# AC 2010-133: TESTING SEVERAL COMPOSITE MATERIALS IN A MATERIAL SCIENCE COURSE UNDER THE ENGINEERING TECHNOLOGY CURRICULUM

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# Testing Several Composite Materials in a Material Science Course under the Engineering Technology Curriculum


## Abstract

The primary objective of a material science course is to provide the fundamental knowledge necessary to understand important concepts in engineering materials, and how these concepts relate to engineering design. In our institution, this course involves different laboratory performances to obtain various material properties and to reinforce students' understanding to grasp the course objectives. As we are on a quarter system, this course becomes very aggressive and challenging to complete the intended course syllabus in a satisfactory manner within the limited time. It leaves very little time for students and instructor to incorporate thorough study any additional items such as composite materials. Therefore, the authors propose to provide basic concepts on composite materials through successive laboratory performances besides the regular classroom lectures. The learning process starts with a basic understanding of composite constituents such as matrix and fiber, their types, properties and the manufacturing processes. After acquiring the necessary theoretical knowledge, students perform a series of experiments dealing with several composite materials.

First, students are introduced to different unidirectional laminates prepared with variable ply thickness. They are asked to sketch the expected force vs. deformation and stress vs. strain diagrams of each laminate before conducting the real experiment. This experiment demonstrates the concept of strength which is geometry or size independent for metals. For composites, this statement could also be true ignoring the heterogeneous effect on a small enough scale. Composite laminates are also prepared with different fiber orientations. Students are asked to draw the expected experimental response when the composites are loaded along the longitudinal and transverse direction of fibers. This experiment demonstrates the concept of anisotropy, an inherently related phenomenon with any composite material. Then students perform the tensile testing of several multi-ply laminates prepared with carbon, glass and kevlar fibers. This experiment exhibits several concepts such as laminate strength that depends on the number of plies, fiber orientation and the types of fiber. The proposed learning methodology studies students' achievements of numerous concepts on composite materials. The purpose of this paper is to explain the details of this laboratory project as well as discussing the educational outcomes obtained in our material science curriculum.


## Background

One of the challenges in modern education is to minimize the gap between the academic knowledge and to comprehend that knowledge for subsequent applications, analysis and design. Students often view education as an effort to memorize as many important facts as possible. On the other hand, we educators want those students to implement their knowledge with proper understanding to solve realistic engineering problems. It is a fact that we cannot apply our knowledge to solve any engineering problem if we do not understand properly, or if we have a lack of concepts. This phenomenon has already been identified by Benjamin Bloom in his cognitive Taxonomy[1] during 1950. He identified six levels in education that most educators consider during teaching. Later on, a former student of Bloom revised the learning taxonomy by changing the names in the six categories from noun to verb forms, and slightly rearranging them. As a quick review, the six levels of Bloom's cognitive domain in the original and revised forms are presented in Figure 1.0 below.

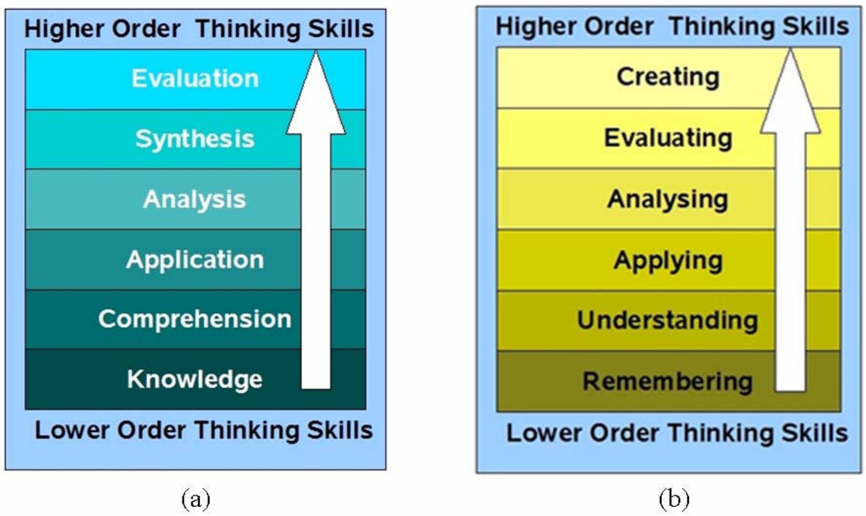



Figure 1: Bloom's taxonomy[1] of cognitive learning (a) Original, (b) Revised

Educators are very familiar with the concept presented in Bloom's Taxonomy. Program classes in the freshman and sophomore levels often emphasize the "Knowledge" and "Comprehension" aspects as the students are involved to build their basic foundation in engineering. Senior level courses should emphasize the "Evaluating" and "Creating" aspects, and prepare students to make necessary design decision before they graduate. In the middle, the educator should emphasize the "Application" and "Analysis" aspects that bridge the gap between lower and higher level skills. The idea that students can learn at different levels is a driving force in how educators develop and construct their lessons. Unfortunately, if the knowledge and understandings are wrong then the higher order thinking skills will also be incorrect. We aspire to help students to reach the highest level of education as well as providing the greatest understanding of the topics and ideas during their freshmen and sophomore levels. This paper presents our efforts to emphasize the "Knowledge" and "Understanding" aspects in a junior level materials engineering class at our institution.

## Introduction

The "Industrial Materials" course runs over a single quarter in our institution. It consists of both a lecture and laboratory work. In addition, many of the students have not yet had course work in technical writing. So we added teaching elements of how to write a successful lab report. The students get exposed to all of the standard material testing procedures including tensile testing, hardness testing, heat treating and the process of mounting, polishing and etching samples to view them under a metallograph.

There is already more material to cover than is allotted for, and yet we are hoping to add additional items on composite materials. Due to having limited time, the authors propose to provide basic concepts on composite materials through successive laboratory performances besides the scheduled classroom lectures. The learning process starts with a basic understanding of composite constituents such as matrix and fiber, their types, properties and the manufacturing processes. After acquiring the necessary theoretical knowledge, students will perform a series of experiments dealing with several composite materials. First, students will be introduced to unidirectional laminates prepared with different ply thickness. Student will be asked to draw the expected experimental response in terms of force vs. deformation and stress vs. strain diagrams of those laminates before conducting the real experiments. Students will get the concept that the ultimate force that a material can withstand depends on its sectional geometry or size, but the strength (force/area) will remain the same. Composite laminates will also be prepared with different fiber orientations. Students will be asked to predict the experimental response when the composites are loaded along the longitudinal and transverse directions of fiber. This experiment will demonstrate the concept of anisotropy, an inherently related phenomenon with any composite material. Students will also perform the tensile testing of several multi-ply laminates prepared with carbon, glass and kevlar fibers. This experiment will demonstrate several concepts such as laminate strength that depends on the number of plies, fiber orientation and the types of fiber. The proposed learning methodology will study students' learning to achieve numerous concepts on composite materials. The purpose of this paper is to explain the details of this laboratory project as well as discussing the educational outcomes obtained in our material science curriculum.

## Details of Proposed Learning Methodologies

### Theoretical Lectures

The learning process starts with a basic understanding of composite constituents such as matrix and fiber, their types, and their properties. First, students are introduced with several composite terminologies through theoretical lectures. The regular lecture classes cover the following items as shown in Table 1.

