5. Conclusion

In conclusion, the four-layer unidirectional carbon fiber tube prepreg layup demonstrated several vital benefits for high-performance applications, such as aerospace, automotive, and sports equipment. The use of carbon fiber provides an excellent strength-to-weight ratio, enabling the production of lightweight and robust composite structures. The layup process was efficient and cost-effective, and the material showed good stability and durability under various environmental conditions.

However, it is essential to note that there were some limitations encountered during the layup process, such as the sensitivity of the prepreg material to temperature and moisture. In order to overcome these limitations, it may be necessary to implement additional processing steps, such as vacuum bagging or autoclave curing.

The unidirectional carbon fiber tube prepreg layup provides a promising solution for high-performance applications, and further research and development in this field are likely to lead to even more advanced composite structures in the future.

Seven Layer Prepreg Textile Carbon Fiber Layup with Tapered Ends

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1. Abstract

This report on Seven Layer Prepreg Textile Carbon Fiber Layup with Tapered Ends investigates a composite material consisting of seven layers of carbon fiber fabric, impregnated with resin. The tapered ends design enhances the strength and performance of the layup for specific applications. Moreover, the report examines the manufacturing process, material properties, and benefits of this layup compared to others. It also highlights the benefits of this layup and its potential use in industries such as aerospace, sports, and high-strength structures. In addition, the study also includes a detailed examination of the manufacturing process and material properties. The report summarizes the findings and offers recommendations for future studies.

2. Background

The advantage and tapering of carbon fiber parts has several advantages in the finished product while coming at a cost during layup. A technique known as ply drop is used to taper carbon fiber parts, and is seen in Figure 1. Plydrop consists of staggering layers in an order to create a stepped slope and then a surface ply covers the

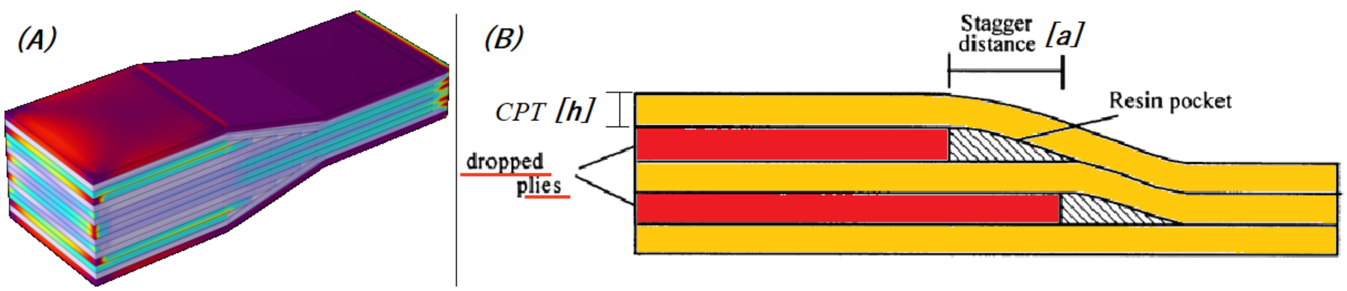

Figure 1: (A) A three dimensional view of ply drop under simulated stress, each layer experiences different amounts of stress, and the color helps show the layering (COMSOL). (B) A simplified schematic of plydrop is shown including possible sources of error in the resin pockets. Additionally, critical dimensions are labeled (Mukherjee).

length of the part. This method of layup is used in parts that require a change in thickness like hat stiffeners, car doors or windmill blades. Figure 1A shows a test slab undergoing simulated stress. Studies such as COSMOL's help us understand how best to taper carbon fiber parts behave under loading conditions. Murkherjee and Varughese sought to create design guidelines and understand the best design for ply drop. There are few ways to successfully layup ply drop. Reducing the thickness of the fiber will lead to smaller gaps and resin pockets, as shown in Figure 1B. These pockets are stress concentrations and often are where cracks and failures occur in components with ply drop. Our goal was to reduce the size of the pocket in this lab. While we couldn't choose thinner fibers we were able to choose a stagger distance. According to Murkherjee a common stagger distance is 6mm though through their study they found that keeping the stagger distance greater than three times the cured ply thickness.

3. Process

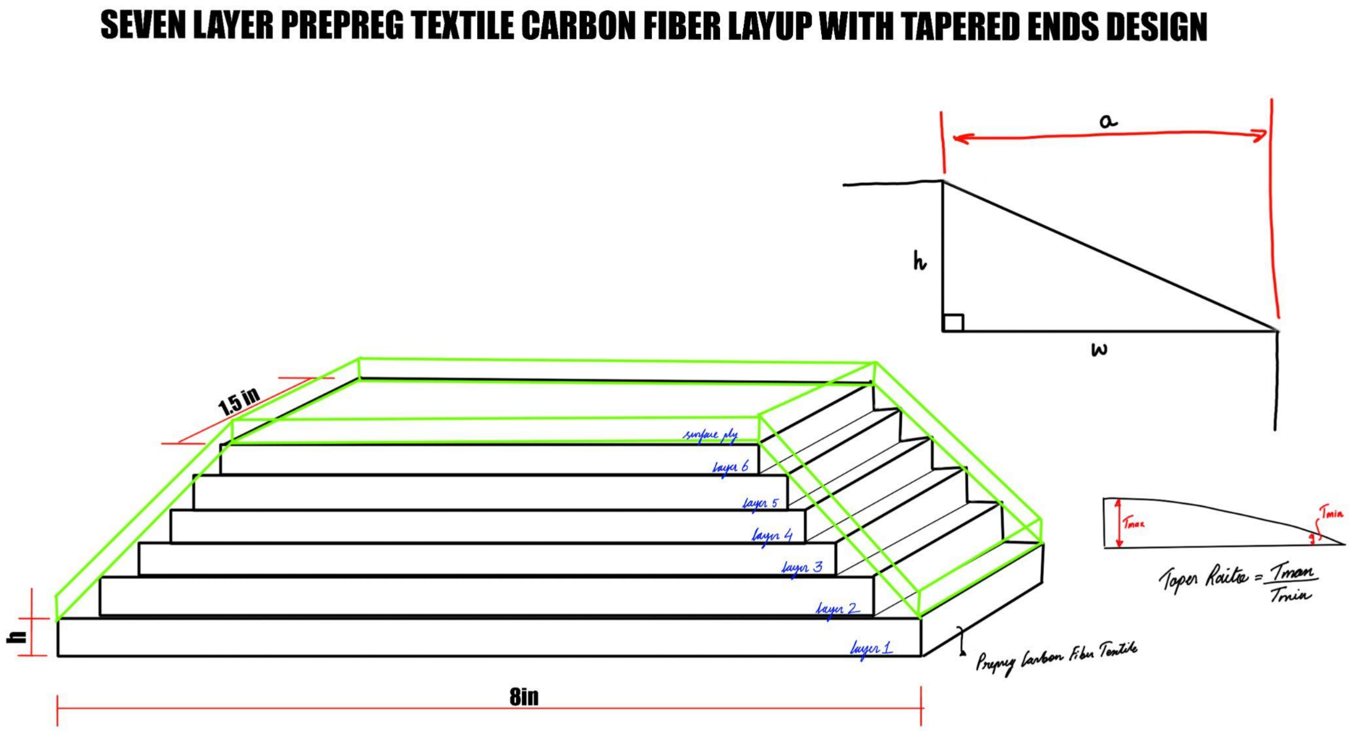

Figure 2: Seven Layer Prepreg Textile Carbon Fiber Lap up with tapered ends design

To construct the Seven Layer Prepreg Textile Carbon Fiber Layup with Tapered Ends, we discussed various design types that we could implement to demonstrate the tapered structure reasonably well to the naked eye. We settled on using a thin pyramid style structure bearing projection base dimensions of 8 in x 1.5 in as seen in Figure 2. After the dimensions plan was set, we drew out a rough sketch of the final product along with the dimensions and the succeeding layers length as well as the surface layup. As for the ends, we decided to keep a gap of 10mm on either end.

