Strength Testing of Hybrid Carbon Composites for Automotive Structures

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Abstract

Vehicles today require fuel-efficient and durable designs to compete in the demanding automotive industry. Hybrid carbon composites are new and popular alternatives to the heavy metals used in the frames of most automobiles.[1] Methods of decreasing the expenses of carbon fiber usage in cars range from different material utilization to optimal structuring of fibers at the production level. Hybrid carbon composites are already popular for use in certain accessories in performance automobiles as well, such as spoilers, scoops, and hoods.

Carbon fiber, being lightweight and strong, can be used in such parts because it keeps the car light and therefore the efficiency high. Not only is it less expensive to make, but it is also becoming easier to produce in larger quantities. Using a combination of traditional and contemporary methods, carbon fiber specimens were created and tested for strength using a Tensile Test Machine. Five different carbon fiber configurations were put under load stress to see which layout was most effective and would also maintain the strength levels necessary for safe automobile structures.

1. Introduction

1.1 Composites

A composite material is defined as a material system consisting of two or more phases on a macroscopic scale whose mechanical performance and properties are designed to be superior to those of the constituent materials acting independently. One of these phases is usually discontinuous, stiffer, and stronger and is called the *reinforcement*, whereas the less stiff and weaker phase is continuous and is called the *matrix*.[2]

A carbon composite is a material in which carbon fiber strands are the reinforcement and a polymer resin is designated as the matrix. The resultant composite is cured to create an almost metallic sheet that is incredibly lightweight and durable. The interlocking pattern in which the carbon fibers and polyester are connected contributes directly to the strength of the final product, as it creates for stronger bonds. As viewed in Figure 1, these composites have nearly endless applications, as they can be molded into any shape imaginable. In almost any problem requiring a lightweight, yet nearly indestructible solution, carbon composites may be utilized. The main difficulty with using carbon fiber structures is that the carbon fibers must be handmade and therefore consume a significant amount of time and energy to produce.

Fig. 1
Raw Carbon Fiber Sheet Infused With Resin

1.2 Applications

With recent developments many industries, especially the automotive and recreation industries, are beginning to use these composites in their products.[3] The automobile industry is always searching for more cost efficient methods of improving their products' attributes to increase revenue, and carbon composites hold all the properties necessary for their endeavors. Carbon composites, made of carbon fibers, have a resilient and lightweight structure; the fibers are particularly strong in their coinciding axis. This could prove to be an integral part of automobiles of the future and seeing that this has already been implemented in certain companies, the promising future for carbon fibers now may be the present.

2. Background

2.1 Layout

Carbon fiber is unique in that it is incredibly lightweight, durable, and strong, but these specific properties vary according to the direction in which the fibers are laid during preparation prior to cooking.[4] As seen in Figure 2, when the fibers are laid all in the same direction – or unidirectional - the structure is especially strong in the direction that the fibers run.

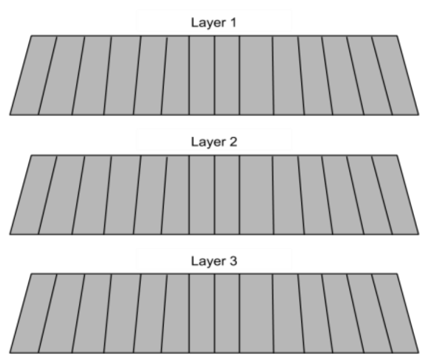

Fig. 2
Unidirectional Layering

However, when the fibers are laid in a direction that is perpendicular to the ones adjacent to it, as seen in Figure 3, the structure becomes strong in both directions, but not nearly as strong as a unidirectional design. This is also known as the 0°, 90° design.

