Investigation of Shear as a Failure Mode in Anisotropic Materials

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Abstract

There is an immediate need in industry for engineers conversant in the fundamental principles of material behavior. This type of knowledge may best be imparted to the undergraduate student by direct, hands-on laboratory experience. Another way to enrich the undergraduate engineering laboratory experience is to introduce the student to current research. When undergraduate engineers are exposed to current research they begin to understand that their undergraduate learning experiences are merely building blocks upon which much more in-depth learning is based. Exposure to actual research projects in the undergraduate curriculum also serves to enhance the students' curiosity about how their undergraduate course subject matter can be used to solve other than "textbook" problems. This article describes how the Department of Mechanical Engineering at Northern Illinois University is bringing current research into the undergraduate laboratory to enhance its curriculum.

Introduction

Three required courses (MEE 212- Strength of Materials, MEE 330- Materials Science, and MEE 331 - Manufacturing Processes) form the core of the materials-related emphasis of the curriculum of the Department of Mechanical Engineering at Northern Illinois University. These courses are offered each semester and average 30 students per semester. Until recently, none of these courses included a laboratory in which students could gain direct, hands-on experience into the behavior of materials. The lack of an undergraduate laboratory specifically focused on introducing the undergraduate mechanical engineering student to the world of materials was viewed as a weakness in our curriculum by the author. Moreover, in the opinion of industry, there is an immediate need for engineers conversant in the fundamental principles of material behavior best reinforced by direct, hands-on laboratory experience. Finally, the National Research Council has stated that materials are strategic to the global competitiveness of the United States[1].

To address the above inadequacy in our curriculum, the author proposed and was awarded a National Science Foundation (NSF) Instrumentation and Laboratory Improvement (ILI) Grant to establish the first engineering materials laboratory for the College of Engineering at Northern Illinois University. The laboratory was equipped with several pieces of materials processing and testing equipment purchased with finding from both the NSF and the State of Illinois. A corequisite laboratory section has been added to our MEE 330- Materials Science course. In order to take the materials science course, students are required to have had, or currently be enrolled in our MEE 212 - Strength-of-Materials course. When enrolled in the materials science course, students are therefore adequately prepared to understand and conduct a wide range of experiments and demonstrations involving both strength-of-materials and materials-science principles.

Even though students receive fairly broad exposure to materials behavior experiments and demonstrations in the laboratory, it is also important to introduce the undergraduate student to post graduate-level research. When students are exposed to "actual research," they begin to understand that their undergraduate learning experiences are merely building blocks upon which much more in-depth learning is based. Exposure to actual research projects in the undergraduate curriculum also serves to enhance the students' curiosity about how their undergraduate course subject matter can be used to solve other than "textbook" problems.

This paper briefly describes how one of the recently purchased pieces of materials testing equipment, an MTS uniaxial servohydraulic testing machine is used to introduce the students to a research project involving the investigation of shear as a failure mode in composite materials. More specifically, graphite-epoxy laminates are used to introduced the student to anisotropic materials and to illustrate how these materials possess inherent planes of weakness with respect to shear stresses. Similar research was the topic of the author's doctoral studies[2].

Laboratory Demonstration

Wood is probably one of the best materials to use to illustrate the principle of anisotropy to students. Wood also works quite nicely to illustrate the principle of shear failure say, along the longitudinal plane of a beam during flexure. However, laminated graphite/epoxy materials can be used to demonstrate this phenomenon and serve to introduce the student to the important area of advanced composite materials in general. Students are relatively familiar with graphite\epoxy due to its increased use in many types of sporting goods equipment over the past several years.

Prior to performing the laboratory demonstration, the importance of materials characterization is discussed with the students. The many methods available to characterize the mechanical behavior of materials are briefly discussed, along with the many different types of equipment used to perform the tests. Specifically, the difficulties associated with the characterization of the shear response of materials, especially laminated materials, is presented. Finally, the general notion of delamination is introduced, along with the problem of the inherent delamination weakness of laminated graphite\epoxy materials. Once the students have gained a brief understanding of the fundamental principles involved, they are ready to observe the laboratory demonstration.

Experimental Setup

A specially designed flexure specimen is required to produce a shear failure within the graphite\epoxy material. The specimen design is based on a variation of the standard short-beam shear test specimen used in the composites industry to measure the shear strength of composite materials[3]. The specimen, referred to as the SCS (steel/composite/steel) specimen consists of a coupon-type, fiber-reinforced composite flexure specimen bonded between two strips of metal using a room-temperature-curing adhesive (see Figure 1).

This design has the advantage of confining the composite specimen to the midthickness region of the beam where the stress state approaches that of uniform shear. In addition, the metal face plates dissipate the stress concentration effects in the vicinity of the load nose which have been shown in the literature to be responsible for failure initiation in classical short-beam tests of graphite\ epoxy specimens as shown in Figure 2.

In order that the test produce a failure within the specimen representative of a pure shear failure, the span length of the flexure specimen is critical. For if the span length is too great, the composite coupon test specimen will fail in tension on the bottom side of the flexure specimen. However, if the span length is too small, the regions of compressive stress resulting from the load and supports will overwhelm the region of the specimen that is subjected to shear (see Figure 3) precluding a pure shear failure. A successful specimen configuration consists of a O. 5-in. wide, by 6-in. long, by 50-ply thick coupon of graphite\epoxy bonded between 0.5-in. wide, by 6-in. long, by l/32-in. thick steel strips and tested at a span-to-depth ratio of 7.5:1.

It should be noted that the test specimen preparation is a rather labor-intensive process as the steel strips have to be heat treated to a specific strength level. Moreover, the adhesive bonding technique required to obtain a high-strength bond between the composite coupon and the steel is critical. However, during the author's prior research, the required procedure to obtain excellent final results has been standardized.