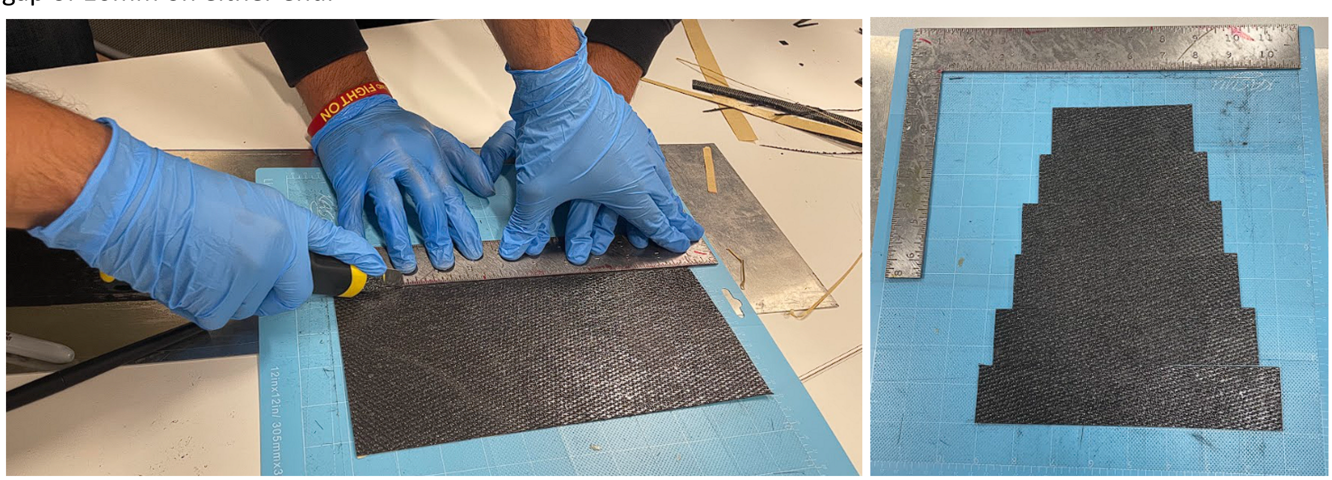

Figure 3(A): Carbon fiber textile being cut to required dimensions. (B): Coupons laid out neatly on mold

Now, the carbon fiber sheets were measured using a steel angle ruler and cleanly cut to right angles using a specialized composite cutter and scissors to obtain a square sheet, thereafter 7 strips/coupons of carbon fiber were cut bearing the dimensions 8 in x 1.5 in and laid out neatly on the mold as seen in Figure 3(A),(B).

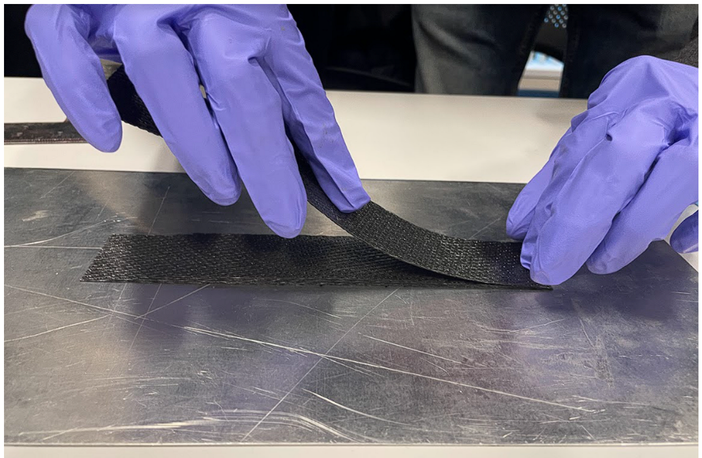

Figure 4(A): sixth layer being applied carefully (B): Tapered structure

The longest strip's adhering covering was stripped off and placed on the mold and sufficient pressure was applied by hand to make sure the entire prepreg carbon fiber strip was sticking to the mold. Subsequently, the second, third, fourth, fifth and sixth layer were placed over each other after intermediately applying pressure after each layer was placed as seen in Figure 4. Once all of the layers were applied, another layer called the surface ply was added. This outer layer helps in spreading the stress concentration formed at the edges of each coupon due to sharp corners. It also acts as a protective layer to the ply drops present inside from wear and tear. The final product looks something like displayed in Figure 5 (A) and (B).

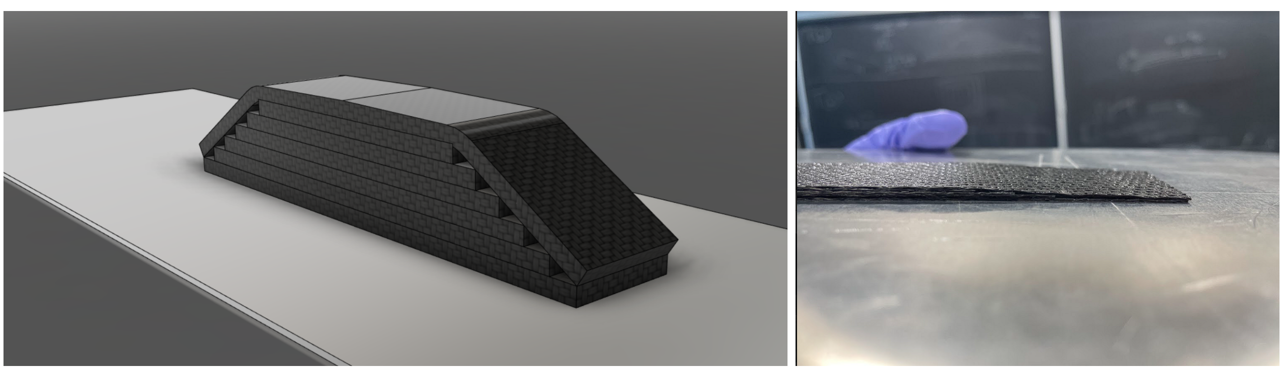

Figure 5(A): 3D model of the Tapered seven layer prepreg textile carbon fiber layup, (B): Actual structure of the tapered design

4. Discussion

In the field of composites, a seven layer prepreg carbon textile fiber layup with a tapered design is a highly advanced and intricate design that can significantly enhance the overall performance of a composite structure. This layup design involves stacking seven layers of prepreg carbon textile fibers in a specific manner, using advanced material handling and curing techniques. The tapered design aspect of this layup involves the gradual reduction in the thickness of the structure, starting from the center and gradually reducing towards the edges.

This tapered design is crucial for several reasons. Firstly, it reduces the weight of the composite structure, making it lighter. Secondly, the tapered design enhances the stiffness and strength of the structure, allowing it to withstand high loads and impacts. Additionally, the use of prepreg carbon textile fibers provides high levels of durability and resistance to environmental degradation, ensuring that the composite structure has a long service life. The textile fibers are pre-impregnated with resin, ensuring a homogenous distribution of resin throughout the layup. This enhances the bond between the fibers and the resin, improving the overall performance of the composite structure. Due to the ply-drop design, the parts are flushed when mounted together, enabling a smooth transition and avoiding any stress concentrations.

An important design consideration in tapered design of composites is the volume or area of air pocket created when two composites of different length but similar thickness are layered. The air pocket is a small right angled triangle in form, with the vertical being the composite ply thickness (CPT) and the horizontal being the difference in length of the two composites. Since the CPT is constant, the difference in length is tried and minimized. The goal is to optimize the taper ratio (Tr = Tmax/Tmin) to avoid air bubble formations and eventually crack propagation. A surface ply is added at the end to evenly distribute the stresses.

Cons of this design is that we can machine composites, even if we did try to machine composites the tiny many fibers would stick out and create a lot of chipping and nor comply to conventional machining tools. The fibers wil fray and will affect the other layers, therefore it is not yet possible to machine composites.

Some pros of ply drop: Reduced overall weight, smooth transition between two joined parts and higher weight to strength ratio. Some cons of ply drop: Difficult to machine and air pocket/resin pockets is inevitable and therefore stress concentration. The only possibility to prevent this is to allow the resin to flow out of the coupon and fill in the gaps in the X - Y direction as resin has zero permeability in the Z direction.

Manufacturing of tapered design is different, in the sense, trimming each coupon takes time, we also have to be conscious o the curing time, its alignment with respect to other layers and maintaining end distances.

Ply drops are widely used in industrial applications. The windmill blades use fiberglass, as using carbon fiber would make the windmill too expensive, the shaft of landing gear of an aircraft uses plydrop, cars and other automotives use ply drops either for functional or aesthetic purposes.

