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Experimental Evaluation of Composite Laminates and Sandwich Structures in Undergraduate Laboratory Education

Swami Karunamoorthy, Hameed Hindi, Ben Humphrey
Parks College of Saint Louis University

Abstract

Composite materials are increasing y used in many structural applications. These materials would be used in addition to or in place of conventional materials for various structural components in future. It is important to give "hands on" experience in composites to the present day engineering and technology students. In order to prepare them for engineering challenges of future, there is a need for undergraduate laboratory education in manufacturing and testing of fiber composite materials. An emphasis is given in this paper to incorporate some applications of composites in an innovative way to undergraduate students. The experience shows that this is a viable and inexpensive approach to complement the education on composite materials.

Introduction

Applications of fiber composite materials and sandwich structures are significant in the design and manufacturing of aerospace vehicles. The maintenance of such vehicles require the knowledge of repair and testing. While understanding the mechanics of composite materials is important, a laboratory component is essential for well rounded education in composite materials. The existing facilities in a conventional structures laboratory can be readily used for testing and evaluation of mechanical properties of the material. However, manufacturing the test specimen is rather cumbersome and expensive depending on the desired quality of the products.

A modem laboratory for producing composite materials and structural components would require an autoclave, hot bonders, heat blankets, vacuum press, temperature controlled oven with vacuum facility, water-jet cutting tool and other sophisticated equipments. However, these equipments are very expensive and unaffordable to most of the academic institutions and beyond the reach for undergraduate laboratory. An innovative method has been recommended for manufacturing that is inexpensive and affordable to a typical composite laboratory for undergraduate students.

An emphasis is given in this paper to, (i) simple methods in manufacturing of composite laminates and sandwich structures, (ii) acid digestion test, (iii) tension test, (iv) bending test, and (v) vibration test.

Manufacturing Procedure

(i) Composite Laminates

For Glass/Epoxy, Fiber glass fabric (#778 1) with a weight of 8.95oz per square yard, eight harness satin weave, and a thickness of 9 roils has been used. Also, the other fabrics that are used in the laboratory include Fiber glass #1527 with plain weave, 17mils thickness, 12.9oz per square yard; and Fiber glass #1583 with eight harness satin weave, 18 roils thickness, 16. 10Z per square yard. The fabric is stacked in layers of desired sequence and wetted with epoxy. The epoxy with 105-A resin & 206-A hardener has been used for room temperature curing.

For Carbon/Epoxy, the prepreg (donated by regional aerospace industry) has been used for lay up in desired stacking sequence. An eight pl y laminate with [0/+45/-45/90] symmetric stacking sequence has been prepared. A typical ply has a thickness of 1/8 mm.

Vacuum Bagging & Room Temperature Curing:

A list of materials required for vacuum bagging include, a) vacuum bag film, b) breather cloth, c) bleeder cloth, d) peel ply, e) vacuum bag sealing tape, f) release film, and g) mold release (Partall #lO). A typical lay up sequence is shown in Figure 1. After the assembly is complete, a vacuum was created inside the bag with an electric pump. Typically, the laminate was cured for twenty four hours at room temperature. At the end of cure cycle, the assembly was removed from the vacuum bag and the laminate has been separated. Then the specimen for tension, bending, and vibration tests were prepared.

(ii) Sandwich Beam

A typical sandwich beam would have a core of wood, honeycomb or foam with a skin of carbon, glass or aramid (Kevlar) fibers. However, a method is presented here to manufacture a sandwich beam with blue foam core and Glass/Epoxy or Carbon/Epoxy skin. In addition to the core and skin materials, some of the recommended materials include Hexcel safe-t-pox y, mylar sheet, bleeder cloth, vacuum bag material, weather stripping and mold release.

Blue foam makes a good choice for core material, since it is inexpensive, easily available, and can be cut to any shape with hot wire. The hot wire cutter used in this laboratory consists of 0.032 inch diameter stainless steel wire (aircraft safety wire) mounted between two posts (24 inches long), and connected to an electric source of five amps. A foam core of 1/4” thick, 2“ wide, and 12” long has been made by hot wire cutter with appropriate temperature for smooth cut without any pitting or bumps on the surface.

The foam core was first brushed with epoxy and then a layer of skin material (Carbon or Glass fiber) has been placed on the foam with a thin coat of epoxy applied on top of it. An epoxy ratio pump has been used to dispense a two part epoxy (100 to 44 ratio by weight), and it ensures an efficient and effective way for appropriate proportioning of epoxy. Then the sandwich was covered with mylar sheet (used as peel ply) for smooth surface finish. The beam was wrapped in bleeder cloth and placed in a vacuum bag. The bag was sealed by the weather strip with a vacuum line embedded inside the vacuum bag. Then it was cured at room temperature for approximate y ten hours maintaining vacuum inside the bag. After the cure, the sandwich beam was removed and trimmed for testing. This procedure is viable for producing airplane wing sections for wind tunnel models and radio controlled airplanes. The sandwich structure is light, strong and has good impact strength during crash landings.

