Design with Composite Materials – a New Course Development for Designers and Technicians

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Abstract

Composite materials are widely used due to their advantages in high strength-to-weight ratios, high corrosion resistance, high fatigue life in cyclic loading, and great potential in styling design. The automotive industry is currently challenged with meeting the new government emission and fuel economy standards. One of the ways of achieving this is with weight reduction, resulting in many new materials being used in automotive construction. The course learning outcomes (CLOs) of programs at research universities and community colleges are very different. This paper presents a new composite course that focuses on student learning outcomes for community college students, future designers, and technicians. The course was developed for the Center for Advanced Automotive Technology (CAAT), which is funded by the National Science Foundation. One of its missions is to create a curriculum that meets the needs of educating people in new technology developments in the automotive industry. The material developed in this course contains the course syllabus, course learning objectives, course materials, homework assignments, term projects and tests.

Keywords

Composite materials, fibers, matrices, engineering properties, design, manufacturing

1. Introduction

Composite materials are widely used in diverse applications due to their advantages in high strength-to-weight ratios, high corrosion resistance, high fatigue life in cyclic loading, and great potential in styling design. From aircraft, spacecraft, submarines, and surface ships to civil structures, automobiles, and sporting goods, advanced composite materials consisting of high strength fibers embedded in matrix materials are gaining increasing popularity.

The topics and scopes of composite materials are extensive[1-5]. From a material science and engineering aspect, microstructures and properties are the main focus. The mechanics of composite materials includes equilibrium, stress, strain, deformation, linear and nonlinear behaviors, and the relationships between them. The manufacturing processes of various composite structures include the tool design, process setup and quality control. The design and analysis of composite products must be based upon a fundamental understanding of all the areas above. Each of these topics could be a separate course, and is frequently offered as such at various educational institutes.

A senior and graduate level composite course was developed by Dong[6]. The course learning objectives (CLOs) of the course "Mechanics, Process, and Design Simulation of Fiber-Reinforced Composite Materials" offered at Kettering University are as follows. Upon completion of the course students will be able to:

(1) Understand the fundamental properties of composite materials;
(2) Apply the fundamental principles mechanics of composite materials;
(3) Apply modern analytical techniques to mechanical systems with composite materials;
(4) Apply computational techniques to mechanical systems with composite materials;
(5) Understand the manufacturing processes and cost analysis in composite materials;
(6) Demonstrate effective communication and teamwork skills through technical presentations and reports in term projects.

Clearly CLOs (3) and (4) are related to advanced theories and finite element analysis (FEA) that not appropriate for community college students who do not have the background knowledge.

This proposed course is intended to introduce students a new composite course that focuses on student learning outcomes for community college students, future designers, and technicians. These students are trained with computer-aided design, engineering graphics, and lab testing in their co-op jobs. Therefore they are in need of learning the principles of designing components made of composite materials. The basics of composite properties, mechanics, and manufacturing processes are introduced. Design guidelines and drafting notations will be emphasized for composite components with various fiber-reinforcements, such as unidirectional fibers, random short fibers, and laminate stacking sequences. The deliverables include course materials, syllabus, pre- and post- course survey questionnaires, Microsoft PowerPoint handouts, homework assignments, quizzes and exams, a final course project, and a roadmap to make the course materials transferable. The course material will be suitable for students at the associate degree level.

2. Course Content

2.1 The course learning objectives (CLOs)

The course learning objectives of the proposed course "**Design with Composite Materials"** can be described as follows:

Upon completion of the course students will be able to

(1) Identify and explain the main applications, pros and cons of composite materials;
(2) Identify and explain the fundamental properties of composite materials;
(3) Identify and explain the stress-strain relationship of composite materials;
(4) Identify and explain laminate conventions and stacking sequence;
(5) Identify and explain the fundamentals of the classical lamination theory (CLT);
(6) Identify and explain the main manufacturing processes of composite products;

(7) Apply the composite design guidelines;
(8) Apply the notation/convention of composite materials in engineering sketching.