5. Conclusion

A seven layer prepreg carbon textile fiber layup with a tapered design could summarize the key findings and highlight the potential benefits of using such a design. Some points that could be included are:

- The seven layer fiber layup provided the desired combination of strength, stiffness, and lightweight properties.
- The tapered design helped distribute the loads more evenly across the structure and reduce stress concentration, leading to improved overall performance.
- The use of prepreg carbon textile fibers allowed for precise control over the fiber orientation and resin content, resulting in a more consistent and optimized composite material.

- The combination of the seven layer layup and tapered design resulted in a high-performing, lightweight, and efficient composite structure that could have a range of potential applications, from aerospace to sports equipment.

In conclusion, the seven layer prepreg carbon textile fiber layup with a tapered design offers a promising solution for creating high-performance composite structures. Further research and development are required to fully realize its potential and optimize its properties for specific applications.

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Carbon Fiber Plate Bending Under Uniform Loading; Comparison of Simulation and Experimental Results

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Abstract

Aluminum and carbon fiber reinforced polymer (CFRP) plates are loaded uniformly at 0, 10, 40, and 70 lbs, with the deflection of the plates measured at nine and fifteen points, respectively. The deflection of each plate is then plotted using Matlab. Next, using Matlab code from Bednarcyk et al., aluminum and carbon fiber plates were simulated under the same loading conditions, and the simulated results were compared to the experimental results.

Background

Finite element analysis is often used in the engineering process by simulating different layups and configurations of a component to understand responses to service loads and reduce the number of physical prototypes that need to be created before the final product. Simulation software has advanced to include composite layups. Integrated Computational Materials Engineering (ICME) is a process with a philosophy of designing a performance material and heavily uses multi-scale computer modeling.

Process

To conduct the hypothesis testing of uniformly loaded CFRP and equivalent mass aluminum plate conditions, we first need to get all the tools required to experiment on a relatively flat table. The tools needed are Pillars, tape, 10lb sandbags, an vernier caliper, a steel ruler, a marker, sheets of paper, angled brackets, and a notepad.

Figure 1: Test Rig

Firstly, we prepared the testing stand by using 8 vertical pillars and 4 angled brackets, as shown in Figure 1. Then, the large vernier caliper was used to measure the dimensions of the CFRP and aluminum plate.

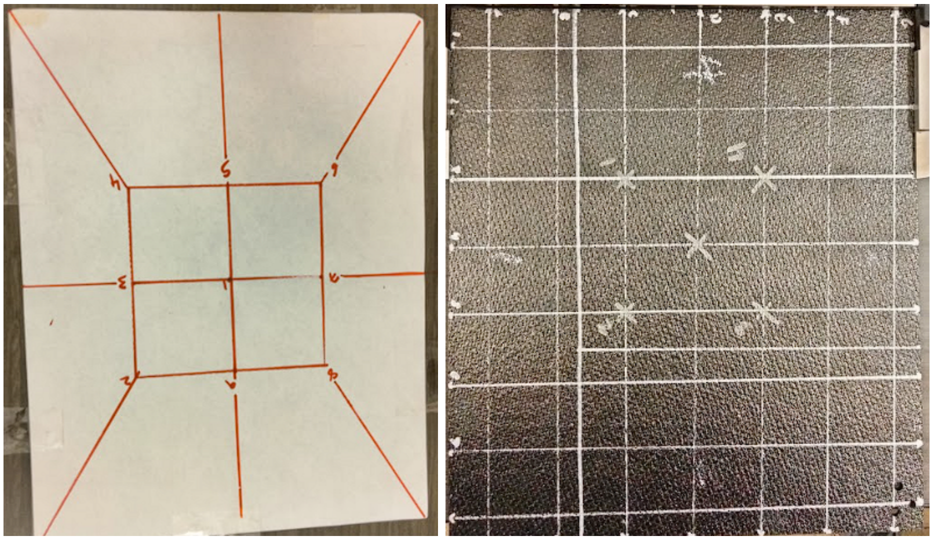


Figure 2:(A) Sheet marked with points (B): CFRP plate with marked points

A sheet of paper (Fig 2(A)) was used to project down the points marked on the CFRP plate; the data will be measured on these points for every increment of weight. The marked sheet of paper is kept under the test rig so that points lie strictly under the plate whose deflections must be measured. Once done, the CFRP plate was placed on the test rig and then checked for any undulations at 0lb uniform loading using the vernier caliper, and the Uz data was noted down.

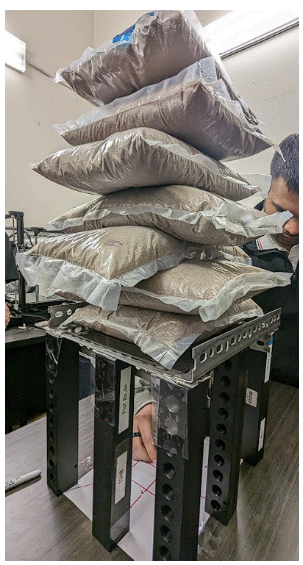


Figure 3: CFRP plate loaded to 70lb

This was done so that date collected from the 10lb load could be minused from the 0lb load to give us a new reference point.

The deflections were first collected from the CFRP plate by loading it at 4 stages: 0lb, 10lb, 40lb and 70lb and shown below:

CFRP start at 10 lbs				
Weight(lb)/point, mm	0lb (null), mm	10lb (starting point), mm	40lb, mm	70lb, mm
1	42.21	41.38	40.32	39.26
2	41.78	41.41	40.44	39.79
3	41.84	41.29	40.64	39.77
4	41.81	41.21	40.67	40.00
5	42.01	41.33	40.41	39.51
6	42.26	41.40	40.45	39.66
7	42.25	41.60	40.61	39.75
8	42.16	41.59	40.31	39.82
9	42.90	41.57	40.29	39.50
10	42.10	41.42	40.30	39.31
11	42.11	41.68	40.27	39.40
12	42.28	41.52	40.62	39.78
13	42.20	41.48	40.54	39.67
14	41.83	41.35	40.47	39.90
15	41.76	41.35	40.56	39.94
				AVG
Length (mm)	229.79	225.21	227.73	227.58
Width (mm)	238.91	242.62		240.77
Effective area (mm^2)	54792.50			
Thickness (mm)	2.80			
Weight (g)	259.00			

Aluminum starts at 10lb			
weight(lb)/point(mm)	10lb (starting point)	40lb	70lb
1	39.52	37.77	36.97
2	40.22	39.06	39.03
3	40.12	38.87	38.30
4	40.29	39.63	38.51
5	39.67	38.15	37.23
6	39.86	38.14	37.35
7	39.79	38.07	37.38
8	39.81	38.26	37.60
9	39.48	38.26	37.95
Length (mm)	304.78		
Width (mm)	304.97		
Effective area (mm^2)	92948.76		
Thickness (mm)	1.00		
Weight (g)	295.00		

Figure 4:(A)Data set for CFRP (B): Data set for Aluminum plate

After the data from the CFRP plate was collected, we swapped the plate for a 1mm thick Aluminum plate whose deflection data was used to compare both the plate's performances under the same loading conditions, and it's data set is shown above.

\

Figure 5:(A) Al plate deflection being measured (B): Vernier caliper used to measure deflection

To collect a data point, the vernier caliper was placed under the plates at each marked point on the sheet to measure the deflection at different load settings.

Discussion

There can be a few improvements made in the experimental process to obtain higher fidelity results. The pillars used to elevate the composite need to be secured to the ground and need to be placed above the paper used to take the deflection measurements. This ensures a stable and reliable set up with the pillars securely mounted and the measurement paper not moving. The L brackets used around the edges of the pillars can have a 45 degree angle cut. This will allow the brackets to lie flat on the pillars instead of overlapping. Tape used to simulate the boundary condition can either be a double sided tape or be avoided all together. Double sided tape can be a middle ground between providing the right amount of compliance and securing the composite plate. The tape might also be avoided as the first weight can hold down the plate. If this method is used, the first weight will act as a reference and the measurements will be taken from the second weight. The reliability of this method in simulating the boundary conditions needs to be validated. The paper used as a reference for measurement points can be printed instead of manually drawing lines. This will increase the accuracy and fidelity of the measurements. Another experimental suggestion would be to use a mirror marked with points and the composite having the same points on a piece of paper under it. This can help in avoiding unnecessary inclinations in the vernier. A dial gauge or LVDT can be used in place of a vernier caliper to measure points.