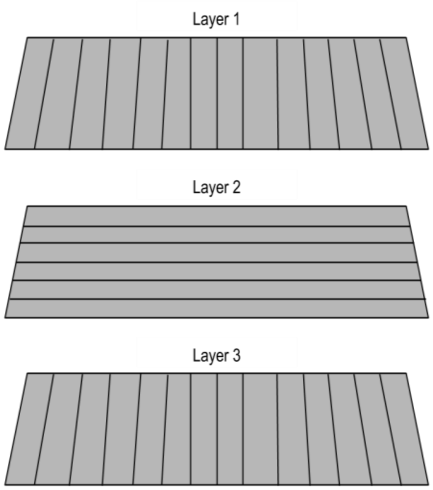

Fig. 3
0°, 90° Layering

2.2 Carbon Fiber Sheets

To make carbon fiber sheets, single layers of carbon fiber, Hexply 8552, are pre-soaked with resin called Hexflow 8552, and are then laid out one on top of another. The air bubbles are then rolled out using a large, heavy pin after each layer is placed. The paper backing is removed, and the process is repeated until the desired thickness is achieved. Lastly, the several layer thick structure is placed into a mold and cooked in an autoclave, which is essentially an industrial pressure cooker, for approximately five hours. After trimming the edges, the resulting molded carbon fiber should be ready for application, as seen in Figure 4.

Fig. 4
Cured Carbon Fiber Sheet

2.3 Chopped Carbon Fibers

In addition to the carbon fiber sheets, randomly chopped carbon fibers (IM-7 Fibers) were also utilized in this experiment. These are recycled fibers (Figure 5) that are about 5.2 microns thick and have been specially treated to improve properties such as structure, shear and handling.[5] The chopped fibers are not as strong as the carbon fiber sheets but are more flexible. They can be soaked in resin and compacted to other chopped fibers or carbon sheets.

Fig. 5
Random Chopped Carbon Fibers

3. Experimental Procedure

3.1 Design

This experiment was designed to test the strength of carbon fiber structures in automotive applications. Four different designs were chosen to test strength regarding impact and collision forces. Each design consisted of ten 6 inch by 6 inch sheets of carbon fiber. Additionally, 20 grams total of various small chopped carbon fibers were compacted between the sheets of carbon and everything was held together with resin. The control group (Design A) for this experiment is a 6in by 6in carbon fiber square consisting of 10 unidirectional layers. Design B is a square consisting of 5 unidirectional (uni) sheets, various fibers, and 5 uni sheets. Design C is a square that has the design of 4 uni, various fibers, 2 uni, various fibers, and 4 uni. Design D consists of 2 uni, various fibers, 6 uni, various fibers, and 2 uni. Finally, Design E is a layout of 2 uni, various fibers, 3 uni, various fibers, 3 uni, various fibers, and 2 uni. Each design was specially created in order to test what kind of pressure it could withstand.

3.2 Preparation

In order to perform this experiment, the 6 inch by 6 inch square sheets must first be cut from the roll of carbon fiber which is pre-soaked with resin. The squares must be cut at precise 90 degree angles in order for the structure to have maximum strength. If the sheets are cut crookedly and placed one on top of another, they won't adhere properly to one another. After the squares have been cut, they are prepared for layering; each square must be clean of all debris or dust stuck to it, otherwise, the squares will not adhere flush to one another. As a result, the structure would be weaker than the optimal strength. Next, the squares will be stacked on top of each other, and the quantity is determined by the number of layers required by the specific design. The carbon fiber sheets are fastened to paper on one side which makes for easier transport. The adhesive side of the stacked sheets are placed together and rolled with a 25 pound steel cylinder in order to eliminate any potential air bubbles. Once the squares are prepared, various small carbon fibers are obtained for each layer of fiber sheets. These fibers will be sprinkled on top of the layer of carbon fiber sheets as designated in the design. Resin is then poured on top of the fibers to bind the small fibers to the sheets. The amount of resin must be adequate to coat the entire layer, but if there is excess, a vacuum later in the process will pull all the extra resin out of the structure. After the square is complete, it must be prepared for the autoclave.

3.3 Vacuum

The carbon fiber compilation must first be vacuum packed before it can be placed into the autoclave. The process begins with the packing down of our carbon fiber matrix by placing it between two metal sheets after surrounding it with cork to prevent resin from leaking. The metal sheets must be fully covered with sheets of blue plastic in order to prevent resin from sticking to the metal. After, the carbon fiber compilation can be placed between the sheets of metal. Breather fabric, similar to a sheet of cotton, must be placed between the metal sheets to let the resin have something to soak into. Once these steps are completed, the carbon fibers are surrounded by cork, which also soaks up the excess resin. Once the cork is laid out, the two metal sheets can be placed together. Sealant tape surrounds the metal sheets. Lastly, the entire system is wrapped in a vacuum bag and the air is removed from the system using a vacuum pump. This step is incredibly important, for if the seal breaks, moisture leaves the resin coating on the fibers. This can occur relatively often during the production of the composites and when this occurs the bag must be replaced and new sealant tape must be applied. The whole system, as referenced in Figures 6 and 7, is placed in the autoclave and will cure for five hours.