Table 1: Topics in Composite Materials Covered in Regular Lecture Classes

| **Chapters** | **Topics to Cover** |
|---|---|
| Introduction | • Basic concepts<br>• Mechanical properties<br>• Stress and strain |
| Materials | • Fiber reinforcements<br>• Matrix materials<br>Thermoset<br>Thermoplastic |
| Composite Fabrication Processes | • Hand Lay-up<br>• Prepreg Lay-up<br>• Bag Molding<br>• Autoclave Processing<br>• Compression Molding<br>• Resin Transfer Molding<br>• Pultrusion |

| | |
|---|---|
| | • Filament Winding |
| Micromechanics | • Fiber volume fraction<br>• Composite modulus<br>• Composite strength |

## The Laboratory Experiments

The learning process in composite materials is then continued through some successive laboratory experiments. Each student is given a copy of the lab handout during the lecture portion of the class. Students are expected to have read through it and be ready when they show up for their lab experience. The laboratory experiments intended to be performed are as shown in Table 2.

Table 2: Laboratory Experiments with Composite Materials

| Expt. # | Name of the Experiment | Significance |
|---|---|---|
| 1 | Tensile testing of uniaxial 3-ply carbon fiber laminate – along the fiber direction (0 degree) | Concept of strength |
| 2 | Tensile testing of uniaxial 5-ply carbon fiber laminate – along the fiber direction (0 degree) | |
| 3 | Tensile testing of uniaxial 7-ply carbon fiber laminate – along the fiber direction (0 degree) | |
| 4 | Tensile testing of uniaxial 3-ply carbon fiber laminate – along the transverse direction of fiber (90 degree) | Concept of anisotropy |
| 5 | Tensile testing of [0/45/90] degree carbon fiber laminate | |
| 6 | Tensile testing of [0/45/90] degree glass fiber laminate | Composite strength and micromechanics |
| 7 | Tensile testing of [0/45/90] degree kevlar fiber laminate | |
| 8 | Solving several mathematical problems | |

Different composite samples were prepared according to the ASTM standard 4762-08 using the carbon, glass and kevlar fibers as shown in Figure 2. Fibers were oriented at preferred or different directions as required for a specific experiment. All experiments were performed using the commercial Tinius Olsen tensile testing machine. A typical experimental setup is shown in Figure 3. Details of the significance of each experiment are described in the following sections.


(a) (b) (c)

Figure 2: Composite samples used in tensile testing. (a) Carbon fiber, (b) Glass fiber, (c) Kevlar fiber


(a) (b)

Figure 3: Tensile testing with composite materials. (a) Loading, (b) Failure

**Expt. # 1-3: Concept of Strength**

The first topic that we try to teach our students is the concept of strength. Most of the students enrolled in this Materials Engineering class do not have in-depth knowledge on Mechanics or Strength of Materials. However, the lecture classes cover different concepts and terminologies related with the standard tensile testing of ductile and brittle materials as shown in Figure 4. The theoretical discussion also includes understanding the concept of stress, strain, yield stress, modulus of elasticity, ultimate strength and fracture strength.

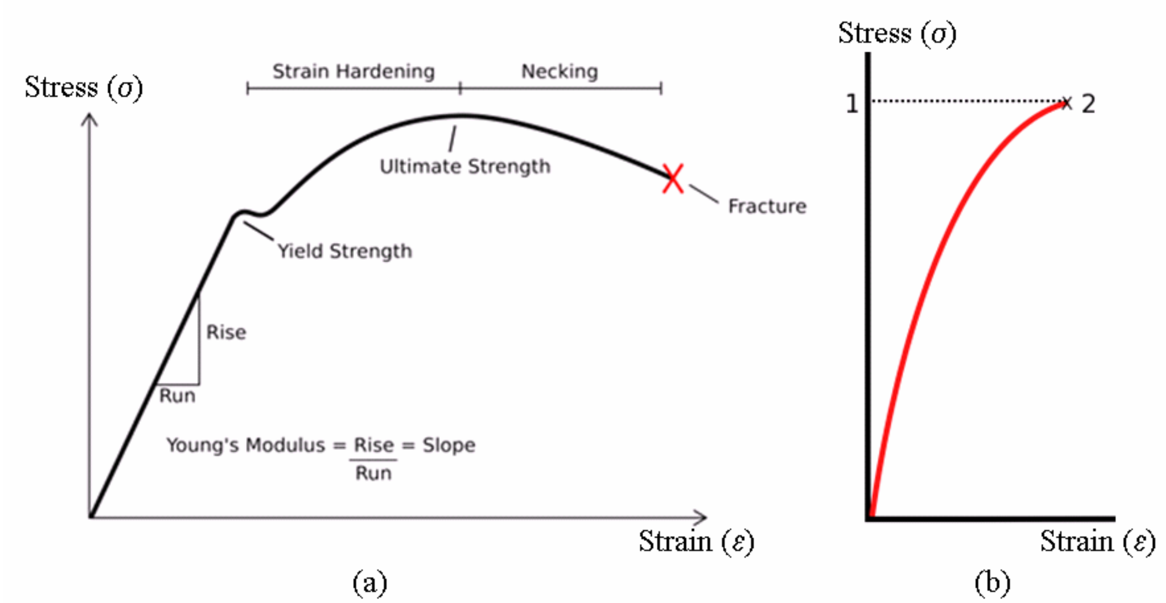



Figure 4: Different terminologies studied in the lecture class related with tensile testing[2]. (a) Ductile material (b) Brittle material

It has been found that students often mistakenly think of strength as *the maximum force* that a material can withstand before it breaks. They also think strength of any material is geometry dependent. For example, 4140 carbon steel has higher strength when its diameter is 1-inch compared to the same steel with diameter of 0.5-inch. However, this concept is wrong. Truly, strength means the load carrying capability per unit area. Therefore, for a particular material (e.g., 4140 steel), strength is geometry independent whereas the maximum load it could carry before failure certainly depends on geometry.

We tried to convey this concept to our students with some experiments dealing with composite materials. First, students prepared several composite laminates with carbon fiber and epoxy resin. For all samples, fibers are unidirectional where the thickness varies with the number of layers or plies. Detail of the geometry is listed in Table 3 below. All samples were then subjected to uniaxial tensile testing. Students recorded the tensile force and the corresponding deflection until the samples failed.

Table 3: Geometry of Composite Samples with Carbon Fiber

| Samples | Width (inch) | Thickness (inch) | Cross-Sectional Area (inch$^2$) | Gage Length (inch) |
|---|---|---|---|---|
| 3-Layer | 0.54 | 0.032 | 0.01728 | 2 |
| 5-Layer | 0.54 | 0.052 | 0.02808 | 2 |
| 7-Layer | 0.54 | 0.070 | 0.0378 | 2 |

The force vs. deflection plots of the unidirectional carbon fiber laminates with variable ply thickness are shown in Figure 5. Students can realize that the ultimate force ($F_u$), where the samples fail, depends on sectional geometry (thickness). For example, the 3-layer and 5-layer carbon fiber samples failed at 2800 lbs and 5000 lbs force, respectively. The ultimate force was found to be increased to 6000 lbs for the composite laminate with 7-layer as shown in Figure 6.

At this point, students fully understand that the ultimate load carrying capability of a material depends on its cross sectional geometry.