Conclusion

The findings of this study suggest that CFRP plates are a better choice than aluminum plates for components that require high stiffness and low deflection under uniform loading conditions.

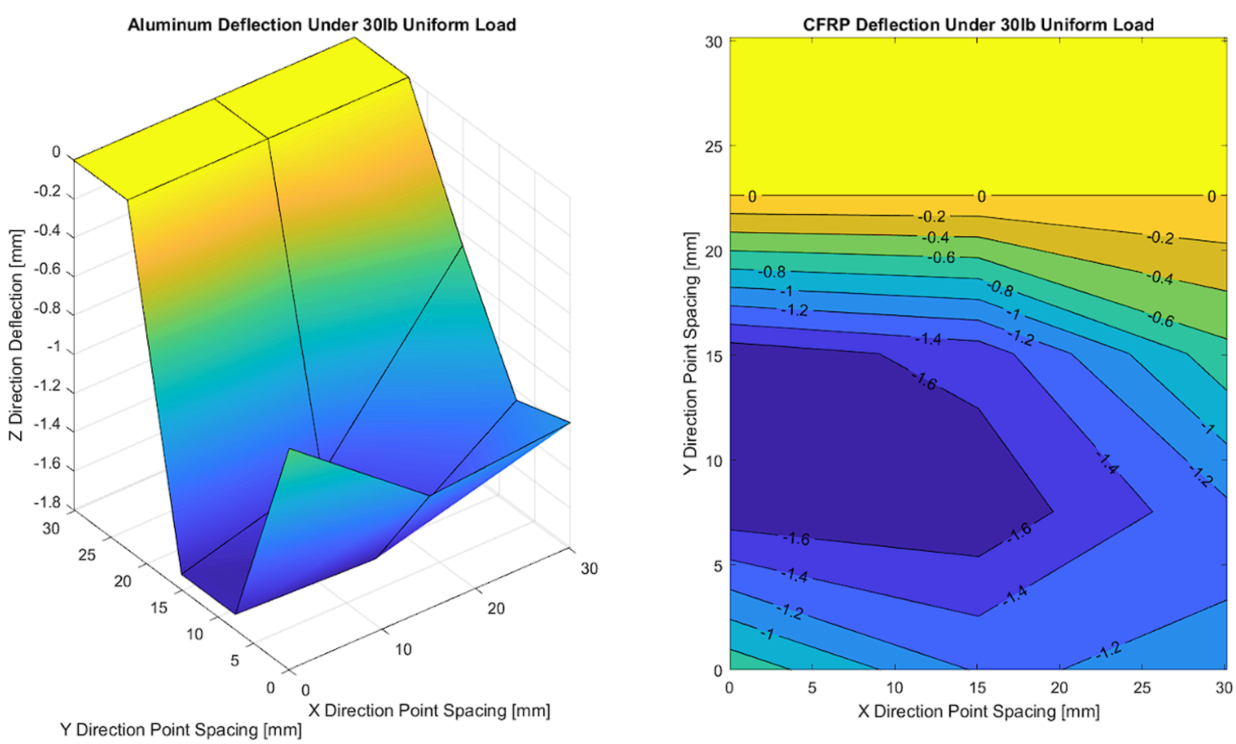


Figure 6:Aluminum deflection at 40lb UDL

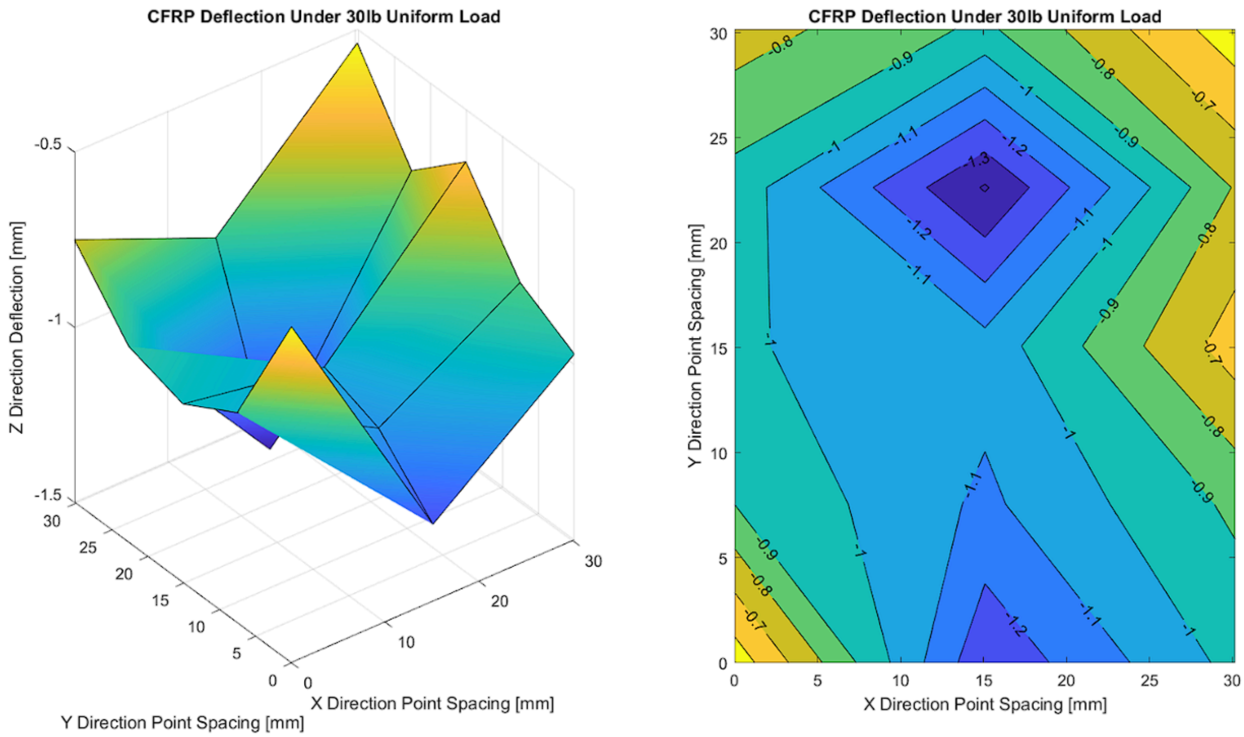


Figure 7: CFRP deflection at 40lb UDL

The simulated results also showed a similar trend, with the CFRP plate performing better than the aluminum plate under uniform loading conditions. These results can be useful for engineers and designers who need to select materials for such components.