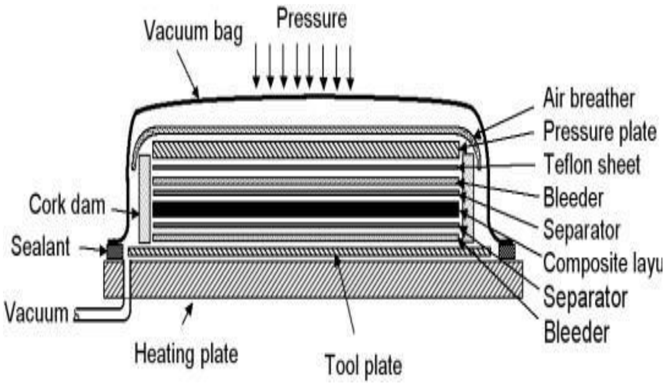

Fig. 6

Carbon Fiber Preparation[6]

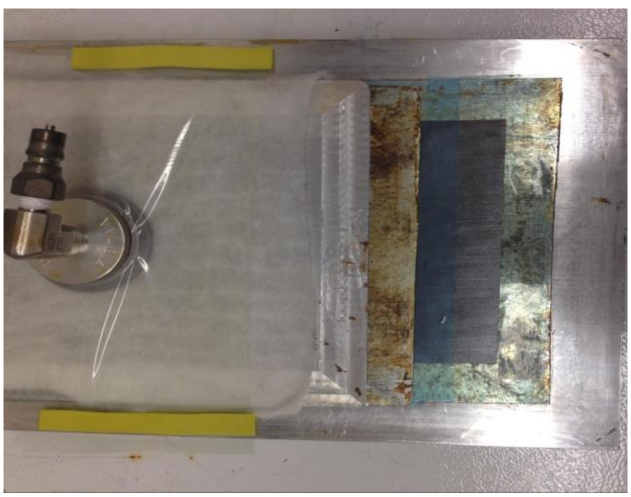

Fig. 7

Experimental Layout

3.4 Autoclave

There is a specific cycle of cooking that the carbon fiber is exposed to throughout these five hours, as seen in Figure 8. First, the autoclave heats to approximately 225°F. It remains that way for just over 2.5 hours. At the end of these two and a half hours, pressure amounting to about 100 PSI is applied to the entire system. As this pressure is applied, the heat raises to about 350°F within the autoclave. Again, it remains this way for another 2.5 hours, and the process is complete.

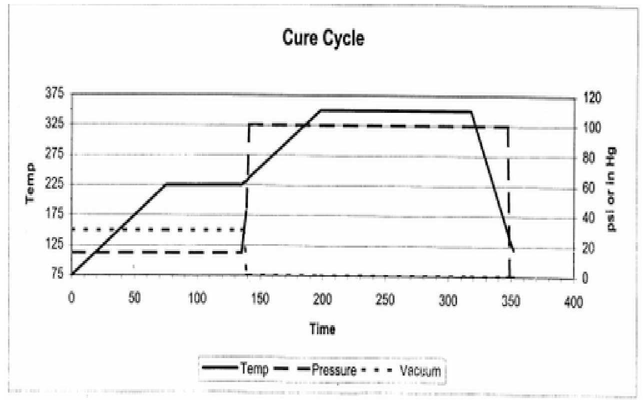

Fig. 8

Autoclave Curing Process[7]

3.5 Finish

After the cooking system is removed from the autoclave, the vacuum seal is released and the carbon fiber sheet is completed. The excess resin would likely bind to the cork that surrounded the carbon fiber matrix during cooking, so it would need to be broken off, and the edge had to be trimmed with the tile saw. After this process, the finished product is ready to be cut to the specific shape for use in the desired products. The baked squares are now cut into 6 inch by 0.25 inch rectangles as in Figure 9. The newly cut rectangles are measured in width and thickness and the data is multiplied to find the area of the cross section. Measured in millimeters squared, the cross section area is inputted into the computer for use in the Instron 88215 Tensile Test Machine. The strength of these carbon rectangles is tested using the machine to simulate the forces on an automobile structure during collisions as well as general use.

