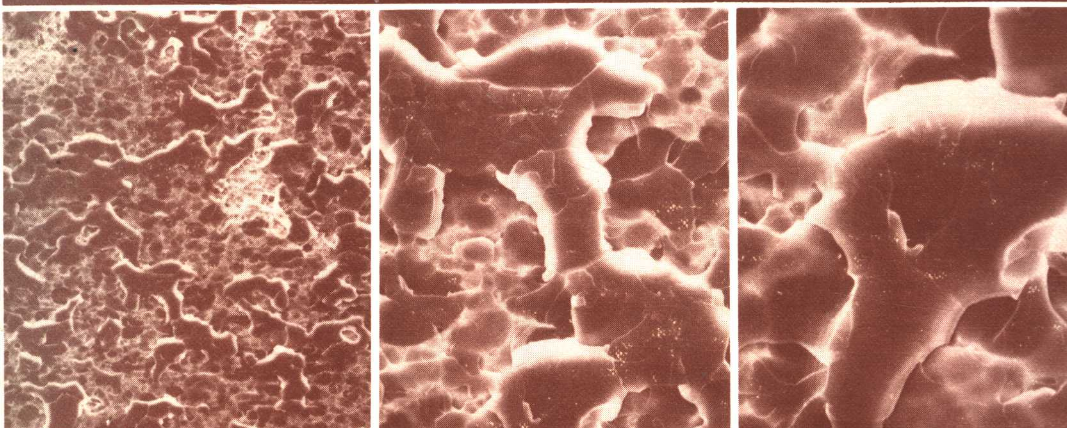
COMPOSITE MATERIALS

TESTING AND DESIGN

Seventh Conference



JAMES M. WHITNEY *Editor*

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ASTM

COMPOSITE MATERIALS: TESTING AND DESIGN (SEVENTH CONFERENCE)

A conference
sponsored by
ASTM Committee D-30 on
High Modulus Fibers and
Their Composites
Philadelphia, PA, 2–4 April 1984

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Foreword

The Seventh Conference on Composite Materials: Testing and Design was held 2–4 April 1984 in Philadelphia, Pennsylvania. ASTM Committee D-30 on High Modulus Fibers and Their Composites sponsored the conference. James M. Whitney, Wright-Patterson Air Force Base, served as conference chairman and editor of this publication. Most of the papers presented are included in this volume, which complements the first, second, third, fourth, fifth, and sixth conference publications—*ASTM STP 460, ASTM STP 497, ASTM STP 546, ASTM STP 617, ASTM STP 674*, and *ASTM STP 787, Composite Materials: Testing and Design.*

Related ASTM Publications

Composite Materials: Testing and Design (Sixth Conference), STP 787 (1982), 04-787000-33

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

Composite Materials: Testing and Design (Third Conference), STP 546 (1974), 04-546000-33

Composite Materials: Testing and Design (Second Conference), STP 497 (1972), 04-497000-33

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Introduction

This volume represents a collection of papers obtained from presentations made at the Seventh Conference on Composite Materials: Testing and Design held in Philadelphia, PA, 2–4 April, 1984. All seven of the conferences held under this title have been sponsored by ASTM Committee D-30 on High Modulus Fibers and Their Composites (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*; Phoenix, 1981, *ASTM STP 787*).

Although this conference has traditionally covered all aspects of composite materials technology, it is interesting to note the emphasis of the papers associated with each of the previous six conferences, as it provides an important historical background to research in the area. In the first two conferences, for example, considerable emphasis was placed on test methods. This was very timely, as in the early days of advanced composites technology there was a tendency to apply metallic materials test methods to fiber-reinforced composites. The heterogeneous, anisotropic nature of composite materials required that many of the test methods borrowed from metallic technology be carefully scrutinized for application to advanced composites.

In the third conference, emphasis began to shift away from the more routine tests and began to focus on such areas as fatigue and creep. The concern over the effects of high humidity on the elevated-temperature properties of epoxy resin matrix composites was also introduced into this conference. This was a prelude to the era of "the moisture problem." Fracture, impact response, and environmental effects were emphasized in the fourth conference. The fifth conference represented a wide spectrum of activity in composite materials. Although a session on environmental effects was presented, the concern over moisture effects was subsiding considerably. Fatigue, time-dependent behavior, and nondestructive evaluation were topics of particular interest in the sixth conference.