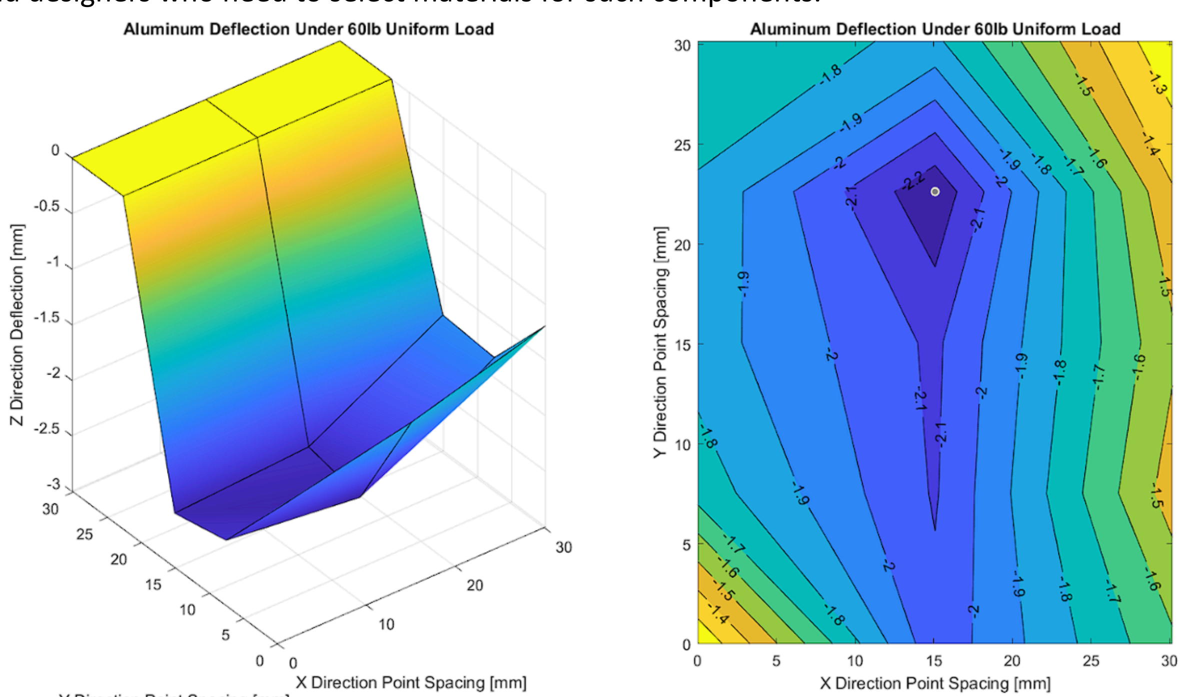


Figure 8:Aluminum deflection at 70lb UDL

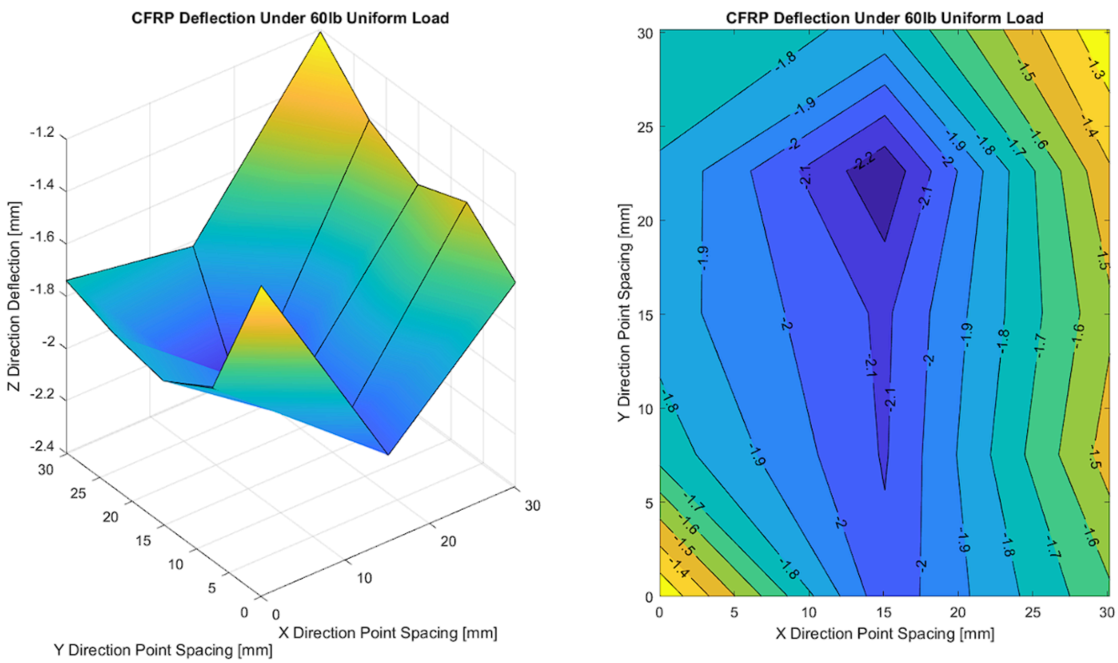


Figure 9: CFRP deflection at 70lb UDL

However, it's important to note that the experimental procedure used in this study could be further refined to obtain more accurate results in future studies. It may also be necessary to conduct additional testing under different loading conditions or with varying geometries of plate to understand these materials' performance fully.

Overall, this study provides valuable insights into the performance of CFRP and aluminum plates under uniform loading conditions and can serve as a valuable reference for future research and design efforts.

Works Cited

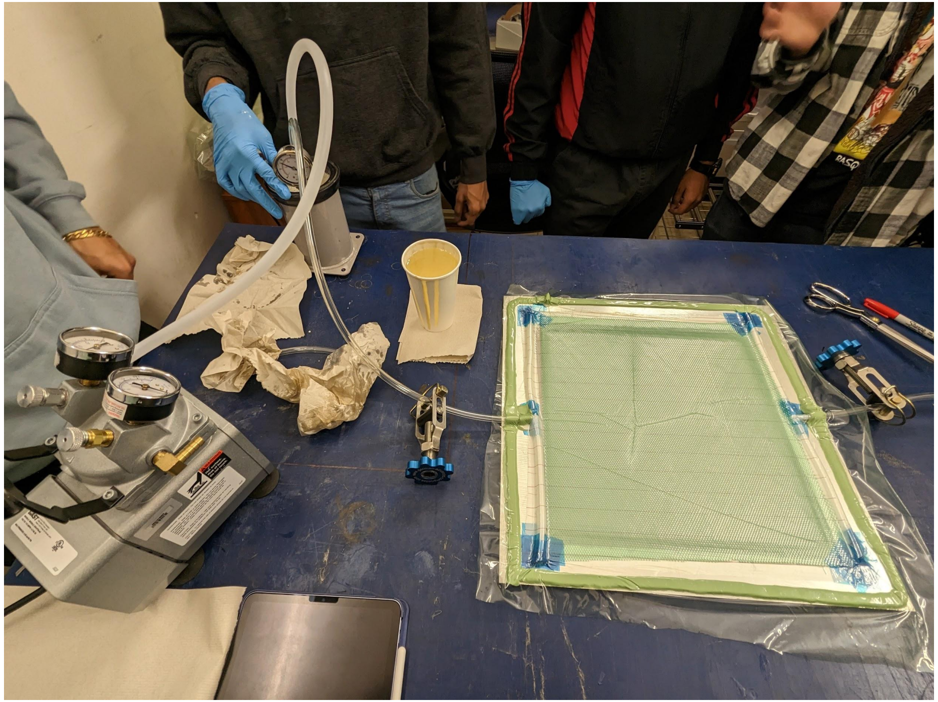
Bednarcyk, B. A., Arnold, S. M., & Aboudi, J. (2021). Practical Micromechanics of Composite Materials. Butterworth-Heinemann.

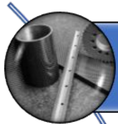
Flexible Fabrication Methods: Vacuum Infusion

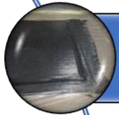
Team 1
AME 599, Prof. Bo Jin
-
Ethan Sanches, Himanshu, Jeremy Rodrigues, and Rohin Lengade

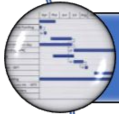
Introduction

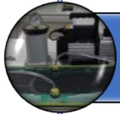
We will be manufacturing a 13 in. by 12.5 in. carbon fiber panel using 20 plies of fabric. This will serve as a precursor to the manufacturing of complex parts.

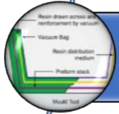


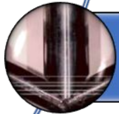

Background & Literature Review


Methods and Experiments


Gantt Chart

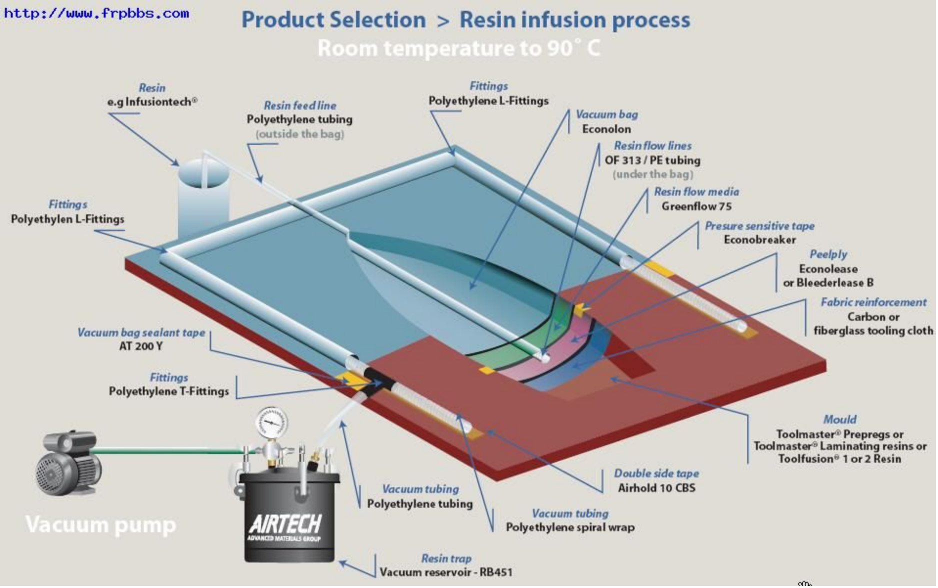

Materials and Equipment


Process


Testing, Challenges & Results


Discussions and Conclusions

Background



Carbon fiber is used across many industries at a varying level of part sizes and shapes.