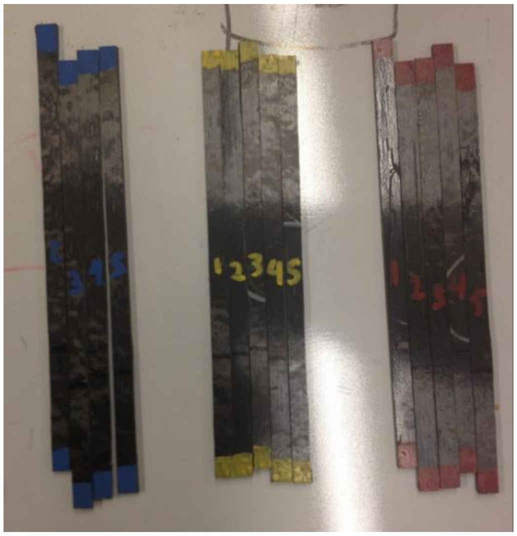

Fig. 9
Cured Carbon Fiber Rectangles

Fig. 10
Composite Breaking in the Tensile Machine

3.6 Apparatus

The two main pieces of equipment that were used in this experiment were the tile saw and the Instron 88215 Tensile Test Machine. The tile saw is used for cutting all of the pieces of carbon fiber after they have been baked in the autoclave. It was fitted specifically for cutting carbon fibers as it is hooked up to a ventilation system and water pump.

The Instron Tensile Test Machine pulls the carbon fiber rectangles vertically until the pressure causes the structure to snap. The carbon fiber can snap in one easy movement or it can snap into many different strands. As seen in Figures 10 and 11, the carbon fiber snapped into many pieces and caved under pressure. The carbon fiber structures were extremely small but still were able to hold loads of great strength.