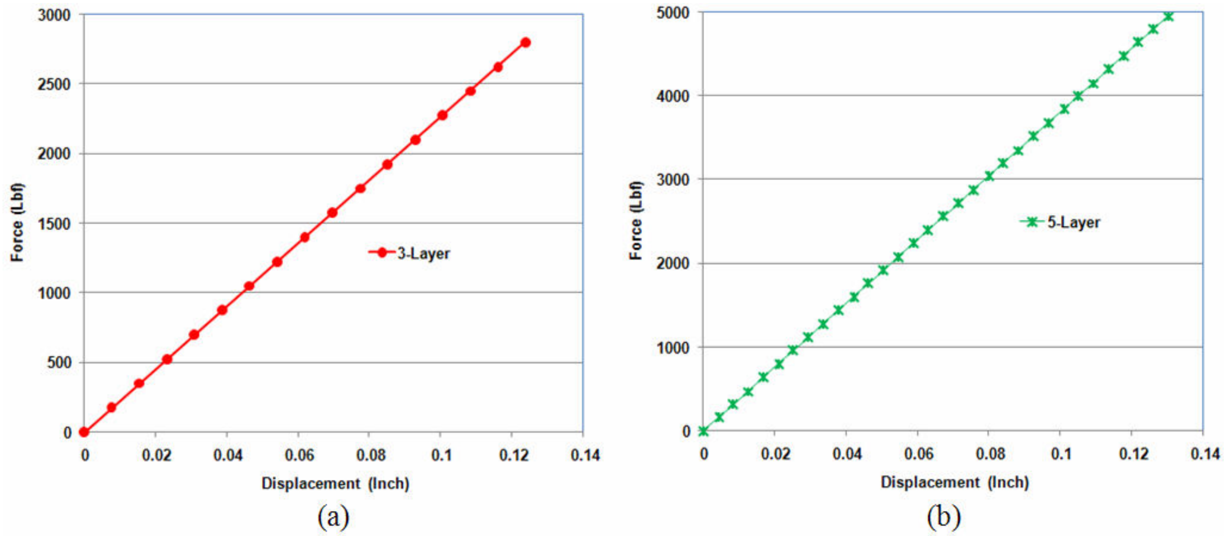



Figure 5: Tensile response (force vs. deflection) of unidirectional carbon fiber laminates. (a) 3-Layer, (b) 5-Layer

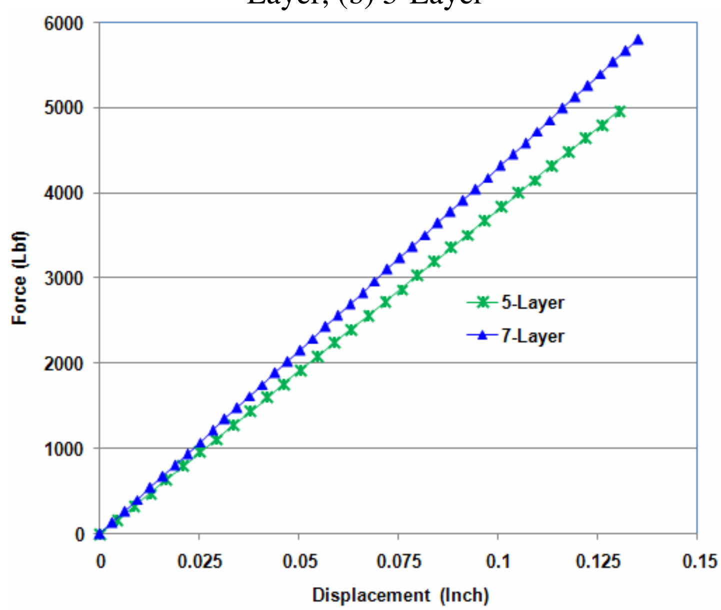
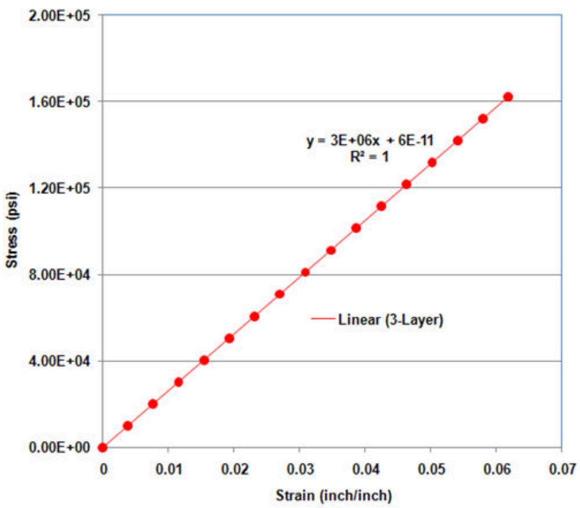
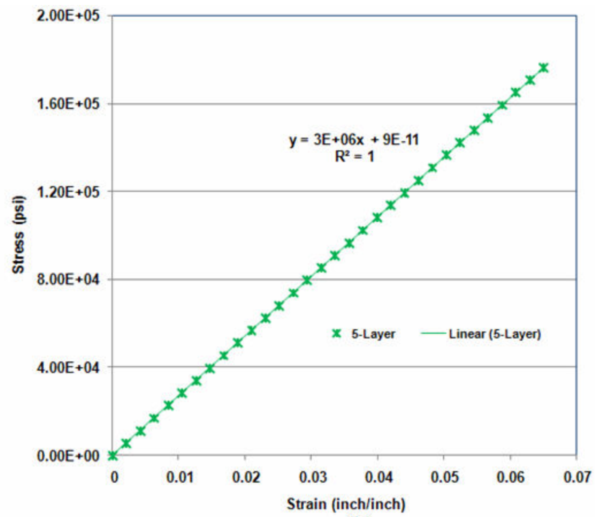



Figure 6: Tensile response of unidirectional carbon fiber laminates. (a) 5-Layer, (b) 7-Layer

Once, students have the force vs. deflection plot, they are instructed to calculate stress (force/area) and strain (deflection/gage length). The stress vs. strain plots for the carbon fiber laminates with variable ply thickness are shown in Figures 7 and 8. Although different samples had significantly different ply thickness and cross-sectional area as shown in Table 3, their ultimate strength was found almost the same, nearly 1600 ksi.



(a)



(b)

Figure 7: Stress vs. strain response of unidirectional carbon fiber ply. (a) 5-Layer, (b) 7-Layer

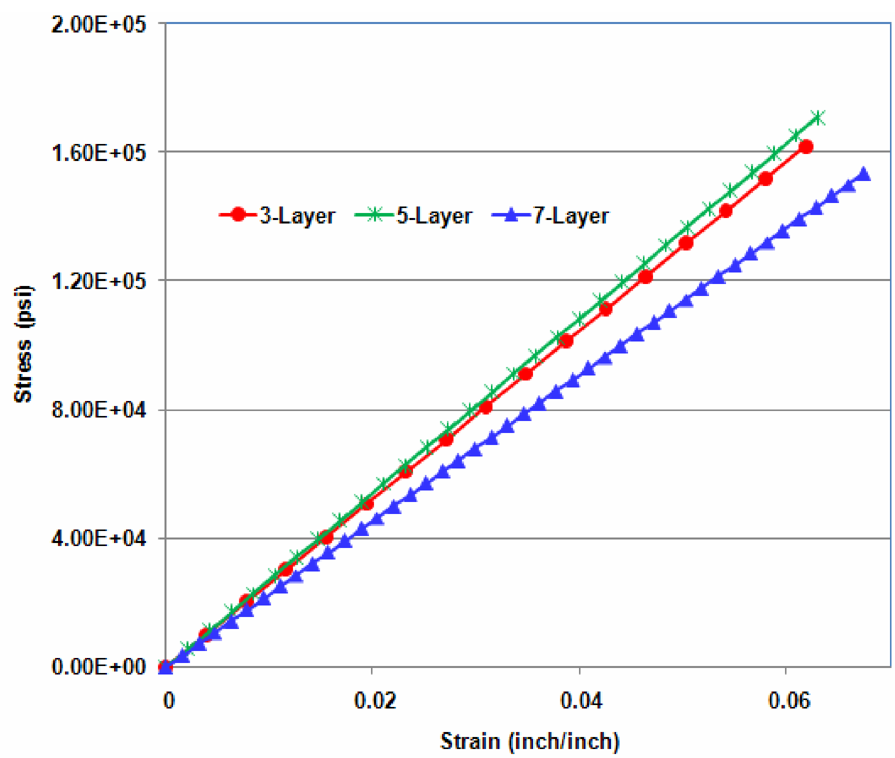



Figure 8: Stress vs. strain response of unidirectional carbon fiber ply laminates

Here, students recognized that the ultimate strength ($\sigma_u$) of any material is geometry independent – unlike the ultimate force ($F_u$). Another interesting topic is the "modulus (E)" of any material, represented by the slope of the stress vs. strain plot. The modulus (E) was also found almost the same for different unidirectional carbon fiber laminates with different ply thickness, as shown in Figures 7 and 8. The slight variation in strength and modulus as shown in the above figures simply represents the experimental errors. Students acknowledge the concept that strength of any material is geometry independent. To design a structure we need to select a suitable material based on its ultimate strength. When strength is known, the ultimate load carrying capability can be determined from its sectional geometry.