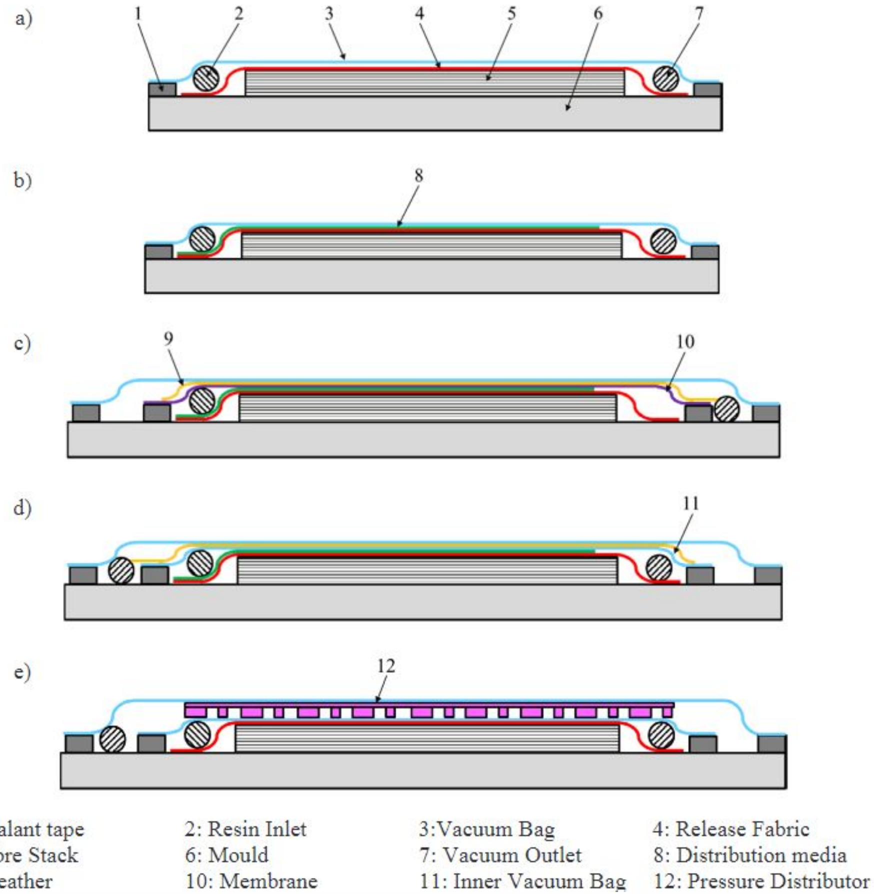
Manufacturing methods vary based on budget, part geometry and available equipment.

Vacuum infusion is a premier method to make any part needed.

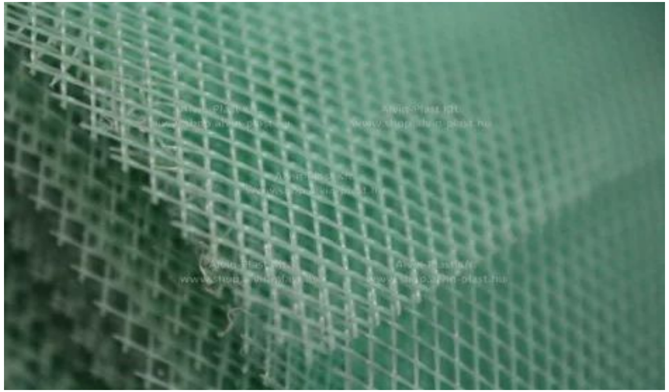
Literature Review

Oosterom et al. compared variation in the vacuum infusion method and how it affects final part performance.

FibreGlast presents a site where each piece of equipment and material can be process as well as in depth tutorials on the process

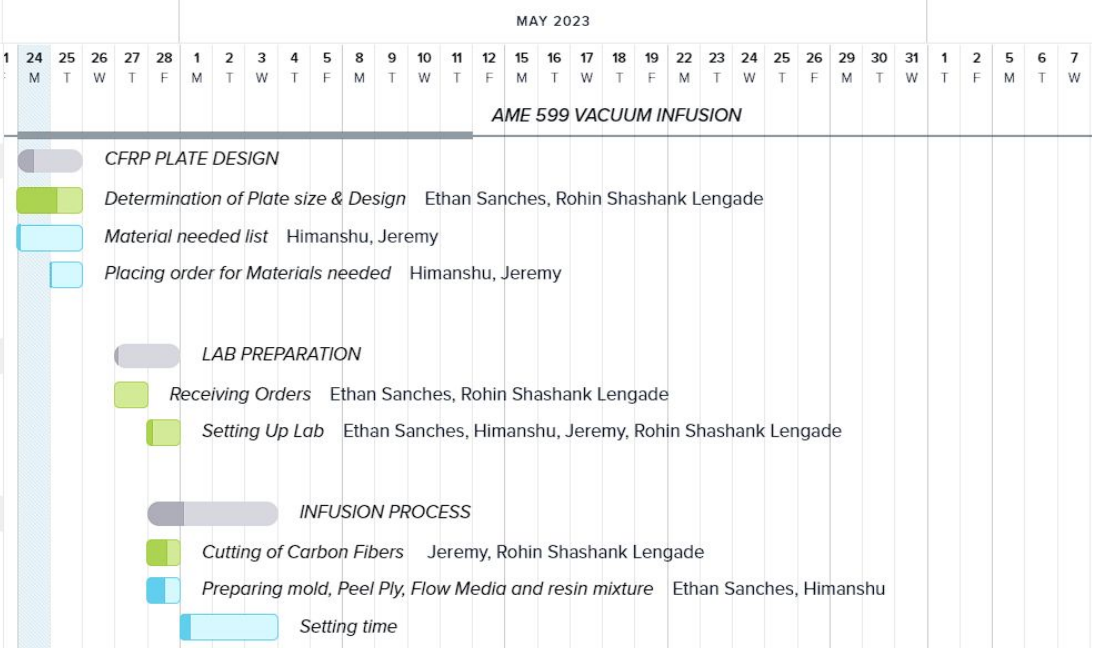


Methods and Experiments



Gantt Chart

	Assigned	Progress
AME 599 Vacuum Infusion		31%
▾ CFRP PLATE DESIGN		26%
Determination of Plate size & Design	Ethan Sanches, R	60%
Material needed list	Himanshu, Jerem	3%
Placing order for Materials needed	Himanshu, Jerem	2%
▾ LAB PREPARATION		7%
Receiving Orders	Ethan Sanches, R	0%
Setting Up Lab	Ethan Sanches, H	13%
▾ INFUSION PROCESS		28%
Cutting of Carbon Fibers	Jeremy, Rohin Sh	60%
Preparing mold, Peel Ply, Flow Media and resin mixture	Ethan Sanches, H	50%
Setting time		10%