An MTS uniaxial servohydraulic testing system is used to subject the test specimens to four-point flexure (see Figure 4). The load applied to the flexure specimen is recorded by a in-line load cell. The deflection at midspan is monitored by the use of a displacement gage located halfway between the supports on the lower side of the specimen. A two-pen xy-recorder is used to obtain a continuous readout of the load-deflection response of the beam. A controlled materials characterization test is therefore demonstrated to the students. Strain gages can be mounted to the upper and lower surfaces of the flexure specimen allowing the students to also monitor the outer fiber strain distributions for both tension and compression of the four-point flexure test. This output can also be continuously monitored via the xy-recorder.

Experimental Results

Both load-displacement and load-strain plots can be obtained either from the software program that controls the test equipment, or from the xy-recorder. The student can directly observe the response of the nonhomgenous composite beam being deformed under four-point loading. It is explained to the student that the nonlinear behavior which occurs in the load-displacement and load-strain responses is the result of the shear deformation of the epoxy matrix of the composite material.

Upon reaching a critical bending load, the shear stress exceeds the shear strength of the material. The result is an interlaminar shear failure along the longitudinal plane of the flexure specimen (see Figure 5). Shear failure of the composite coupon is accompanied by a load "pop." The shear failure is explosive in nature.

Lab Report

The students are required to submit a two-page report on what they observed and learned during the laboratory research demonstration. The report must include a brief summary of the specimen preparation procedure along with a brief description of the equipment and instrumentation setup. The student is also required to estimate the interlaminar shear strength of the graphite\epoxy material based upon the elementary strength-of-materials formula for the shear stress distribution through the thickness of a beam under flexure.

References

1. Materials Science and Engineering for the 1990's: Maintaining Competitiveness in the Age of Materials, National Research Council, National Academy Press, Washington, D. C., 1989.

2. Short, S. R., Characterization of Interlaminar Shear Failures of Graphite/Epoxy Composite Materials, Ph.D. Dissertation, The University of Dayton, Dayton, OH, 1990.

3. Short, S. R., "Characterization of Interlaminar Shear Failures of Graphite/Epoxy Composite Materials," Composites, Vol. 26, 1995, pp. 431-449.

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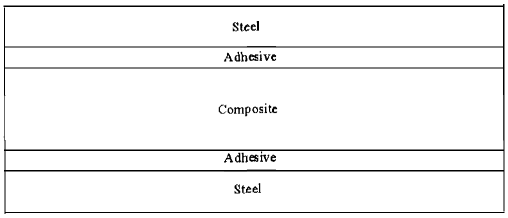

Figure 1. SCS test specimen.

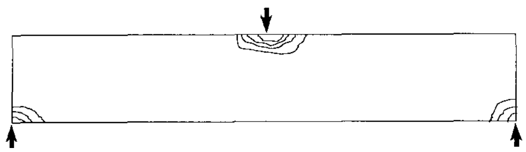

Figure 2. Load and support regions are subjected to stress concentrations.

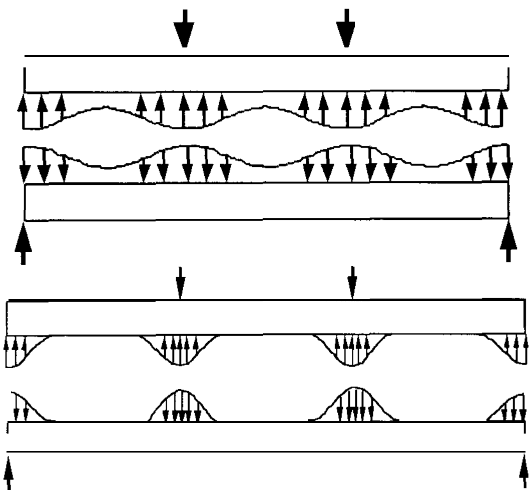

Figure 3. The region of overlapping through-thickness compressive stress is a function of the span length of the flexure specimen.

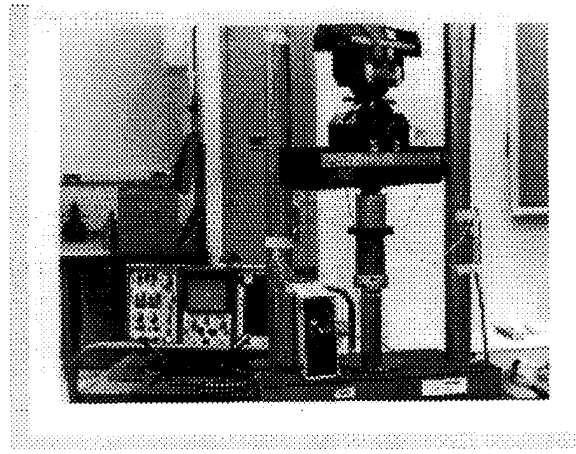

Figure 4. MTS test setup.

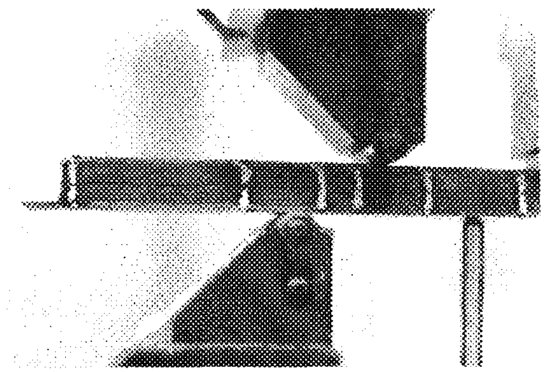

Figure 5. SCS test specimen exhibiting shear failure along the neutral plane.