Composite Materials Testing

(i) Acid Digestion Test

Fiber volume fraction is an important parameter to verify the test results with theory and it should be determined first. A typical acid digestion test procedure is given below to estimate the volume fractions of fiber and matrix of a composite laminate (Reference 1). An existing chemistry laboratory can be used for this test.

A square sample of approximately 2 inches in dimension has been made from the laminate manufactured. The weight of the sample laminate was determined first (WC); then a dry funnel with filter was weighed (W_o). After complete digestion of matrix, the weight of the funnel containing dry fibers was then determined (W_1).

The sample (composite) weight, $WC = W_f + W_m$
The fiber weight, $W_f = W_1 - W.$
The matrix weight, $W_m = WC - W_f$

Now the volume fraction of fiber can be calculated as,

$$V_f = \frac{\rho_m W_f}{\rho_m W_f + \rho_f W_m}, \qquad V_m = 1 - V_f$$

where, "ρ_f" is the density of fiber and “pm” **is** the density of matrix. This relation assumes no void is present in the sample. However, the error introduced by this assumption is not significant.

(ii) Tension Test

A tension specimen has been cut from carbon composite laminate and end tabs were adhesively bonded at both ends of the specimen. For testing, MTS machine with automatic data collection system by a desk top computer has been used. The applied load and corresponding elongation were recorded by the computer for every second. Then the calculated stress and strain were presented in graphical form as shown in Figure 2. The slope of the linear region of this diagram gives tension modulus for the laminate. Also, the ultimate stress, yield stress, resilience, and toughness of the laminate can be easily determined from the stress - strain diagram.

(iii) Bending Test

A beam specimen has been cut from the laminate, and a rectangular rosette strain gage has been bonded on both top and bottom surfaces. The beam was simply supported and the loads were applied such that the beam was under pure bending condition between the supports. The maximum deflection at the center of the beam was measured by a deflection gage, and hence the curvature due to applied bending moment can be easily determined. The data were plotted as moment curvature diagram (Figure 3), and the bending stiffness of the laminate can be found from the slope of the diagram. The strain measurements were obtained from strain indicators and these data can be used to estimate the measured compliance [Reference 2] and they were compared with predicted compliance by classical laminate theory.

Similarly, the bending test was performed for a sandwich beam with blue foam core. From the moment curvature diagram, the bending stiffness was determined and flexural modulus was predicted.

(iv) Vibration Test

For vibration test, laminate and sandwich beams were used on a shaker table with fixed - free boundary conditions. The frequency was measured and the modeshapes were observed with a stroboscope. The results were verified with classical vibration theory by replacing the Young's modulus with flexural modulus for the laminate.

Conclusions

This laboratory education on composite materials provides better understanding of anisotropic behavior of laminates and sandwich structures. The method given for manufacturing of specimen is efficient and inexpensive. The testing can be done with existing equipments in a typical structures or stress analysis laboratory.

The volume fraction of the constituents of a composite laminate can be easily determined by acid digestion test. The material characteristics can be determined from the stress - strain diagram obtained from tension test. The bending stiffness and compliance coefficients can be predicted from a simple bending test. The resulting flexural modulus is different from tension modulus (Young's modulus) unlike isotropic materials. The dynamic characteristics can be estimated from vibration test. The response from students indicate that this is a viable approach to give "hands on" experience on composite materials for undergraduate students in engineering as well as technology. Such an experience would prepare them for a better tomorrow.

References

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SWAMI KARUNAMOORTHY

Dr. Swami Karunamoorthy is currently an Associate Professor of Aerospace & Mechanical Engineering at Parks College of Saint Louis University. He has ten years of teaching experience in mechanics, structures, helicopter theory, and composite materials. He has several research publications in both engineering discipline and engineering education. He is an active member of ASEE, AIAA, ASME, AHS and ABET.

HAMEED HINDI

Mr. Hameed Hindi is a Professor in the department of Aerospace Technology at Parks College of Saint Louis University. His teaching experience has been primarily in aircraft metallic structures. His extra curricular activities include restoration of damaged aircraft and building composite airplane models with foam core sandwich structures. He is an active member of SAE, EAA and faculty advisor to SAE student chapter.

BEN HUMPHREY

Mr. Ben Humphrey is a Professor in the department of Aerospace Technology at Parks College of Saint Louis University. He has ten years of teaching experience in Non-Metallic Structures. He developed and implemented an advanced composite technology in the curriculum. He is an FAA authorized inspector, with Airframe and Power plant licenses. He enjoys flying and presentl y rebuilding his fabric covered 1946 Aeronca 1 lAC airplane.

