DESIGN OF A NEW LAB ON THREE POINT BEND TEST ON A FIBERGLASS COMPOSITE

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ABSTRACT

In a very packed curriculum, it can be difficult to provide undergraduate mechanical engineering students with broad exposure to a wide range of materials, especially composites. A variety of industries and companies are using composites on an increasingly larger scale. Typically, the study of composite materials is reserved for graduate level work in mechanical engineering. Hands-on work with composite materials can be difficult to fit into an undergraduate mechanical engineering program. As one of the laboratory activities in the undergraduate, one credit hour Introduction to Materials lab, sophomores and junior students are provided the opportunity to gain hands on experience with manufacturing and testing composite materials. In this laboratory activity, students learn about the application, the advantages, the disadvantages and the properties of composite materials. Students are exposed to the anisotropic nature of composites by fabricating two fiber-glass reinforced three-point bend samples having a 0º and 90º fiber orientation, respectively. They also calculate the flexural strength and modulus of the two samples by doing a three point bend test and then comparing the results with 0º and 90º fiber orientation. To understand the effect of fiber volume fraction, the students also compare the results with samples which have no fibers. The feedback from the students was assessed through a Likert's scale and more than 80% of the students agreed that they were able to satisfy the learning objectives.

INTRODUCTION

Over the years, composite materials have evolved to revolutionize the world of material science. Their high strength and low weight properties make them an exceptional contender amongst other materials in product design. As a result, composite materials have replaced metals and polymers in many large scale structures such as ships, bridges, rockets and aircraft and also in small scale structures such as bicycles, tennis rackets, and micro-air vehicles. In just a few short decades, composites went from primarily high tech military applications to numerous consumer applications. The availability of a variety of composite materials inspired new ingenuity and research in the field of material science to develop new composites, manufacturing methods and to expand the applications of composite materials [1] [2] [3]. A majority of this

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research is conducted in educational institutions, government entities and also in private industries [4] funded internally and also through government organizations such as National Science Foundation (NSF) [5].

The University of Dayton (UD) and University of Dayton Research Institute (UDRI) have been actively engaged in developing and modeling advanced composites. Additionally they offer composite related courses at the graduate level [6]. Similarly, many universities across the United States and across the globe provide courses and research opportunities related to composite materials at a graduate level. Comparatively little to no exposure about composite materials is given to undergraduate students. As a result, most students get exposure to advanced composite materials at the graduate level only [7]. This situation can influence the career of students and the future of composite materials in an intangible way. In academia, exposure to various technologies can inspire students to pursue certain career paths after graduation. Composite materials and their applications have the ability to inspire students and motivate them to pursue a career in the field of material science. Therefore, it is prudent to expose all undergraduate engineering students to composite materials in an effort to produce more innovative designers and better engineers. And by exposing a majority of the students to composites, the industry will have a trained work frame that can contribute to growth and innovation in ground breaking materials [8].

Efforts have been taken at several universities to include composite materials in the undergraduate curriculum. To meet the growing needs of the composite industry, Winona State University (WSU) started Composite Materials Engineering (CME), an undergraduate engineering program solely devoted to the study of composite materials [9]. West Virginia University (WVU) and the University of Akron (UA) also provide courses in composite materials for undergraduate civil engineering students [10]. Computer modeling (MathCad) and computer analysis (ANSYS) of composite materials are taught to undergraduate students at Virginia Military Institute (VMI) along with validation of the results with experimental data [11]. Even at UD, a course on design with fiberglass composite materials is given to qualified senior undergraduate students and graduate students [12]. At UD, undergraduate students also have an opportunity to work with composites in extra-curricular activities such as on the Design, Build, Fly (DBF) team. Every year the DBF team designs and produces a remote controlled aircraft to satisfy the objectives of the Speed Fest competition hosted by Oklahoma State University. The team makes the entire aircraft (wings, tail and fuselage) using glass and carbon fibers. A majority of the students on the DBF team are undergraduate students and they get to work with composite materials and learn how to fabricate them into an aircraft and actually make it fly.

In an effort to provide undergraduate mechanical engineering students broader exposure to composite materials, juniors and sophomores at UD are being taught to fabricate reinforced fiberglass composite as a part of their materials lab coursework. As one of the laboratory activities in the undergraduate curriculum, one credit hour, Introduction to Materials Lab, students are provided the opportunity to gain hands-on experience with fabricating and testing composite materials. Although this is a required course for mechanical engineering students, any undergraduate engineering student has the opportunity to take this laboratory course. In this laboratory activity, the students learn about the behavior, application, advantages, disadvantages and properties of composite materials. Students are exposed to the anisotropic nature of composites by fabricating two fiber-glass reinforced three-point bend samples having a 0º and 90º fiber orientation, respectively. By making the samples themselves, students get the opportunity to work with fibers and also learn about the different constituents involved in making composites. This paper summarizes the learning objectives and procedure the students followed in the laboratory. Representative three point bend test results are also included to convey the level of knowledge about composite materials they gained through this exercise. This laboratory exercise was first started in the fall of 2013 and to this day, it relies on seeking improvement through feedback from students and from other sources.

