COMPOSITE MATERIALS: testing & design (6th Conference)

I. M. DANIEL, *editor*

ASTM STP 787

COMPOSITE MATERIALS: TESTING AND DESIGN (SIXTH CONFERENCE)

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sponsored by ASTM
Committee D-30 on
High Modulus Fibers and Their Composites
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Foreword

The Sixth Conference on Composite Materials: Testing and Design was held 12–13 May 1981 in Phoenix, Arizona. ASTM Committee D-30 on High Modulus Fibers and Their Composites sponsored the conference. I. M. Daniel, Illinois Institute of Technology, served as conference chairman and has also edited this publication. Most of the papers presented are included in this volume, which complements the first, second, third, fourth, and fifth conference publications—*ASTM STP 460, ASTM STP 497, ASTM STP 546, ASTM STP 617,* and *ASTM STP 674, Composite Materials: Testing and Design.*

Related ASTM Publications

Damage in Composite Materials, STP 775 (1982), 04-775000-30

Short Fiber Reinforced Composite Materials, STP 772 (1982), 04-772000-30

Composites for Extreme Environments, STP 768 (1982), 04-768000-33

Joining of Composite Materials, STP 749 (1981), 04-749000-33

Test Methods and Design Allowables for Fibrous Composites, STP 734 (1981), 04-734000-33

Commercial Opportunities for Advanced Composites, STP 704 (1980), 04-704000-33

Nondestructive Evaluation and Flaw Criticality for Composite Materials, STP 696 (1979), 04-696000-33

Composite Materials: Testing and Design (Fifth Conference), STP 674 (1979), 04-674000-33

Composite Materials: Testing and Design (Fourth Conference), STP 617 (1977), 04-617000-33

A Note of Appreciation to Reviewers

This publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of ASTM publications is a direct function of their respected opinions. On behalf of ASTM we acknowledge with appreciation their contribution.

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Introduction

The Sixth Conference on Composite Materials, held on 12–13 May 1981 in Phoenix, Arizona, was sponsored by ASTM Committee D-30 on High Modulus Fibers and Their Composites. Like the previous five similar conferences (New Orleans, 1969, *ASTM STP 460*; Anaheim, 1971, *ASTM STP 497*; Williamsburg, 1973, *ASTM STP 546*; Valley Forge, 1976, *ASTM STP 617*; New Orleans, 1978, *ASTM STP 674*) it dealt with all aspects of testing and design. The object of the conference was to bring together the active workers in composites technology and to provide a general forum for presentations and discussions of the latest developments in composites testing and design, including applications to the aircraft, automotive, and other industries.

Of the 41 papers presented at the conference, 31 are included in this volume. They are arranged in eight sections: Test Methods; Material Characterization; Fracture and Failure Analysis; Fatigue; Nondestructive Evaluation; Time-Dependent and Dynamic Response; Environmental Effects, Durability, and Reliability; and Testing of Composite Structures. The breadth and depth of the subjects covered indicate that the field of composites technology has reached some state of maturity and that researchers are not preoccupied with a single aspect of the topic.

Because of the general nature of the conference, no single topic was covered extensively, as would be the case in a more specialized symposium. New test methods for mechanical and damage characterization are described, including the novel "deply" technique. New types of composites, such as SMC, short fiber, and ribbon-reinforced composites, are being characterized. Fatigue behavior received considerable attention, including the effects of spectrum variations and stress biaxiality. In the section on Nondestructive Evaluation novel ultrasonic backscattering techniques are introduced. Time-dependent behavior received considerable attention both in the short (dynamic) and long timescales, and will continue to do so as more composite structures are designed to withstand impact loadings and more demands are made for prediction of long-time behavior. Unlike prior conferences, the subject of environmental effects did not receive extensive coverage, probably because these effects, serious as they may be, are better understood today and are not considered as threatening as they appeared before.

Although composites are available for a variety of structural applications, all aspects leading to an optimized design of a reliable and durable structure need further study and development. In this respect this volume makes a valuable addition to the composites library of the researcher and designer. It complements the series of STPs of the previous conferences as well as those of specialized symposia on composite materials.

Special thanks are due Drs. C. C. Chamis, G. P. Sendeckyj, J. B. Whiteside and J. M. Whitney, who helped me organize the program; all session chairmen, authors and reviewers; and last but not least the ASTM staff.

I. M. Daniel
Professor and Director, Experimental Stress Analysis Laboratory, Illinois Institute of Technology, Chicago, Illinois; symposium chairman and editor

Test Methods

T. H. Mao[1] *and M. J. Owen*[2]

Through-the-Thickness Tensile Strength of Fiber-Reinforced Plastics

REFERENCE: Mao, T. H. and Owen, M. J., "**Through-the-Thickness Tensile Strength of Fiber-Reinforced Plastics,**" *Composite Materials: Testing and Design (Sixth Conference), ASTM STP 787*, I. M. Daniel, Ed., American Society for Testing and Materials, 1982, pp. 5–18.

ABSTRACT: The through-the-thickness tensile strength of fiber-reinforced plastics is difficult to measure, but for some purposes it is a significant design property. This property appears to be critically dependent on the test method and specimen preparation. The authors have examined the possibility of producing tensile failures in a disk subjected to diametral compression, a method well known in the field of testing of brittle isotropic materials.

In the isotropic case there is a uniform tensile stress distribution perpendicular to the diameter which is the axis of compression. Slices of round pultruded rod are transversely isotropic, and the method of test gives convenient and consistent results.