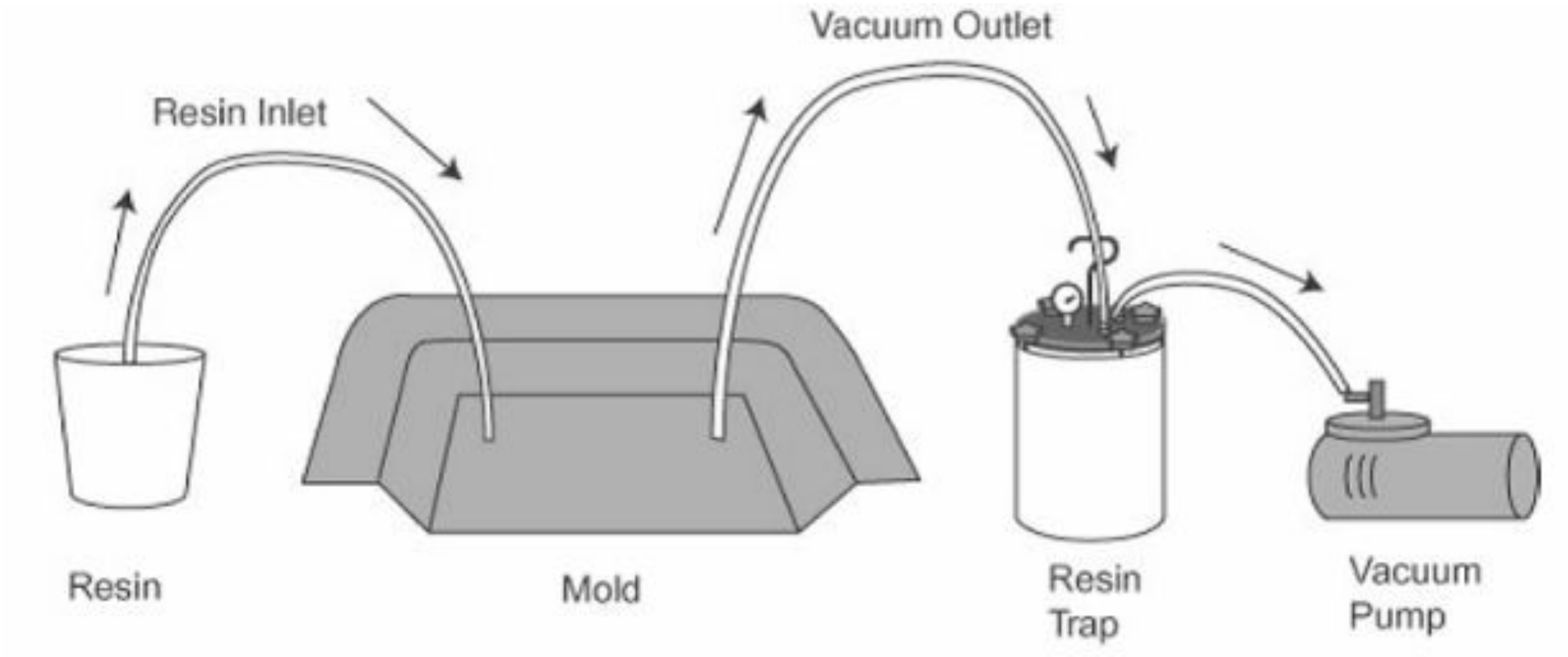
	Assigned	Progress
▼ POST PROCESSING		43%
Removal of Peel Ply and Flow Media	Ethan Sanches, R	10%
Clean CFRP Plate	Himanshu, Jerem	60%
Post Processing, cutting excess edges	Himanshu, Rohin	60%
▼ FINTE ELEMENT ANALYSIS		70%
Model part	Ethan Sanches	90%
Run on Ansys	Ethan Sanches, H	50%
▼ TESTING OF CFRP PLATE		27%
Arrange for Equipment needed	Jeremy, Rohin Sh	10%
Setup Lab	Jeremy, Rohin Sh	60%
Perform UDL Bending Test	Ethan Sanches, H	50%
Collect data points	Himanshu, Jerem	50%
Model data points in MATLAB	Himanshu, Jerem	10%
Compare with FEA and Other metals	Ethan Sanches, H	5%

Materials and Equipment

Resin: INF114   Hardener: INF-212
Used a 3.65:1 resin ratio as recommended by Pre-Set Epoxy
438g of resin and 120g of hardener for 558g total

Item	Costs
Recurring Costs (fiber, resin, bagging etc.)	$ 1,047.90
Reusable Equipment	$ 1,861.29
Total	**$2,909.19**

Process



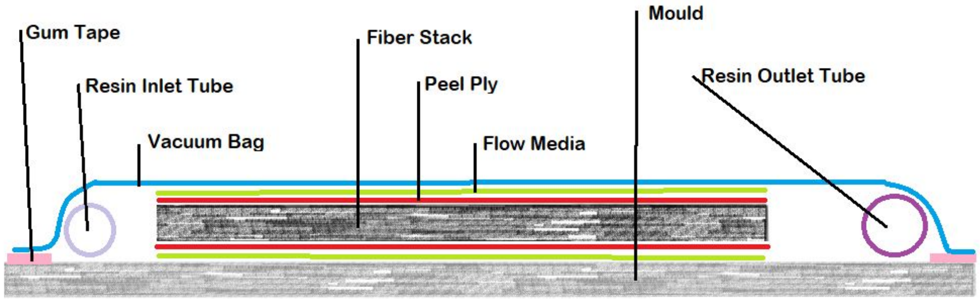
Vacuum Outlet
Resin Inlet
Resin
Mold
Resin
Trap
Vacuum
Pump

Process

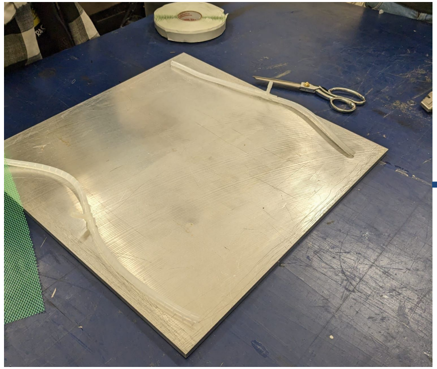
- Clean the plate with Acetone
- Cut the flow media to the right size
- Arrange the flow media and composite sheets
- Prepare the inlet and outlet
- Make sure this arrangement is taped properly
- Enclose and seal using vacuum bag and gum tape
- Connect the inlet and outlet tubes respectively

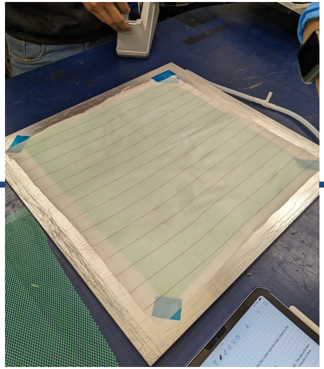
- De-gas the resin
- Begin vacuum infusion