LEARNING AND EXPERIMENTAL OBJECTIVES

The learning objectives of the exercise were focused on teaching students about composite materials and focused on engaging them in hands-on laboratory activity. The students have a total of five hours and twenty minutes separated equally in two days with a week apart. Due to this short duration, the activity could not go more profoundly into the subject of composites. Instead, students are exposed briefly to applications, fabrication and testing of the composites. The activity was designed such that by the end of this activity they will be able to:

- Fabricate fiberglass composites with Epoxy resin and hardener.
- Determine the anisotropic properties of the composite material by varying the orientation of the fibers across a number of samples.
- Determine the strength to weight ratio of the composite material.
- Compare the strength of the material with and without fiber.
- Be able to conduct three point bend test and analyze the data generated from this test
- Be able to relate basic research with data generated from laboratory experiments to interpret the data and to draw conclusions
- Gain more experience in working on small teams.
- Understand the basics of operating a universal test machine
- Understand how to read and interpret ASTM test standards
- Understand how to measure samples
- Understand how to record test procedures

Once the learning objective was conceived, the experimental objective was sought out to determine the effect of fiber orientation on a fiberglass/epoxy composite material's Flexural strength and Flexural modulus. From this experimental objective, students get an opportunity to apply the knowledge they gained about three point bend testing and flexural strength and flexural modulus in their "Introduction to Materials" to the composite materials they create.

PROCEDURE

The procedure of the laboratory exercise included fabrication of the fiberglass composite and then three point bend testing of the fabricated sample.

Fabrication of Fiberglass composite

In order to accomplish the experimental objective, each student made two fiberglass composite samples, one with a 0° fiber orientation and the other with a 90° fiber orientation (Figure 1). Each sample had a length of 4”, a width of 1” and a thickness of approximately ¼”.

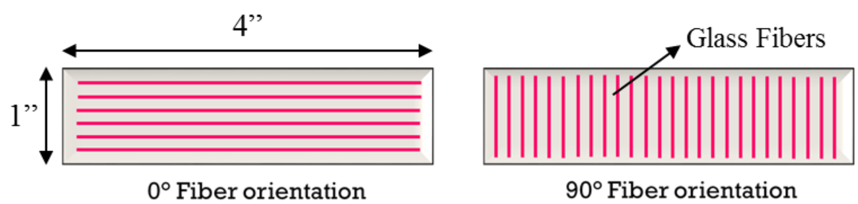

Figure 1 0°and 90° fiber oriented samples that each student should fabricate

The samples were laid-up in a rubber mold (Figure 2) that was formed from Silicone Rubber. (AeroMarine 125 Silicone RTV Rubber A and B).