To demonstrate the effectiveness of the curriculum, assessment questions are developed for pre- and post- course offering survey. As a pilot course offering, this course, with a smaller class size, is planned with faculty member(s), potential future instructor(s) sitting in to be trained. Feedback for this pilot offering will be studied and all necessary adjustments will be made to improve the curriculum.

2.2 Course Outline

Comparing to composite course developed by Dong[6] for typical research universities, the following topics are included in the new course:

(1) Elastic Stress-Strain Characteristics
(2) Introduction of Fiber-Reinforced Composite Materials
(3) Engineering Properties Using Micromechanics
(4) Classical Laminate Theory
(5) Failure Theories
(6) Manufacturing Techniques
(7) Composite Design Guidelines

Clearly it is intended to ramp down the theoretical aspects to make the course more suitable for community college students. The advantages of the new course are more practical, application-based, without the differential equations in the mechanics of composite materials, and without the nanotechnology topics.

3. Examples of Homework Assignments and Project

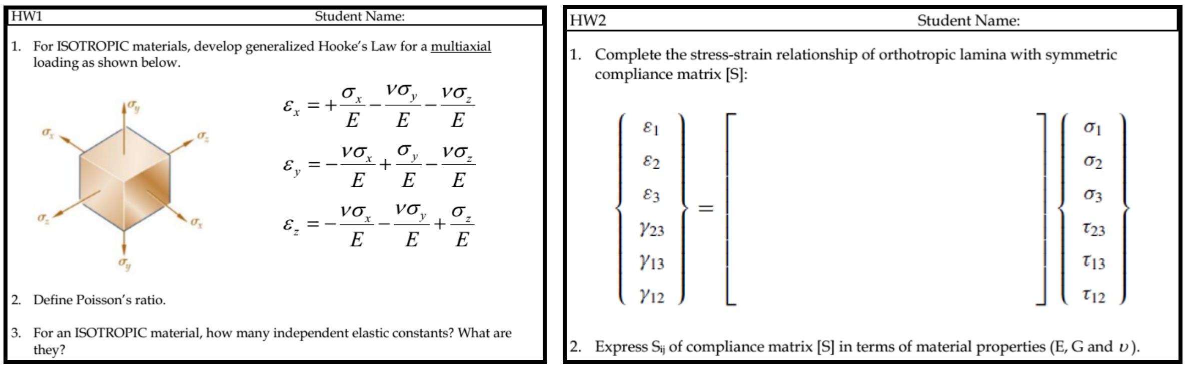
One of the most important and challenging tasks in a material engineering course is the development of practical and application-based examples, since engineering students have a proclivity for constructionist learning. Because this course focuses on application and design based on a composite material's properties and mechanics, the homework assignments need to be practical, rigorous, and interesting, using state-of-the-art engineering tools found in industry, while being revised appropriately for completion within a semester.

The objective of homework assignments in the course is to understand the difference between traditional isotropic materials and fiber-reinforced orthotropic materials in order to design stronger and lighter products using fiber-reinforced composite materials. Through the pedagogical integration of the practical homework assignments with theoretical concepts, the course learning objectives are attained.

3.1 Isotropic and Orthotropic Properties

The first homework is assigned in Week #1 after a review session of Mechanics of Materials. Students are asked to derive the generalized Hooke's Law for a multiaxial loading condition of an isotropic material, as shown in Figure 1(a). Through this process the students demonstrate their understanding of the stress-strain relations, the definition of Poisson's ratio, and the material properties of an isotropic material.

The second homework, as shown in Figure 1(b), is assigned in Week #2 after studying the orthotropic lamina theory. Students are asked to fill in the blank "compliance matrix" in the stress-strain relationship of an orthotropic material. Similar to homework #1, the students will demonstrate their understanding of an orthotropic material coordinate system, properties, and stress-strain relationship. The third question in homework #2 asks the students to name the independent elastic constants of an orthotropic material. By comparing this to the first two problems in homework #1 in Figure 1(a), the differences between isotropic and orthotropic materials are clearly shown.