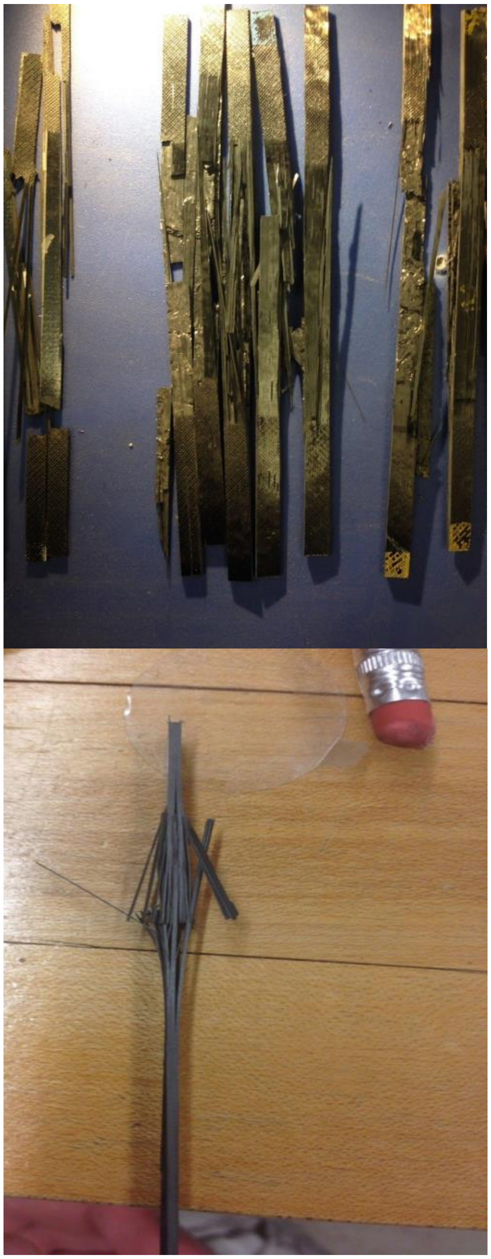

Fig. 11
Broken Carbon Fiber Structures

4. Results and Discussion

4.1 Data

	Rectangle Number	*Width (mm)*	*Thickness (mm)*	*Cross Sectional Area (mm²)*
A	1	4.55	1.57	7.144
	2	4.91	1.58	7.758
	3	5.73	1.53	8.767
	4	5.58	1.55	8.649
	5	5.91	1.53	9.042
B	1	6.24	1.93	12.043
	2	6.22	2.32	14.430
	3	6.31	2.06	12.999
	4	6.26	2.03	12.708
	5	6.37	2.25	14.333
C	1	5.68	2.34	13.291
	2	6.24	2.24	13.978
	3	5.95	2.42	14.399
	4	6.07	2.34	14.204
	5	6.03	2.46	14.834
D	1	6.13	2.08	12.750
	2	6.08	2.1	12.768
	3	6.06	2.21	13.393
	4	6.15	2.25	13.838
	5	6.17	2.38	14.685

E	1	6.45	2.36	15.222
	2	6.76	2.36	15.954
	3	5.94	2.44	14.494
	4	6.37	2.46	15.670
	5	6.31	2.48	15.649

Fig. 12
Carbon Fiber Rectangle Measurements

4.2 Calculations

The above information was obtained using calipers by measuring the width and thickness of each sample, and multiplying them together to receive the cross-sectional area. After testing, the cross sectional area of each structure, the amount of force they withstood, and the distance they stretched were taken and plugged into the stress and strain equations. This would allow for calculations of the overall strength of the sample without any bias based on the size of the individual sample.

$$e = \frac{\Delta L}{L} = \frac{\ell - L}{L}$$

$$\text{Stress} = \sigma = \frac{F}{A}$$

4.3 Results

	Young's Modulus (GPa)	Ultimate Tensile Strength (GPa)	Fracture Strain
A1	144.14	1.59	0.009
A2	164.47	2.13	0.012
A3	151.19	1.93	0.012
A4	154.9	1.93	0.012
A5	153.63	1.93	0.012
	153.666	1.902	0.0114
B1	124.98	1.23	0.009
B2	119.31	0.84	0.006
B3	191.02	1.01	0.005
B4	129.87	1.15	0.008
B5	115.84	1.12	0.008
	136.204	1.07	0.0072
C1	125.29	0.77	0.006
C2	105.13	0.86	0.008
C3	106.78	0.98	0.009
C4	114.81	1.1	0.008
C5	102.65	0.79	0.007
	110.932	0.9	0.0076
D1	150.81	0.861	0.005
D2	128.48	1.142	0.008
D3	132.55	0.654	0.0021
D4	107.07	0.558	0.005
D5	113.2	0.57	0.005
	126.422	0.757	0.00502
E1	111.39	0.667	0.006
E2	106.11	0.82	0.007
E3	98.786	0.69	0.008
E4	113.3	0.72	0.009
E5	99.178	0.58	0.006
	105.7528	0.6954	0.0072
A	153.66	1.902	0.0114
B	136.204	1.07	0.0072
C	110.932	0.9	0.0076
D	126.422	0.757	0.00502
E	105.4528	0.6954	0.0072

Fig. 13
Stress and Strain Data

As stated before, the stress and strain that was calculated would allow for the actual strength of the layout without any bias based on variations in size. To do this, the stress and strain of each sample were taken and plugged into the Young's Modulus equation. After doing this, it was determined that Design A, the control, had the highest average ultimate tensile strength, fracture strain, and young's modulus, while design E had the lowest for all three. This shows that separating the layers of carbon fiber and putting sections of random chopped fibers and resin in between weakens the overall tensile strength of the system weaker. However doing this can increase the volume of the final product, so if only a certain amount of tensile strength is needed for an application, more can be received for a lower price, with the cost being in the lower strength value.

$$E \equiv \frac{\text{tensile stress}}{\text{extensional strain}} = \frac{\sigma}{\varepsilon} = \frac{F/}{\Delta L/}$$

4.4 Discussion

Testing of the composites' strength was done through tensile strength testing, so samples withstood stress across one axis. The fiber sheets used in experimentation were therefore all oriented unidirectionally, to find the maximum strength of the material. All the materials tested had 10 sheets of resin-infused fibers and 20 grams of randomly chopped fibers to implement consistency, while the structure of the layout was variable. This method of testing reveals the most effective structure to implement recycled fibers in larger industries, such as automobiles.