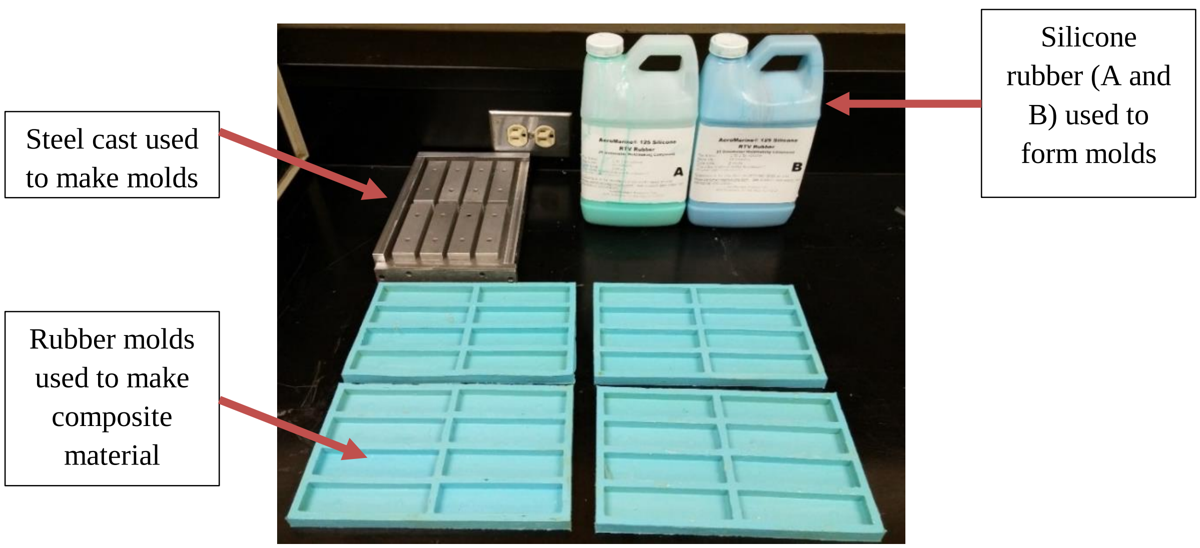

Figure 2 Silicone rubber molds for laying the composites

In order to ensure all samples had the same fiber volume ratio, each student was given two sets of glass fibers with the same weight to fabricate one 0° fiber oriented sample and one 90° fiber oriented sample. Students were required to cut 4” long fiber strands and 1” long fiber strands to fit into the mold. The matrix of the composite was made by mixing Epoxy Resin (Fibre Glast Epoxy Resin 2000) with Hardener (Fibre Glast 2060, 60 Minute Epoxy Cure) with the mixture ratio of 100g: 27g by weight.

Figure 3 Fibre Glast Epoxy Resin and Hardener forms the matrix of the fiberglass composite

To lay the composite, the surface of the mold was coated with a layer of the epoxy/hardener mixture. After making the layer, the students placed the fibers on top of the coating and then finally covered it with another layer of epoxy/hardener mixture, sandwiching the fibers in-between the layers of the mixture (Figure 4). Both the 0º fiber oriented sample and the 90º fiber oriented sample were made in the same manner. Since the fabrication process involves placing individual fiber strands at desired orientation by hand without any equipment, the orientations of the fiber in the matrix were not precise. The amount of epoxy-hardener mixture was not precise among the different samples as well.

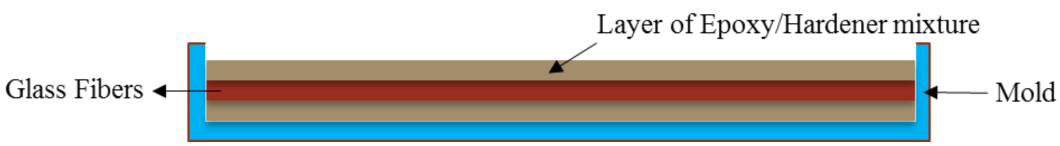

Figure 4 Fabrication of fiberglass composite

After laying up the composite, the molds were left undisturbed for the epoxy resin/hardener mixture to cure at room temperature for more than 24 hours. Once all the samples were cured, the students subjected their samples to a three point bend test. A cured sample made by a student is shown in Figure 5.

Figure 5 Reinforced fiberglass composite made by a student

Three point bend test

The three point bend tests were conducted on the samples to determine the maximum load at sample failure and maximum deflection during the sample break using an Instron machine (Load Frame number: 4486) with ±1124 lbf load cell (Instron/2525-805). ASTM D7264/D7264M-07 was used as a guide for the three point bend test. ASTM standards are followed in materials laboratory to expose students to professional standards and regulations in testing. Before loading the samples in the machine, students were asked to remove the flash on the edges of the sample using sand paper (80/100 grit) and to measure the width and thickness of the sample in three different regions using digital calipers. BlueHill (Version 2.16) was used for data acquisition from Instron. The three point bend test setup is shown in Figure 6. The span was set to 2”.