HW1 Student Name:

1. For ISOTROPIC materials, develop generalized Hooke's Law for a multiaxial loading as shown below.

$$\varepsilon_x = +\frac{\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$\varepsilon_y = -\frac{\nu\sigma_x}{E} + \frac{\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$\varepsilon_z = -\frac{\nu\sigma_x}{E} - \frac{\nu\sigma_y}{E} + \frac{\sigma_z}{E}$$

2. Define Poisson's ratio.

3. For an ISOTROPIC material, how many independent elastic constants? What are they?

HW2 Student Name:

1. Complete the stress-strain relationship of orthotropic lamina with symmetric compliance matrix [S]:

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{13} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} \quad \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{13} \\ \tau_{12} \end{Bmatrix}$$

2. Express S_{ij} of compliance matrix [S] in terms of material properties (E, G and υ).

(a)Isotropic Materials (b) Orthotropic Materials

FIGURE 1 – HOMEWORK #1 AND #2

3.2 Applying Theory in Practical Application

After learning the micromechanical behavior of a lamina and the "rule of mixtures," expressions of Young's moduli in the directions of fibers and matrix can be calculated based on the volume fractions of the fibers and matrix[3-5]:

$$E_1 = E_f V_f + E_m V_m \tag{1}$$

$$E_2 = \frac{E_f E_m}{V_m E_f + V_f E_m} \tag{2}$$

Where

E_1 = Young's modulus in the 1-direction (fibers direction)

E_2 = Young's modulus in the 2-direction (matrix direction)

E_f = Young's modulus of fibers

E_m = Young's modulus of matrix

V_f = Volume fraction of fibers

V_m = Volume fraction of matrix

Using equations (1) and (2), given the material specifications, the students are able to solve a structural beam application as shown in homework #3 (Figure 2). The beam is simply supported with a point load at the mid-span. The maximum displacement, the maximum bending stress, and the mass can be calculated using four different materials (rolled steel, aluminum-6061, composite GF, and composite CF, respectively). Once the students tabulate the results, it is very easy to compare the structural responses under the same load and boundary conditions but using different materials. Other homework assignments and course projects are designed to assess the corresponding topics, in a similar way as described in these examples.

HW3	Student Name:

A beam is supported and loaded with **5000 N force** at mid-span as shown in the sketch below. Calculate
(A) The maximum displacement,
(B) The maximum bending stress, and
(C) The mass of the beam for the following isotropic (steel and aluminum) and orthotropic (Composites with unidirectional fibers in the longitudinal direction) materials. Tabulate and compare the results:

1. Rolled Steel: E=206GPa, $\rho=7.85\times10^{-6}$kg/mm^3
2. Aluminum-6061: E=69GPa, $\rho=2.711\times10^{-6}$kg/mm^3
3. Composite GF: E-Glass (V_f=70%, E_f=70GPa, $\rho=2.6\times10^{-6}$kg/mm^3)
   Polyurethane (V_m=30%, E_m=0.9GPa, $\rho=0.2\times10^{-6}$kg/mm^3)
4. Composite CF: Carbon (V_f=70%, E_f=400GPa, $\rho=1.96\times10^{-6}$kg/mm^3)
   Polyurethane (V_m=30%, E_m=0.9GPa, $\rho=0.2\times10^{-6}$kg/mm^3)