To compare the strengths of the rectangles, the Ultimate Tensile Strength (UTS) of each rectangle was found. The cross sectional area of the rectangles had to be utilized in order to accurately compare strength values. When the carbon fiber square was cut into significantly smaller rectangles, they were not all the same precise dimensions. This would affect the strength needed to break the different rectangles, so the data received was plugged into a stress formula, in order for the cross sectional area of each strip was taken into account. The capability of the material to withstand stress based on the amount of material was found through the load and area of the rectangles.

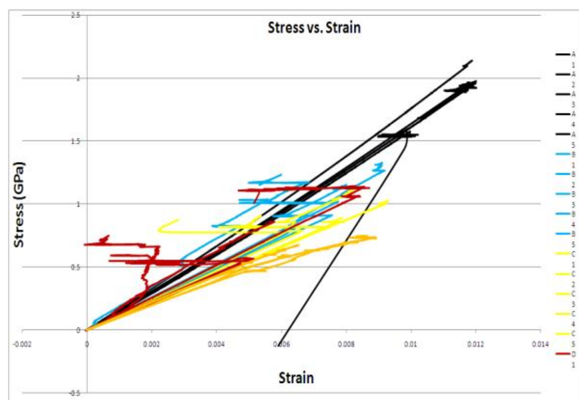

Fig. 14
Stress vs. Strain

5. Conclusions

5.1 Evaluation

The data revealed that the strength of the carbon composite depended on the separation of the fiber sheet in the layering of the materials, as the layouts with the lesser amount of dispersion between long-stranded, non-recycled sheets of fiber had the higher UTS values. The control, layout

A, exhibited the most impressive values in all of the measured categories. Layout B, the structure that utilized the random chopped fibers, had the highest Tensile Modulus. As a result, there will be smaller deformations for a given load. This is most likely a direct result of the two thick five sheet carbon fibers that surrounded the chopped fibers. Out of all the structures that used the random chopped fibers, Design B also had the highest ultimate tensile strength which means that it can accumulate the highest stress before the other designs with random chopped fibers (C-E). Again, this is most likely due to the two thick 5-ply specimens that surround the random chop fibers. All of the specimens that consisted of random chopped fibers had a similar range of fracture strains, 0.005 to 0.01 with an average of around 0.007 (0.7%) strain. If the structures were ordered from highest tensile modulus to lowest tensile modulus, it would be A, B, D, C, and E. This mostly corresponds to the highest number of sheets that went uninterrupted by random chopped fibers. The conclusion that we gather is that having more carbon fiber sheets together will offer more stiffness.

5.2 Errors

There were multiple factors in this experiment that may have contributed to errors in the data. First, if the carbon fiber sheets were not cut exactly into 90 degree angles, it would make layering of the fibers crooked. In turn, the whole structure would become weaker overall, since the direction of the fibers' strength will not be in the direction of the composite's application. Next, the random chop fibers that were placed between the carbon fiber sheets might have not absorbed all of the resin equally. Therefore, there some parts of the carbon square could be stronger than other parts.

Also, the bag could have been improperly vacuum-packed between the formations of individual composites, resulting in the carbon fiber square to lose moisture during the cure cycle. This makes the final square more brittle and weaker than it should be. In addition, it will contain many imperfections on the surface, making it visually displeasing.

5.3 Future Applications

The results of this experiment indicate that carbon fibers are a viable solution to certain problems in the automotive industry. The more sheets that were placed together, the stronger the structure would be. The carbon fibers could be used for accessories or even for the structure of the automobile. These could range from anything that needs to be lightweight to anything that would need a high tensile strength. In certain situations, it may also be a suitable replacement to steel components that would usually make the car heavier, and therefore less efficient. Parts that carbon fiber may replace include spoilers and hoods of cars, as well as core components such as the chassis or frame. The cost of creating these is currently incredibly high, more than three times that of steel at $16 per pound. This is mostly due to the cost of energy when creating the fibers themselves. There is also an expensive process of treating the toxic fumes that are release from the fibers as this happens. Currently, new ways of development are being worked on to reduce the cost of creation by up to 70%. When that happens, carbon fiber is likely to make a much larger impact on the automotive industry as a whole.[8]

6. Acknowledgements

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