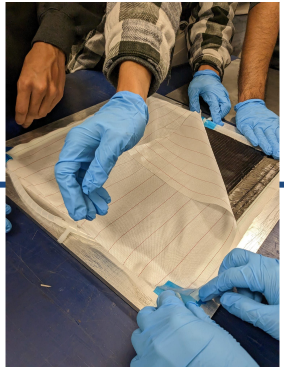
- Testing

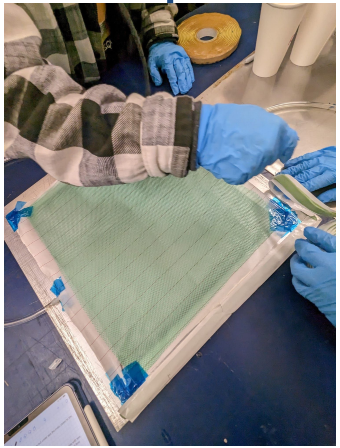


Process

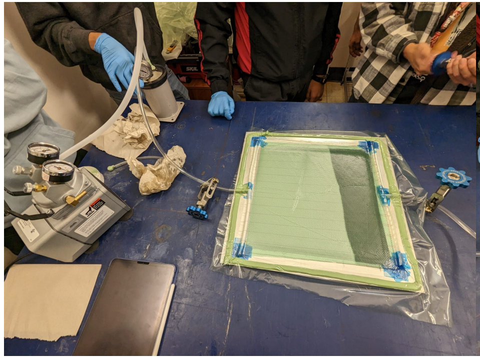


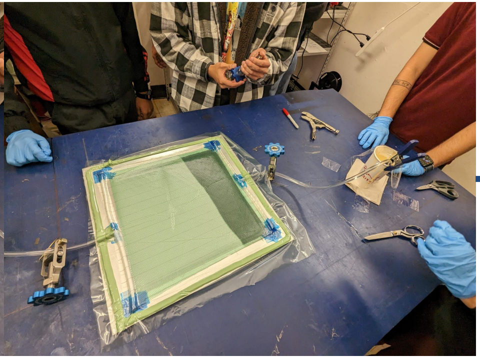




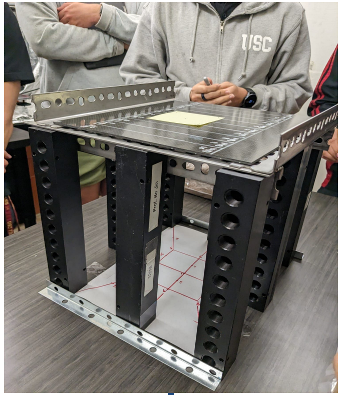


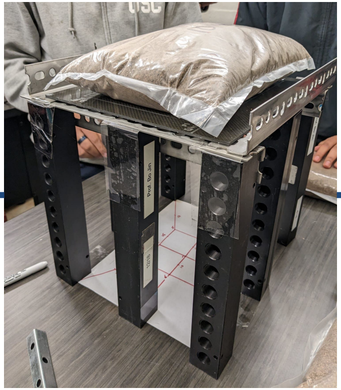
Process





Testing

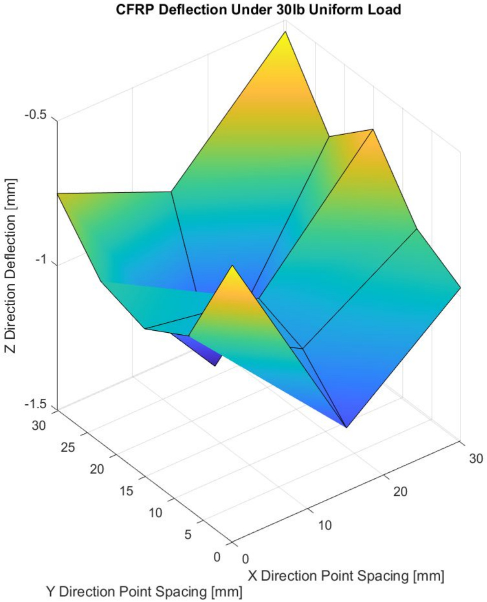


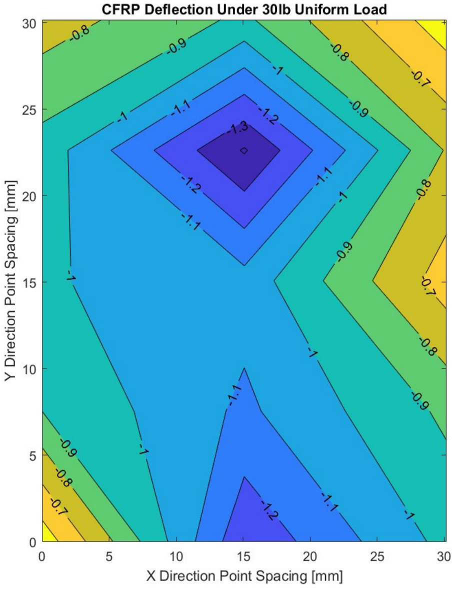


Challenges

- Process took > 2 hours
- Manual & skill driven
- Repeatability
- Testing
- Automation

Results





Computer analysis can be used to check and improve the process as well as verify CFRP superior performance as compared to metals.

Discussion

- Advantages: High strength-to-weight ratio, uniform resin distribution, & complex shapes .
- Challenges: Precise environmental control, careful planning.
- Applications: Aerospace, automotive, marine, wind & sporting goods.

Conclusion

- Carbon Fiber Vacuum Infusion Layup Process demonstrated the effectiveness for creating strong composite materials using carbon fiber with precise control of critical parameters.
- Vacuum infusion layup is a promising technology for creating lightweight and robust composite materials. The lab provides a foundation for further research and development.
- We can further analyze final product mechanical properties comprehensively, explore various fiber orientations, and test a wider range of resin types to push the limits of the process.

References

van Oosterom, S., Allen, T., Battley, M., & Bickerton, S. (2019). An objective comparison of common vacuum assisted resin infusion processes. *Composites Part A: Applied Science and Manufacturing*, *125*, 105528. https://doi.org/10.1016/j.compositesa.2019.105528

FiberGlast. (n.d.). *Vacuum infusion complete guide*. Fibre Glast Developments Corp. Retrieved April 22, 2023, from https://www.fibreglast.com/product/vacuum-infusion-Guide#:~:text=The%20Vacuum%20Infusion%20Process%20(VIP,laminate%20via%20carefully%20placed%20tubing.

Appendix

Item	Price Each	Qty.	Price Total	Where to purchase
Aluminum Plate (14"x14"x0.25")	$ 120.07	1	$ 120.07	McMaster-Carr
Peel Ply (30"wide by the yard)	$ 4.45	10	$ 44.50	Fiberglast.com
Vacuum Bag Film (60" wide by the yard)	$ 7.45	10	$ 74.50	Fiberglast.com
Flow media (41"x50ft)	$ 55.15	1	$ 55.15	Fiberglast.com
Epoxy Resin INF-114 (1 gallon)	$ 199.99	1	$ 199.99	RockWest Composites
Epoxy Hardener INF-212 (0.33 gallon)	$ 99.99	1	$ 99.99	RockWest Composites
Teflon tape (0.25"x36")	$ 5.84	1	$ 5.84	McMaster-Carr
Freekote 700-NC (1 gallon)	$ 133.92	1	$ 133.92	Ellsworth Adhe
General purpose Tape (1 roll)	$ 9.37	1	$ 9.37	McMaster-Carr
Carbon Fiber (20 plies, +/- 45deg, 150 gsm) per yard	$ 26.36	10	$ 263.60	Composite Envisions
Acetone (cleaning agent) 1 gal.	$ 40.21	1	$ 40.21	McMaster-Carr
Scale (to 0.001g, max 420g)	$ 499.00	1	$ 499.00	Afforablescales.com
Electric Scissors	$ 38.49	1	$ 38.49	Joann
Spiral Tubing (10ft spool)	$ 29.95	1	$ 29.95	Fiberglast.com
T-tubes	$ 2.95	4	$ 11.80	McMaster-Carr
Ruler	$ 23.49	1	$ 23.49	McMaster-Carr
Paper Towels	$ 50.16	1	$ 50.16	McMaster-Carr
Composite scissors	$ 29.48	1	$ 29.48	McMaster-Carr
Gum Tape	$ 9.95	1	$ 9.95	Fiberglast.com
Catch pot	$ 159.95	1	$ 159.95	Fiberglast.com
Cups	$ 9.99	1	$ 9.99	Ralphs
Stirring implements	$ 4.99	1	$ 4.99	Joann
Vacuum pump	$ 695.95	1	$ 695.95	McMaster-Carr
Clamps	$ 49.90	3	$ 149.70	German Advanced Composites
Large Cutting Mat	$ 145.16	1	$ 145.16	McMaster-Carr
Nitrile Gloves	$ 3.99	1	$ 3.99	Unisafegloves.com
		TOTAL	$2,909.19	

Appendix

PRO-SET®

Technical Data

INF-114
INF-212

INFUSION EPOXY

COMBINED FEATURES

Very low viscosity for rapid saturation of fiberglass, Kevlar® and carbon fiber laminate with resin infusion and VARTM processes.

HANDLING PROPERTIES

Property	Standard	Units	72°F (22°C)	77°F (25°C)	85°F (29°C)
150g Pot Life	ASTM D2471	minutes	214-262	166-204	112-138
500g Pot Life	ASTM D2471	minutes	144-178	118-146	87-107
Viscosity Mixed	ASTM D2196	cP	294	240	193
Viscosity (resin)	ASTM D2196	cP	1433		
Viscosity (hardener)	ASTM D2196	cP	13		

MIX RATIO

Method	Resin:Hardener	Resin:Hardener
Weight	3.65:1	100:27.4
Weight Range	3.78:1–3.42:1	100:26.4–100:29.2
Volume	3.00:1	100:33.3
Volume Range	3.11:1–2.81:1	100:32.2–100:35.5