FIGURE 2 – HOMEWORK #3

4. Assessment Techniques and Tools

Assessment is done before and after the course offering in order to assess the effectiveness of the students' learning as well as the course materials. Since this is an upper level course, students are expected to move beyond the first levels of Bloom's taxonomy[7] of learning, knowledge and comprehension to reach proficiency in the application of composite design principles and analysis techniques, Bloom's level 3. Students are also expected to be able to trouble shoot current designs, Bloom's level 4: analysis, and offer a proposed alternative solution to address deficiencies, Bloom's level 5: synthesis. In addition to the above quantitative course assessment, the process education methodology by PacificCrest[8] is used for assessment. The SII is a method of assessment articulated by Pacific Crest which requires the assessor to focus on three main items: strengths, areas for improvement, and insights gained. "Strengths" identifies the ways in which a performance was commendable and of high quality. Each strength should include a statement as to why that particular strength was considered important and how the strength was produced. "Areas for improvement" identify the changes that can be made in the future to improve performance. “Improvements” should include the issues that caused any problems and mention how those changes can be implemented most effectively. “Insights” identify new and significant discoveries that were gained concerning the performance area.

The following SII questions will be used for additional post-course assessment to facilitate continuous improvement:

(1) What are the three strengths of this course? Please explain.
(2) What are the top three things that you have learned?
(3) What are the three improvements for this course that would help you learn better?
(4) How can these improvements be made?
(5) What action plans can be put in place to help yourself learn more?
(6) What have you learned about your own learning process?
(7) Is there anything else you would like the instructor to know about the class?

The following assessment questionnaires were launched before and after the course offering in order to assess the effectiveness of the students’ learning as well as the course materials:

<u>Please answer the following questions by choosing one of the following:</u>

<u>5-Strongly Agree, 4-Agree, 3-Disagree, 2-Strongly Disagree, 1-N/A</u>

(1) I have the knowledge of Statics.
(2) I have the knowledge of Mechanics of Materials.
(3) I have a good understanding of material properties of traditional engineering materials (i.e., isotropic materials such as steel).
(4) I have the knowledge of traditional manufacturing processes (such as machining, stamping, casting).
(5) I have the knowledge of composite materials.
(6) I have a good understanding of material properties of composite materials (i.e., orthotropic materials).
(7) I know the three types of fibers used in composite materials.
(8) I know the two types of resins (matrices) used in composite materials.
(9) I know the three basic forms of composite materials.
(10) I know the 12 elastic constants of composite materials.
(11) I have the knowledge of composite manufacturing processes (such as pultrusion, resin transfer molding, filament winding, wet layup, foam core molding).
(12) I know the Pros and Cons of different composite manufacturing processes.
(13) I have a good understanding on application of different composite materials.
(14) I know the conventions and notations for composite materials in engineering drawings.
(15) I know the conventions and notations for laminate stacking sequence.
(16) I know the design guidelines for composite materials.
(17) I can design products using composite materials.

(18) I can communicate effectively with composite CAE analysts.
(19) I can communicate effectively with composite manufacturing engineers/suppliers.
(20) Overall, I am able to design and develop products with the best choice of materials.

The first course offering was completed in 2006 fall semester at the Macomb Community College, located in Warren, Michigan. Assessment results show that the average score of 1.5 for these 20 questions before the course offering was improved to 4.1 after the course offering. These assessment results proved the effectiveness of the students' learning as well as the realization of the course learning outcomes.

6. Conclusions

A new course in composite materials has been developed for community college students, future designers and technicians. The project was sponsored by the Center for Advanced Automotive Technology (CAAT) which is funded by the National Science Foundation and located at Macomb Community College (MCC) in Warren, Michigan. One of the missions of CAAT is to create curriculum that meets the needs of educating people in new technology developments in the automotive industry. The material developed in this course contains course the syllabus, course learning objectives, course materials, homework assignments, term projects and tests. The course covers fundamental properties of composite materials, classical laminate theory, material characterization, manufacturing techniques, composite structure design. A course project has also been developed to apply knowledge learned in the course to design an engineering structure using composite materials. An assessment will be performed before and after the course to assess how effectively students learning outcomes are achieved. This course will be offered at MCC this fall semester. The course materials are available online and can be found at CAAT website[9] (http://autocaat.org/webforms/ResourceDetail.aspx?id=3679).

7. Acknowledgements

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