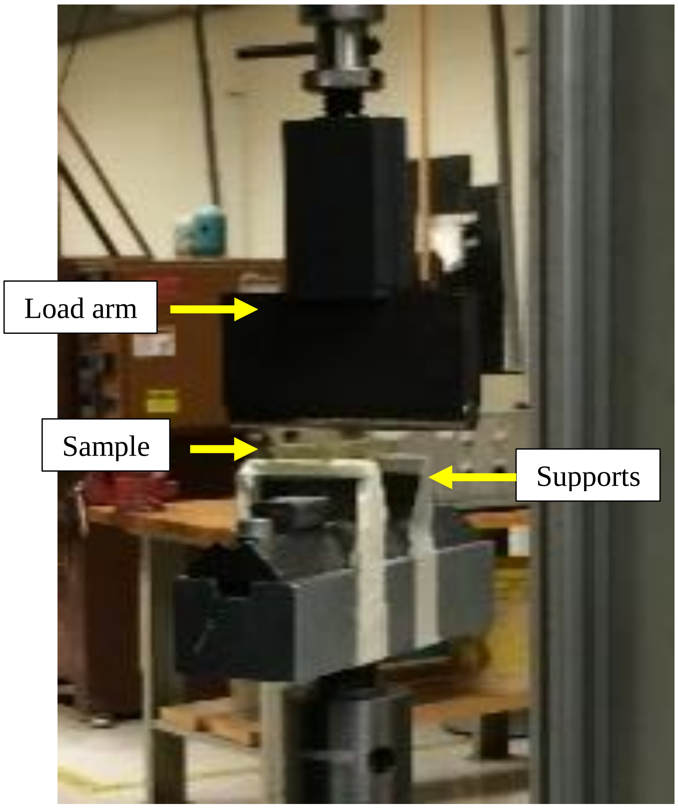

Figure 6 Three point bend test setup with support bars and load arm

ANALYSIS OF RESULTS

Following the bend test of the samples, the students calculated the flexural strength and flexural modulus of each sample using Equations 1 and 2.

$$\sigma = \frac{3FL}{2wh^2} \quad (1)$$

$$E = \frac{FL^3}{4wh^3\delta} \quad (2)$$

where σ is flexural strength (psi), F is force at sample failure, L is the distance between support bars, w is the width of the sample, h is the thickness of the sample and δ is the maximum deflection at the point of failure. Students shared the data they generated within the class and calculated average values and standard deviations for the results. The flexural strength and flexural modulus results generated by a team of students is shown in Figure 7 for a total of 11 samples. Students also weighed their samples and calculated the strength to weight ratio of the composites. In the end, they compared this ratio with the strength to weight ratio of the metal using data obtained from Matweb [13]. To understand the effect of fiber volume fraction, the students also compared the results with samples which had no fibers.