Results are also presented for the through-the-thickness strength of laminated materials. The disks were prepared by turning a cylindrical bar from a piece of thick laminate. Stress distributions have been analyzed by finite element analysis and compared with published theory. Both methods have been compared with strain gage results obtained from orthotropic disks. The finite element results agree quite well with published theory, but there is considerable scatter in the strain gage results. Experimental results for the strength of disk samples are consistent and compare well with other methods. The disk method also appears to be economical.

KEY WORDS: composite materials, glass fiber, polyester, epoxy, pultruded rod, woven roving fabric, disk, through-the-thickness strength, compression, transverse tensile strength

The through-the-thickness tensile strength of glass-reinforced plastic (GRP) laminates is a significant property in certain types of structure; for example, those in which there are load-bearing tee-shaped intersections. Through-the-thickness tensile strengths have been reported in the literature [*1*], but attempts by the authors to measure this property indicated that it is critically dependent on specimen preparation and shape.[3] There are obvious

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[2] Professor of Reinforced Plastics, Department of Mechanical Engineering, University of Nottingham, United Kingdom.

[3] The italic numbers in brackets refer to the list of references appended to this paper.

difficulties because the thickness of most laminates is relatively small compared with the length of normal tension test specimens. In an extensive piece of work at the U.S. National Bureau of Standards on the properties of pultruded GRP rods, Halsey and others [2,3] estimated the transverse tensile strength using disks sliced from the rods. When an isotropic disk is subjected to compression along a diameter the stress distribution includes a compressive principal stress along the diameter perpendicular to the line of loading, and an almost uniform smaller tensile principal stress perpendicular to the diameter which is the loading axis. If the material is very weak in tension it will fail due to the tensile principal stresses normal to the loading axis. The principal stresses along this axis consist of a large compressive stress and a small tensile stress, but provided that the maximum principal stress criterion of failure applies it provides a measure of the tensile strength. The method is used for brittle materials such as ceramics and pharmaceuticals (pills). The pultruded rods tested by Halsey and his colleagues could be treated as isotropic in their plane and failed in the expected brittle manner.

In the present work the authors have attempted to extend the disk method to laminated GRP by using Okubo's anisotropic analysis [4]. Firstly they obtained transverse tensile strengths by the disk method for a number of samples of pultruded rod. Secondly they prepared disks of laminated material by turning bars from thick laminates intended for ship construction and then slicing the bars into disks. Tensile strengths determined from laminated disks were compared with direct determinations. Thirdly they attempted to check the validity of Okubo's analysis. This was done by preparing a number of model disks with varying degrees of anisotropy and subjecting them to strain gage analysis. Strain gage results were compared with both theoretical predictions and finite element calculations.

Transverse Tensile Strength of Pultruded Rods

Five samples of round pultruded rods were obtained from Bastion Glass Fibre Rod and Sections Ltd. All rods were made with epoxy resin systems. Details are given in Table 1. Disks of various thicknesses were sliced from the rods by a diamond slitting wheel. Before testing the disks were ground on both flat faces to ensure parallelism and a good surface finish.

It is known from the theory of elasticity [5] that the tensile stress σ_y is constant along the loading diameter of an isotropic disk compressed diametrically, and can be expressed as

$$\sigma_y = \frac{2P}{\pi DT} \tag{1}$$

where

P = compressive load,
D = diameter of the disk, and
T = thickness of the disk.

TABLE 1—*Details of Bastion pultruded rods.*[a]

Specimen Designation	Rod Type	Ciba Epoxy Resin System
A	14-mm ground rod	CY182/HY917/K61B
B	14-mm ground rod	MY740/HY917/K61B
D	⅝-in.-diameter natural rod	MY740/HY917/DY070
E	⅝-in.-diameter natural rod	MY740/HY917/K61B
K	⅜-in.-diameter natural rod	MY740/HY917/DY070

[a] Ground rod has a surface subjected to a grinding operation. Natural rod has a surface in the as-pultruded condition. All rods have 80 percent fiber volume fraction by weight. The pultruded rods were obtained from Bastion Glassfibre Rod and Sections Ltd., Crowther Industrial Estate, Washington, Tyne and Wear, United Kingdom.

Disks with nominal thicknesses of 2, 3, 4, and 6 mm were subjected to diametral compression in an Instron testing machine using the loading fixture shown in Fig. 1. Average values of strength, computed from Eq. 1, for each type of rod and each thickness, are plotted against thickness in Fig. 2. The main features of the results are the consistency of the individual values and the fact that the thinner disks are apparently stronger than the thicker ones. All disks failed suddenly by cracking along the vertical diameter—that is, parallel with the line of load. Many of the disks had secondary cracks (Fig. 3). Because of the deformation of the sample the actual loading is not a concentrated point load but is spread over a finite area and thus modifies the stress distribution at the point of loading. The compressive stresses perpendicular to the line of loading are three times higher than the tensile stress at the center of the disk and, being in the region from 115 to 120 MPa, are virtually equal to the yield stress of a resin. The tensile strengths observed from these tests are almost three times as high as those reported by Halsey and his colleagues [2,3], who tested pultruded rods made with polyester resins.

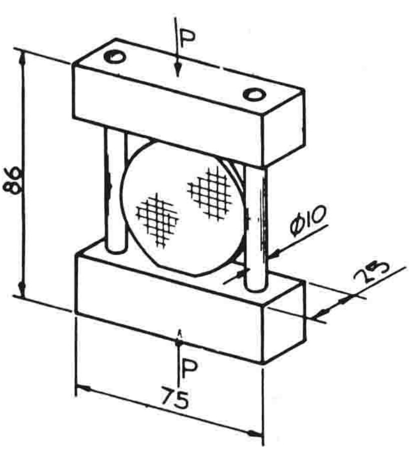

FIG. 1—*Test fixture.*