**Expt. # 4 & 5: Concept of Anisotropy**

When students understand the concept of strength, the next step is to teach the concept of anisotropy, which is an inherent property of composite materials. Composite materials (or composites for short) are engineered materials made from two or more constituents with significantly different physical or chemical properties. The two constituents, matrix and fiber, remain separate and distinct on a microscopic level within the finished structure. The fibers impart their special mechanical and physical properties to enhance the matrix properties. Anisotropy can be defined as a difference, when measured along different axes, in a material's physical and mechanical properties.

To understand the concept of anisotropy, students also performed several experiments dealing with composite materials. First, samples were prepared where the fibers were oriented at different directions. Composite samples were then tested under tensile loading. Figures 9 and 10 represent the anisotropic response of two different composite samples where load was applied along the longitudinal and transverse directions of fiber.

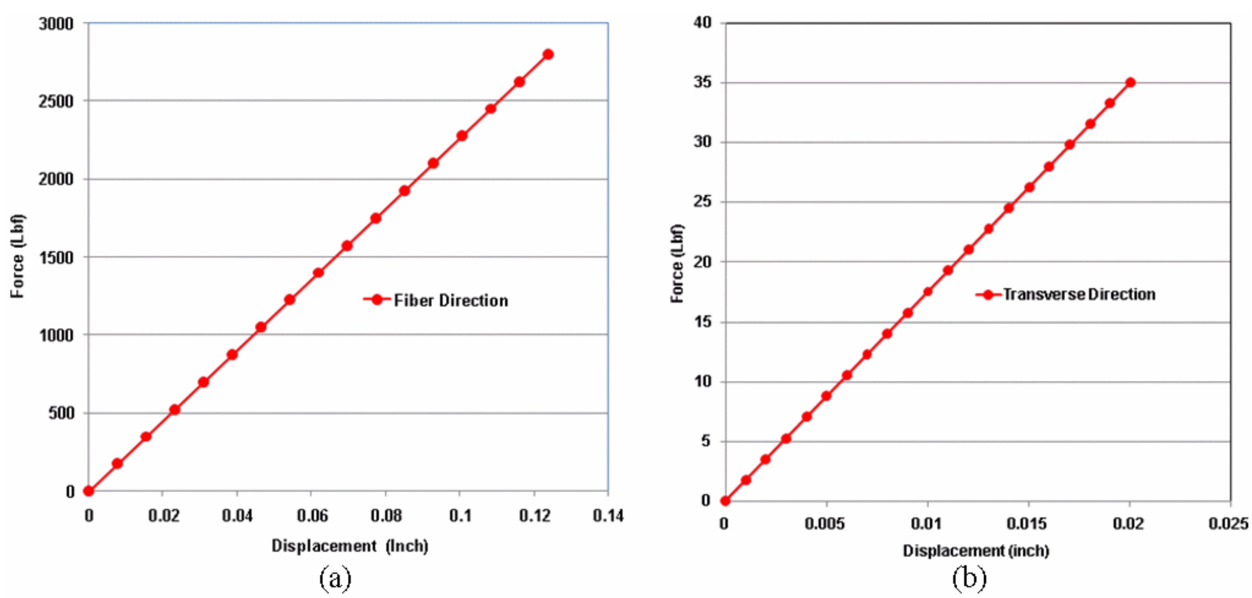



Figure 9: Anisotropic response (force vs. deformation) of 3-ply unidirectional carbon fiber laminate. (a) Fiber direction, (b) Transverse direction

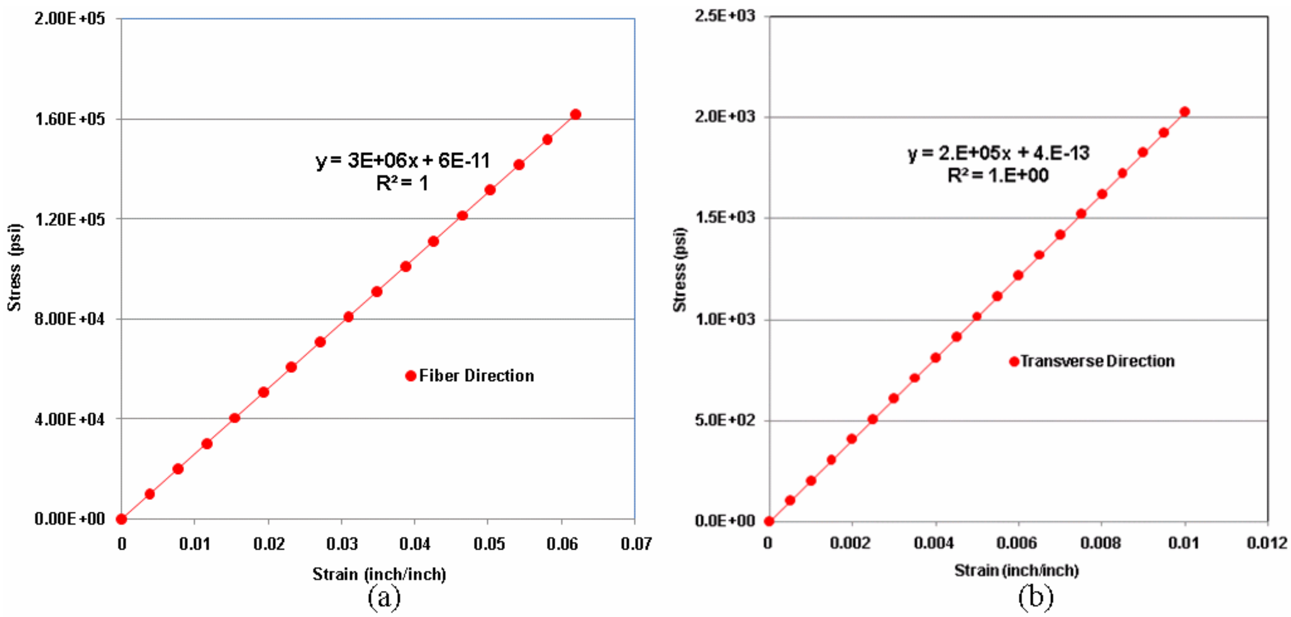



Figure 10: Anisotropic response (stress vs. strain) of 3-py unidirectional carbon fiber laminate. (a) Fiber direction, (b) Transverse direction

It was evident to students that the composite sample resisted a significantly higher load, approximately 2800 lbf, when loaded along the longitudinal (fiber) direction. On the other hand, the composite sample failed at only 35 lbf when loaded along the transverse direction of the fiber. Subsequently, the ultimate strength ($\sigma_u$) was found to be 1600 ksi and 2 ksi, respectively when the samples were loaded along the longitudinal and transverse directions of fibers. This information is apparent in Figure 10.