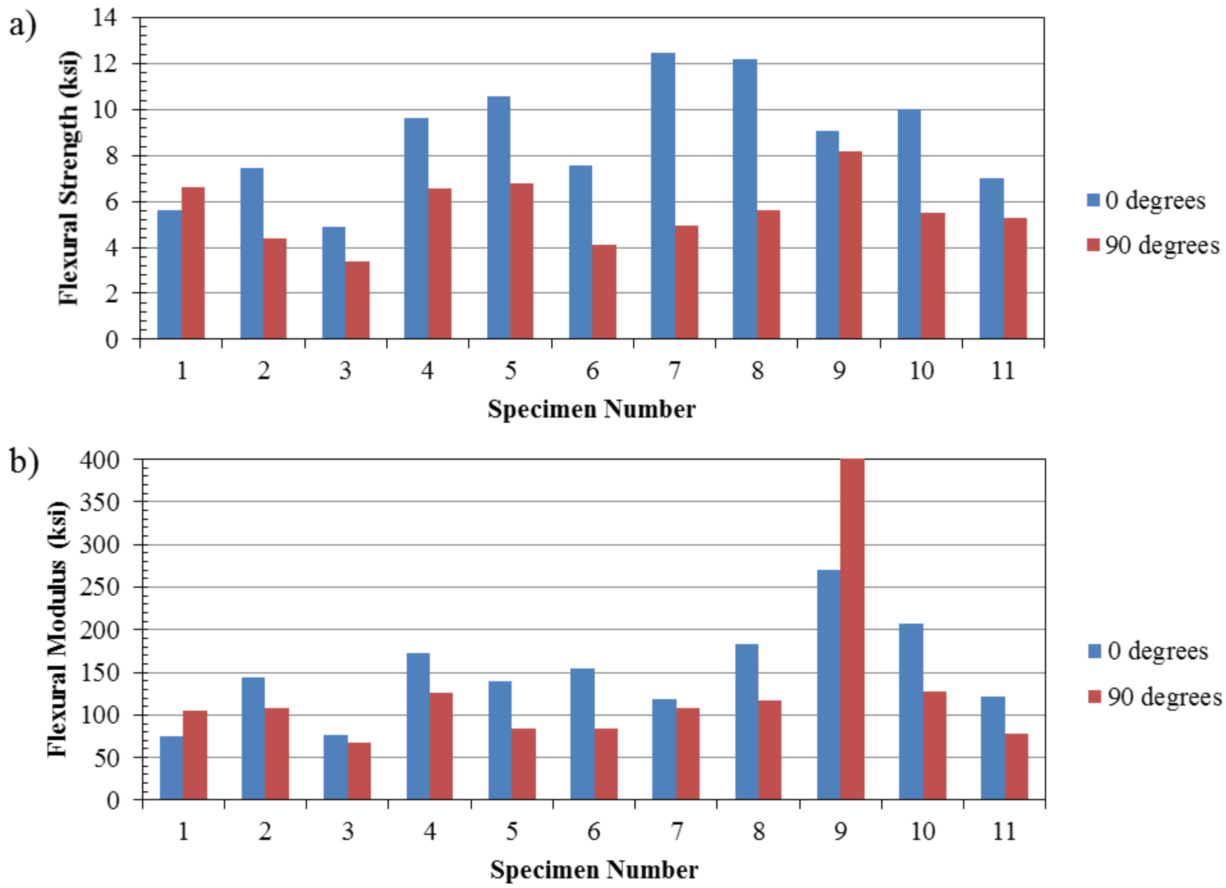

Figure 7 Results generated by a team of students a) Flexural strength and b) Flexural modulus for 0° and 90° fiber oriented samples

From Figure 7, students can understand that on an average, 0° fiber oriented samples have higher strength and modulus than the 90° fiber oriented samples. In this way, the anisotropic nature of composites is clearly seen by the students.

After doing the data analysis, students were given a chance to write a two page report. In the report, students were required to introduce the testing, describe the procedure, present and discuss the results. Students rely on online resources to find explanations to reason the observations they made in the exercise. The research done for the discussion portion of the lab report provided a means of inquiry based learning for the students.

FEEDBACK

By the end of the exercise, all of the students had a basic idea of how to fabricate a simple fiberglass composite using different constituents. Students also learned about composites anisotropic properties and how orientation of the fiber can affect the strength of the composite materials. Moreover, they learned how to calculate flexural strength and flexural modulus. Since this laboratory exercise is a new introduction in the laboratory schedule, feedback from students was sought. The feedback from students was assessed through a Likert scale assessment form. All the questions on the assessment form were designed to determine if the learning objectives of this exercise had been met. Table 1 shows students responses to the laboratory exercise.

Table 1 Feedback from students for Composite lab

This laboratory exercise helped me to	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Learn how to make simple fiber reinforced composite	25	27	-	-	-
Learn about different consituents involved in the making of composite material	12	30	10	-	-
Learn about the classification of composite materials	10	25	14	3	-
Understand the anisotropic nature of the composites	11	23	14	3	-
Appreciate the strength to weight ratio of the composites	23	25	3	1	-
Appreciate the wide array of applications of composites	25	22	3	2	-
Understand the advantages of composites over metals	24	22	6	-	-
AVERAGE	**19**	**25**	**8**	**2**	-
STANDARD DEVIATION	**7**	**3**	**5**	**1**	-

From Table 1, on an average, more than 80% of the class agreed that they achieved their learning objectives. Besides the Likert scale assessment, feedback was also obtained through open ended questions. Those questions and most common answers are shown below.

1. What did you like the most about this laboratory exercise?
    - *Learning how to make composites*
    - *Seeing in real life, the strength of the composite samples against metals*
    - *Learning about different applications of composites*

- *Making and testing the samples we created in laboratory*

2. What did you not like the most about this laboratory exercise?
    - *Hard to lay fibers by hand*
    - *Hard to cut 1" long fibers and place them in the mold*
    - *Hard to place the fibers at exactly 0° and 90° orientations*

3. Did you have fun doing this lab?
    - *Yes*
    - *Not really*

4. What suggestion would you give to improve this exercise?
    - *Extend the scope of the exercise by using different fiber materials*
    - *Provide better tools to lay fibers in the mold*
    - *Increase the length of the fibers required so that it is easier to cut*

5. What is the one product you would like to make using composite material?
    - *Airplanes*
    - *Cars*
    - *Phone case*
    - *Baseball bat*
    - *Football helmet*

Based on the feedback from the students, it was determined that this new laboratory provided a meaningful learning experience for the students. As such, it will continue to be included in the laboratory schedule. The little exposure they had to composite materials is purely through hands on work which makes a great impact on the students and the way they think about composites. Efforts are being taken to act upon the drawbacks of the exercise by searching for better tools for the students to layup the fibers. Efforts are also being taken to introduce carbon fiber sample so that students can see the difference between fiberglass and carbon fiber composite.

CONCLUSION

As a part of Materials lab coursework, sophomores and juniors at UD have an opportunity to fabricate and test reinforced fiberglass composite samples. Most of the students walked into this lab without having any prior knowledge of composite materials. By doing hands on work with composites, they finished with a basic understanding of the applications, advantages and disadvantages of composite materials. Apart from learning how to fabricate the composites, they became aware of resources such as material suppliers, composite material data bases and ASTM composite standards.

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