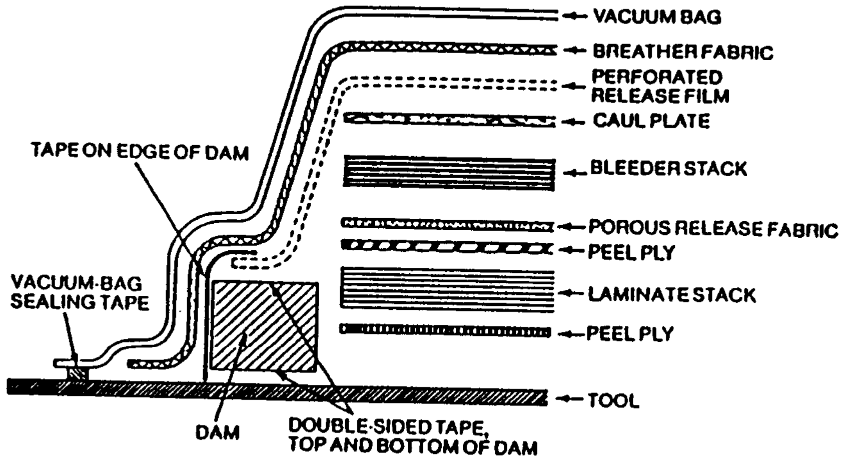

Figure 1. Vacuum Bag Lay up for Room Temperature Cure

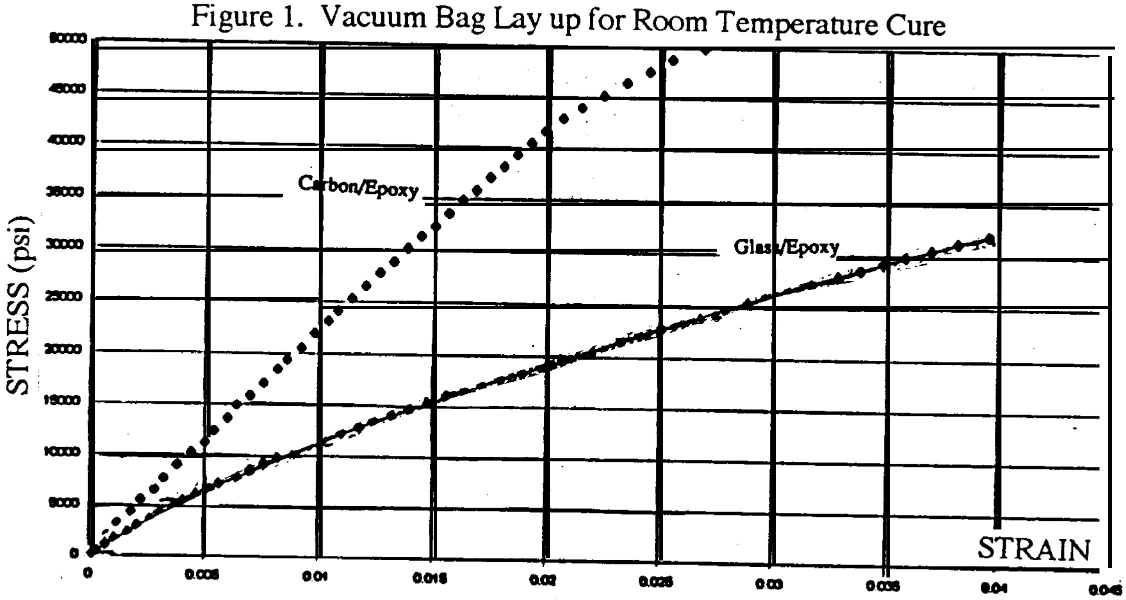

Figure 2. Stress - Strain Diagram

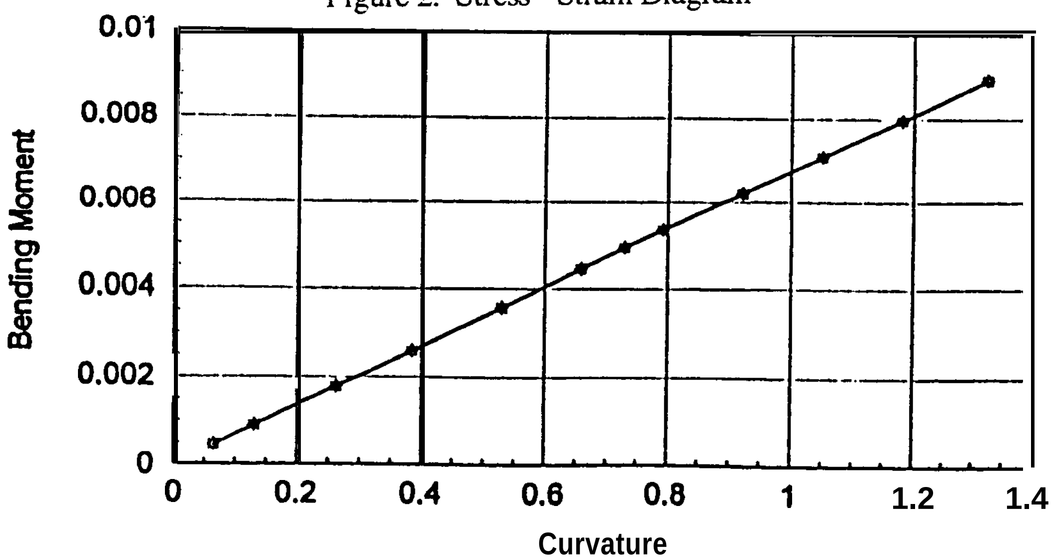

Figure 3. Moment Curvature Diagram