The modulus of elasticity, represented by the slope of the stress vs. strain curve, was also found to be different for different fiber orientations. For this particular example, the elasticity was found to be reduced by 10 times when the load was applied along the transverse direction. Elasticity is related to stiffness, which dictates the deformation response of any structure. Therefore, composite samples become more flexible and offer higher deformation when fibers are oriented transverse to the load direction.

To minimize the anisotropic effect, engineers often use composite laminates where fibers are oriented at different (or preferred) directions. Students prepared other composite samples where the carbon fibers are oriented at 0, 45 and 90 degree directions. This sample was also tested under tensile loading similar to others discussed earlier. The mechanical response of the [0/45/90] degree laminate was then compared with the unidirectional composite laminate where fibers are oriented along the loading direction. First, students studied the force vs. deflection response, as shown in Figure 11. The response was noticeably different compared with the unidirectional laminate. For the [0/45/90] degree laminate, the ultimate force was found to be around 2300 lb, which was slightly less than that of the unidirectional laminate. The experimental outcomes were found to match with expected results. Students also compared the stress vs. strain response as shown in Figure 12. A noticeable difference was also observed when comparing the ultimate strength and the modulus of elasticity between these two samples.

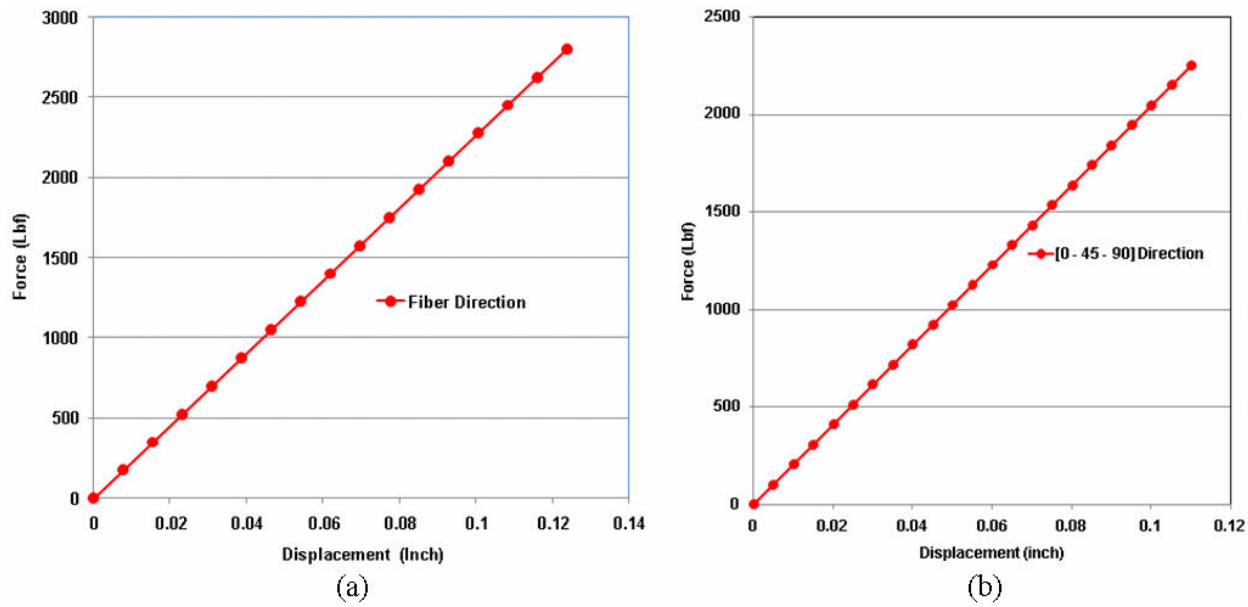



Figure 11: Anisotropic response (force vs. deformation) of 3-ply carbon fiber laminate. (a) Fiber direction, (b) [0/45/90] degree direction

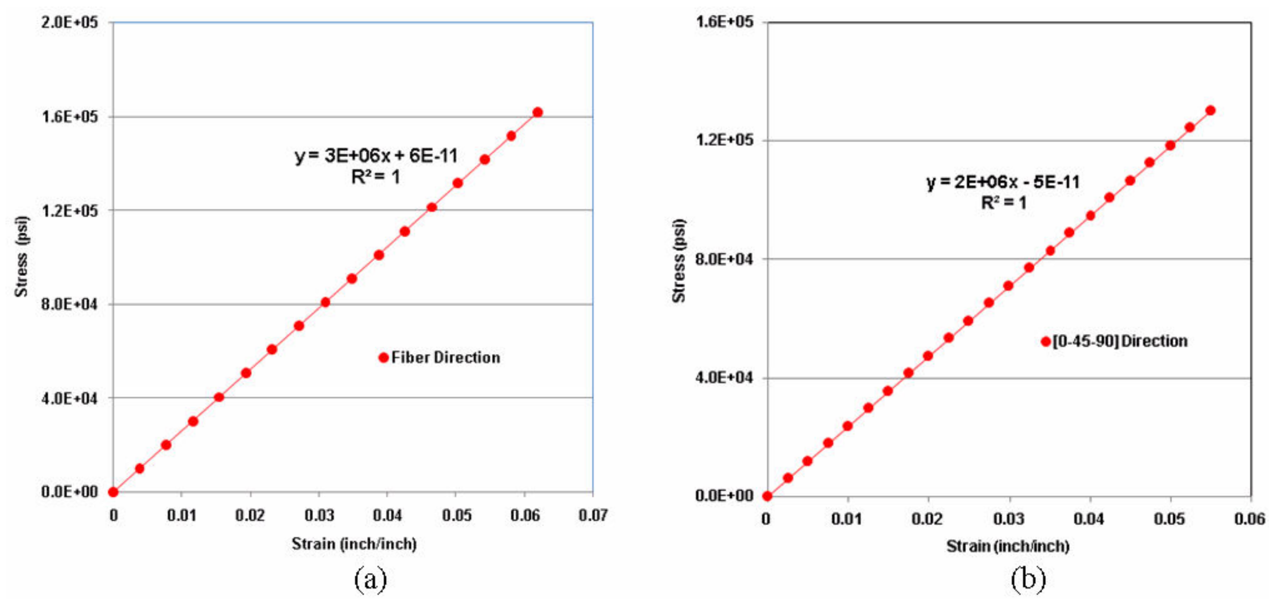



Figure 12: Anisotropic response (stress vs. strain) of 3-ply carbon fiber laminate. (a) Fiber direction, (b) [0/45/90] degree direction

However, the anisotropic effect was found to be significantly reduced between the unidirectional and [0/45/90] degree laminates compared to the unidirectional composite laminates loaded along the longitudinal and transverse directions of fibers. Students realized the fact that the anisotropic effect of any composite material could be compensated by orienting fibers in different directions. Students were also asked to predict the mechanical response of a composite panel where fibers were oriented at [0/45/-45/90] directions and compare the response with unidirectional and [0/45/90] degree panels.

**Expt. # 6 - 8: Composite Strength and Micromechanics**

As discussed earlier with our students, composites are engineered materials made from two different constituents called matrix and fiber. The fibers impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent, while the wide varieties of matrix and fiber materials allow the designer of the product or structure to choose an optimum combination.

In our theoretical lectures, students are introduced to different types of fiber and matrix materials. The physical and mechanical properties of a few commonly used fiber and matrix materials are shown in Table 4. The modulus and strength values of the fiber materials are also graphically shown in Figure 13. Students also performed tensile testing of several composite laminates made of carbon, glass and kevlar fibers as shown earlier in Figure 2. All samples were prepared with epoxy matrix where fibers were oriented along [0/45/90] degree directions. Therefore, the overall experimental response represents how the composite strength depends on fiber properties.

Table 4: Properties of fiber and matrix materials

| | **Fiber Materials** | | | **Matrix Materials** | | |
|---|---|---|---|---|---|---|
| | Density (g/cc) | Modulus (GPa) | Strength (GPa) | | Modulus (GPa) | Strength (MPa) |
| S-Glass | 2.59 | 86 | 4.14 | Epoxy | 3.12 | 75.8 |
| Kevlar 49 | 1.45 | 131 | 3.62 | Polyester | 3.4 | 55 |
| Carbon-PAN | 1.75 | 230 | 3.24 | PEEK | 3.24 | 100 |

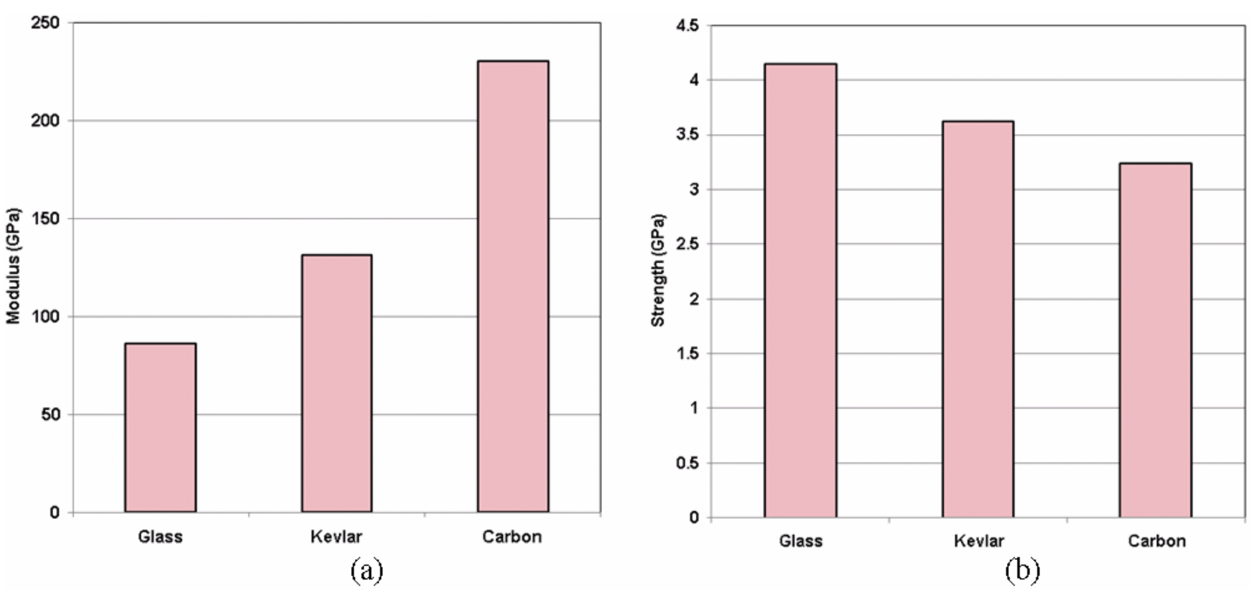



Figure 13: Modulus and ultimate strength of a few commonly used fiber materials.

Composites are anisotropic heterogeneous materials, which simply mean material properties depend not only on directions but also on locations. Micromechanics is a branch of physical science, which studies the response of composites considering the interaction effects of their constituent materials. It deals with mathematical formulations to represent anisotropic heterogeneous composites to an equivalent anisotropic homogeneous material. Strength, in general, is geometry or size independent, but not necessarily true for composites. Since composites are heterogeneous on a small enough scale, the composition of different size (or cross section) could be different and hence have different strength property. However, students learned different important terminologies first. Examples include fiber volume fraction ($V_f$), representative volume element (RVE), longitudinal or transverse modulus, specific modulus, specific weight etc. Once they know the basic terminologies, then we taught the standard mathematical formulations to determine the equivalent composite modulus ($E_c$) and ultimate longitudinal strength ($\sigma_l$) as shown in the following equations.

$$E_c = E_f V_f + E_m (1 - V_f) \qquad \text{(Eq. 1)}$$

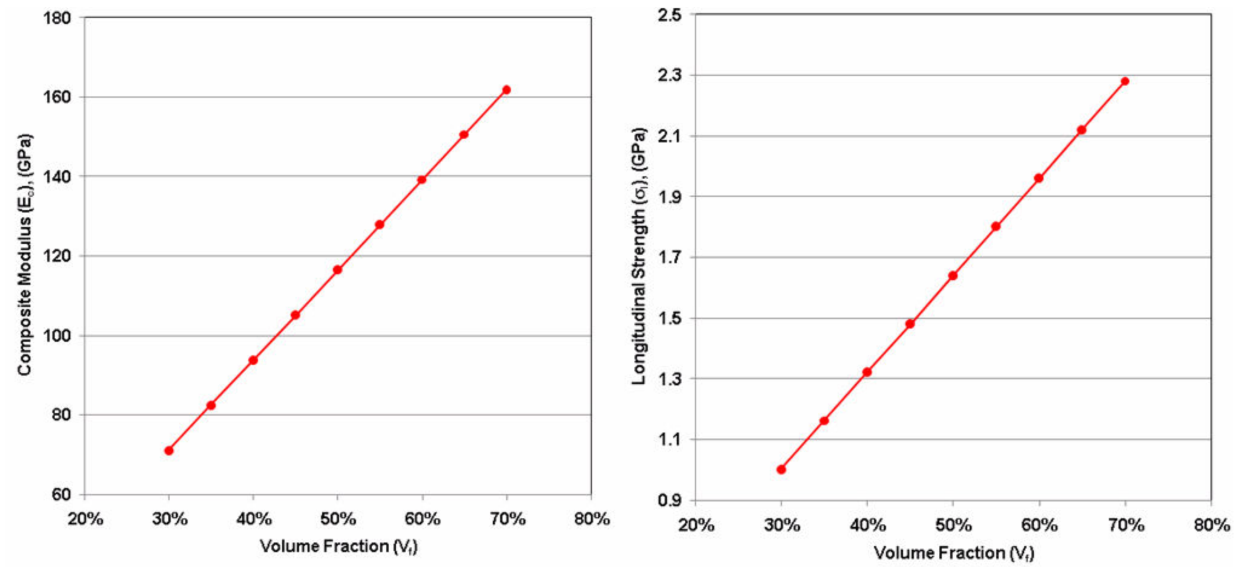
$$\sigma_l = \sigma_f [V_f + \frac{E_m}{E_f}(1 - V_f)] \qquad \text{(Eq. 2)}$$

In Equations (1) and (2), the subscripts *f* and *m* represent the fiber and matrix properties, respectively. It is important to mention here that micromechanics *approximately* predicts the theoretical modulus (with great success) and ultimate strength (with lesser success), which might not exactly match with true experimental results. However, the theoretical predictions offer the insight of the expected experimental outcomes. Students are asked to solve several mathematical problems using the Equations (1) and (2). A few typical mathematical problems are outlined in the Appendix. They are also asked to plot composite modulus ($E_c$) and ultimate longitudinal strength ($\sigma_l$) for a particular set of constituents (fiber and matrix) with different fiber volume fractions ($V_f$).

Although, the Equations (1) and (2) are very straight-forward, students often miss or overlook a few interesting points, which are mentioned below. These points are discussed in the class.

- Different fiber materials, that are commonly used, have significantly different moduli. But their ultimate strength is almost the same, not significantly varying. This point is addressed in Figure 13.
- Composite modulus ($E_c$) depends not only on constituent fiber and matrix moduli ($E_f$ and $E_m$), but also on fiber volume fraction ($V_f$). Keeping constituent moduli the same, different composite modulus ($E_c$) can be achieved by varying fiber volume fraction ($V_f$). This point is addressed in Figure 14(a).
- The ultimate composite strength in the longitudinal direction ($\sigma_l$) does not depend on the ultimate strength of matrix material ($\sigma_m$). It depends on fiber strength ($\sigma_f$), constituent moduli ($E_f$ and $E_m$), and fiber volume fraction ($V_f$). Again, keeping fiber strength and constituent moduli the same, different composite strengths can be achieved by varying fiber volume fraction ($V_f$). This point is also addressed in Figure 14(b).

- The composite modulus ($E_c$) and longitudinal strength ($\sigma_l$) varies linearly with fiber volume fraction ($V_f$), as shown in Figure 14. It simply means, if $E_c$ = 70 GPa and $\sigma_l$ = 1 GPa for $V_f$ = 30%, then $E_c$ and $\sigma_l$ should be approximately 140 GPa and 2 GPa, respectively for $V_f$ = 60%. This argument is well reflected in Figure 14.




(a) (b)

Figure 14: Variation of composite modulus and longitudinal strength (constituents: carbon fiber and epoxy matrix) with fiber volume fraction.

Other mathematical problems are also designed, which help students to get the proper concept of "modulus". A typical problem is outlined in the Appendix, where the summary is as follows. First, students are asked to find the modulus of a unidirectional composite made by different fiber materials (carbon, glass and kevlar), but for a specific matrix and fiber volume fraction. They are asked to use the Equation (1), which is mentioned earlier. Then, they are asked to find stress corresponding to different strain values using the following equation:

$$Stress\ (\sigma) = Modulus\ (E) * Strain(\varepsilon) \qquad \text{(Eq. 3)}$$

The stress and strain values are put on a plot. Finally, they are asked to compare strain corresponding to a specific stress (e.g., σ = 100 MPa) for different composite materials. At this point, students realize that composites with higher moduli offered the least strain, as shown in Figure 15. It needs to be mentioned here that modulus, represented by the slope of the stress-strain curve, is related with *stiffness*, which is a property of both material and geometry. Stiffness dictates the deformation response of any structure. For a given geometry, material with a higher modulus will also possess the higher stiffness, and subsequently offer the lower deformation for a specific load.

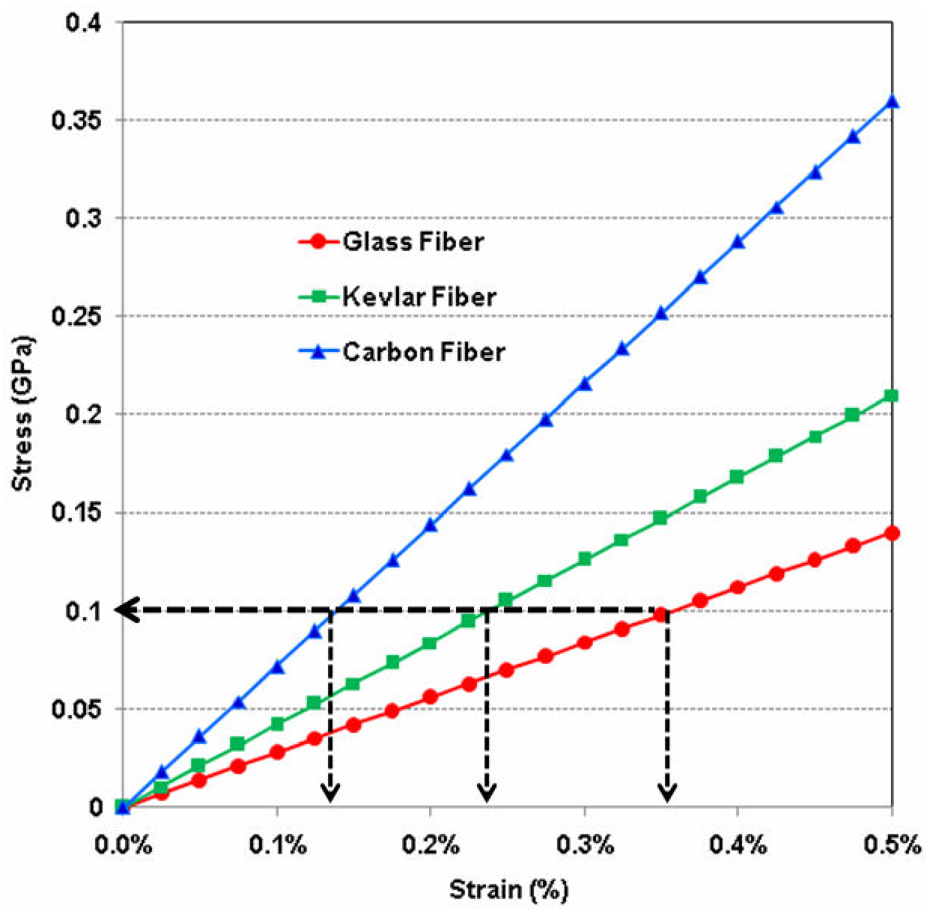


Figure 15: Stress vs. strain profile for a composite made by different fiber materials.

**Survey on Learning Evaluation**

A set of questions are prepared based on the numerous concepts of composite materials covered through the theoretical lectures and laboratory experiments. This particular question and other regular standard tests (administered time to time) are used to evaluate the students' learning on the intended course outcomes. First, students are asked to solve a set of standard questions (Pre-test) at the very beginning of the quarter. The test objective is solely to check the students' pre-knowledge on mechanics and composite materials. Therefore the test performance does not affect the individual grade. The same questions are asked again at the end of the quarter. This time, the test performance affects the individual grade. Upon comparison of the different test scores, which are administered from time to time, the instructor can evaluate whether students really learned and if so, how much. It also helps the course instructor to modify his teaching methodologies if require. A set of sample questions, used to check students' pre and post knowledge in composite materials, are presented in the Appendix.

**Conclusion**

The paper discussed how to teach several concepts of composite materials, under a material science course, through performing a series of laboratory experiments besides the regular lectures. The learning process started with theoretical lectures providing an understanding of different terminologies related with composite materials. Then, different laboratory experiments were performed to strengthen the students' concepts of strength, anisotropy, and micromechanics. Several composite samples (laminates) were prepared by using carbon, glass and kevlar fibers, and with different fiber orientations. First, tensile testing was performed for different uniaxial carbon fiber laminates varying their sectional thickness. Students observed the "force vs. deformation" response and then determined the "stress vs. strain" plot. The overall experiment provided the concept that "strength" of any material is geometry independent, where the ultimate force a material can withstand depends on its sectional geometry.

Students also conducted several tensile tests of composite laminates where the carbon fibers were oriented in different directions. The "force vs. deformation" response was found significantly different for different fiber orientations. Composite laminates were found to be considerably stronger when loaded along the fiber direction. On the other hand, they were found to be very weak when loaded normal to the fiber direction. These experiments helped students to strengthen their concept of "anisotropy", which is an inherent property of composite materials. Laminates with fiber orientation at [0/45/90] degree directions were also tested and then compared with other uniaxial laminates. Students realized that the anisotropic effect could be reduced significantly by orienting fibers at different (or preferred) directions.

Finally, students were introduced to the concept of micromechanics, which is important to consider when comparing a heterogeneous composite to an equivalent homogeneous material. Students learned how to predict the mechanical response, for example the modulus and ultimate strength, of any composite material from its constituents and fiber volume fraction. It was also important to know that different modulus and strength values could be achieved using the same constituents but varying the fiber volume fraction. Keeping the constituent properties the same, the composite modulus and strength were found to change linearly with varying fiber volume fraction. Students were asked to solve several mathematical problems dealing with micromechanics. Mathematical problems were designed to convey different specific concepts to our students. Students studied the numerical response of "stress vs. strain" for several composites made by different fiber materials. Students recognized the fact that having the same geometry, composite with higher modulus possesses the higher stiffness and offers the least deformation under a specific load.

All of the above concepts and discussions are challenging to teach for the undergraduate engineering technology students. Therefore, the authors will conduct a survey in a form of a test to evaluate whether (and how much) students really learned the intended course outcomes on composite materials. The outcomes of this evaluation will help the educators to judge the success of their efforts, as well as to make necessary modifications in the proposed learning methodologies.

**Bibliography**

1. Taken from http://en.wikipedia.org, on Bloom's Taxonomy.
2. Images from http://wikipedia.org, on tensile response of ductile and brittle materials

**Appendix**

Laboratory Handout Sample

# TECH 353
# Sample Mathematical Problems on Micromechanics of Composite Materials

NOTE: This lab requires each student to bring a pen/pencil, Textbook, and Calculator to the lab.

Submitted by:

____________________________________

**Question # 1:**

You are given data on physical and mechanical properties of different commonly used fiber and matrix materials as shown in the following Table.

| | **Fiber Materials** | | | **Matrix Materials** | | |
|---|---|---|---|---|---|---|
| | Density (g/cc) | Modulus (GPa) | Strength (GPa) | | Modulus (GPa) | Strength (MPa) |
| S-Glass | 2.59 | 86 | 4.14 | Epoxy | 3.12 | 75.8 |
| Kevlar-49 | 1.45 | 131 | 3.62 | Polyester | 3.4 | 55 |
| Carbon-PAN | 1.75 | 230 | 3.24 | PEEK | 3.24 | 100 |

Now, compute and compare the expected ultimate tensile strength ($\sigma_l$) and modulus of elasticity ($E_c$) of a composite made from unidirectional strands of carbon-PAN, S-glass and kevlar-49 fibers. Assume, the volume fraction of fiber ($V_f$) is 30% in each case, and an epoxy matrix is used.

| | **Composite Modulus, $E_c$ (GPa)** | **Composite Strength, [redacted] (GPa)** |
|---|---|---|
| S-Glass | | |
| Kevlar 49 | | |
| Carbon-PAN | | |

**Question # 2:**

This is the continuation of Question # 1. Assume that you have made a composite using carbon-PAN fiber and epoxy matrix. Now perform the followings:

a. Compute the expected ultimate tensile strength ($\sigma_l$) and modulus of elasticity ($E_c$) of the composite if the fiber volume fraction is varying from 30% to 70% with 5% increment.

| Fiber Volume Fraction ($V_f$) | Composite Modulus (GPa) | Composite Strength (GPa) |
|---|---|---|
| 30% | | |
| 35% | | |
| 40% | | |
| 45% | | |
| 50% | | |
| 55% | | |
| 60% | | |
| 65% | | |
| 70% | | |

b. Plot the ultimate tensile strength ($\sigma_l$) vs. fiber volume fraction ($V_f$). Is it a linear relationship?

c. Plot the modulus of elasticity ($E_c$) vs. fiber volume fraction ($V_f$). Is it a linear relationship?

**Question # 3:**

This is also the continuation of Question # 1, where you have computed the composite modulus ($E_c$) made by different fibers, such as carbon-PAN, glass and kevlar, materials. Now perform the followings:

a. Compute the expected stress occurred in the composite materials made by different fibers for different strains ranging from 0.025% to 0.5% with an increment of 0.025%.

| Strain | Stress<br>Glass Fiber Composite<br>(GPa) | Stress<br>Kevlar Fiber Composite<br>(GPa) | Stress<br>Carbon Fiber Composite<br>(GPa) |
|---|---|---|---|
| 0.025% | | | |
| 0.05% | | | |
| 0.075% | | | |
| ----- | | | |
| ----- | | | |
| ----- | | | |
| 0.45% | | | |
| 0.475% | | | |
| 0.50% | | | |

b. Now, plot the stress vs. strain for the different composite materials made by glass, kevlar and carbon fibers.

c. Now, if the desired stress is 0.1 GPa (= 100 MPa), what would be the corresponding strain for the different composite materials made by glass, kevlar and carbon fibers?

d. If they have the same geometry (for example, length and cross-sectional area), then which composite would offer the least deflection when subjected to a specific load?

**Sample Questions (Pre-Test) to Check Students' Basic Concept on Mechanics and Composite Materials**

1. Stress is defined as
   a) Average force that a material can withstand
   b) Force per unit area that a material can withstand

2. Strain is defined as
   a) Average elongation that a material offers under loading
   b) Elongation per unit length that a material offers under loading

3. Engineers often deal with "stress vs. strain" rather than "force vs. elongation". Why?

4. A tensile tester usually creates a graph of "Force vs. Elongation". But we need to turn this into a graph of "Stress vs. Strain".
   a. How to find "stress" from "force":
   b. How to find "strain" from "elongation":

5. Which subcategory of Material Properties usually requires the deformation or destruction of the material? (1 Point)
   a. Chemical properties
   b. Mechanical properties
   c. Physical properties

6. Which two (2) examples of the following are Mechanical Properties:
   a. Yield strength
   b. Modulus
   c. Corrosion resistance
   d. CTE

7. Yield strength usually means the strength (or load) level when materials offer
   a. Elastic or temporary deformation
   b. Plastic or permanent deformation
   c. Complete rupture of the materials

8. You have two pieces of 4140 steel with different cross-sectional geometry? Which one offers higher strength?
   a. Piece with bigger cross-section
   b. Piece with smaller cross-section
   c. Strength is same – geometry independent

9. You have two pieces of 4140 steel with different cross-sectional geometry? Which one offers higher stiffness?
   a. Piece with bigger cross-section
   b. Piece with smaller cross-section
   c. Stiffness is same – geometry independent

    d. Stiffness is geometry dependent -- needs additional information

10. I am going to create identically shaped beams out of two different materials. If I place an identical load on each of the beams, which one will deflect/stretch the most?
    a. The one with the High Modulus of Elasticity
    b. The one with the Low Modulus of Elasticity
    c. They should have same deflection

11. You have a piece of ply-wood and like to perform a tensile test to determine its strength. The strength should be
    a. Higher along the grain direction
    b. Higher normal to the grain direction
    c. Strength is the same at any direction

12. Which of the following represents an anisotropic material?
    a. Aluminum
    b. Steel
    c. Wood

13. You have a composite material made of glass fiber with epoxy resin. Its' load carrying capability depends on
    a. Amount of fiber
    b. Fiber orientation
    c. All of the above
    d. None of the above

14. You have a composite material made of glass fiber with epoxy resin, where fibers are oriented at different directions. Which of the following would offer the least anisotropy?
    a. Fibers oriented at [0 and 90] degree directions
    b. Fibers oriented at [0, 45 and 90] degree directions
    c. Fibers oriented at [0, 45, -45 and 90] degree directions
    d. Does not matter, anisotropy cannot be lessen by fiber orientation

15. Arrange the following materials from higher modulus to lower modulus
    Steel, Carbon Fiber and Glass Fiber