The seventh conference reflects the current issue of toughness as related to damage tolerance of advanced composites. Sessions on failure mechanisms, delamination, and strength strongly emphasize toughness. Structural aspects of damage tolerance are also addressed. Many of the papers reflect the maturity to which composites technology has arrived. Most of the easy problems have been solved. Researchers are now faced with characterizing and analyzing the complex failure mechanisms associated with stress concentrations and delaminations. The conference also contains a number of papers on the emerging materials. In particular, multi-dimensionally reinforced materials in the form of woven and braided structure are discussed.

This volume contains 23 of the 31 papers presented at the conference. The five major sections correspond to the conference sessions: Structures, Failure Mechanisms, Strength, Delamination, and Analysis and Characterization.

Since topics of major interest are included in this volume, it is highly recommended to researchers and designers in the field of composite materials. This volume along with the other six volumes from the testing and design conferences provide an excellent background for the beginner who wishes to know details about the development of composite materials technology.

Special thanks go to the session chairman, authors, reviewers, and ASTM Staff who made the conference and this resulting volume possible.

James M. Whitney
Materials Research Engineer, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH; symposium chairman and editor.

Structures

Ramon A. Garrett[1]

Effect of Manufacturing Defects and Service-Induced Damage on the Strength of Aircraft Composite Structures

REFERENCE: Garrett, R. A., "**Effect of Manufacturing Defects and Service-Induced Damage on the Strength of Aircraft Composite Structures,**" *Composite Materials: Testing and Design (Seventh Conference), ASTM STP 893*, J. M. Whitney, Ed., American Society for Testing and Materials, Philadelphia, 1986, pp. 5–33.

ABSTRACT: This paper describes the effects of manufacturing defects and service-induced damage on the static and fatigue strength of aircraft composite structures.

Seven manufacturing defects associated with mechanical fasteners were investigated: out-of-round holes, delaminations at the exit side of drilled holes, porosity, improper fastener seating depth, tilted countersinks, interference fit, and multiple fastener installation and removal cycles. Both static and fatigue test results are described, along with correlation with analysis techniques. The interaction of the effects of these defects on hole wear, measured in fatigue tests of structural joints, is described.

The effects of two types of service-induced damage are also described: low-energy impact damage and penetration damage. The relative sizes of visible and non-visible damage as determined by visual and nondestructive inspection techniques are compared. An evaluation of stitching and the inclusion of glass or Kevlar fiber buffer strips to improve the damage tolerance of carbon/epoxy structures is included. Results of tests of carbon/epoxy panel structures are discussed. Correlation of experimental results with predicted residual static strength is good.

KEY WORDS: composite materials, composite structures, graphite laminates, epoxy laminates, impact damage, defects, residual strength, static strength, fatigue strength, fatigue (materials), postbuckling

Future aircraft will require airframes that are lighter weight, easier to maintain, and more durable than current construction approaches and materials. The use of composite materials in primary structures offers promise of significant weight savings, due to their greater specific static strength and even larger improvement in fatigue strength. However, proof of the ability of composite structures to be tolerant of both initial manufacturing defects and damage induced by service usage was necessary before their application to aircraft primary structures.

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Programs to evaluate the damage tolerance of composite structures have been initiated by several different agencies under the Department of Defense. Each of these programs have been directed towards a different aspect of the subject area; this paper summarizes some of the work performed by the McDonnell Aircraft Company in each area.

The effect of manufacturing defects on the static and fatigue strength of laminates with loaded and unloaded fastener holes was conducted in the Ref *1* program and is described in the next section. The effect of low-energy impact damage on composite structures was included in several programs with the United States Navy (Ref *2*, *3*, and *4*). Finally, the effect of penetration damage conducted in conjunction with the Ref *2* program is described. Table 10 is included in the Appendix for converting English Units used throughout this paper to SI Units.

Manufacturing Defects at Fastener Holes

The effects of several types of possible manufacturing defects associated with mechanical fasteners in aircraft structures were investigated under the Ref *1* program. This investigation was performed using laminates with loaded fastener holes, a common critical structural design feature in aircraft composite structures. In many cases, tests were conducted with specimens in which the defect or anomaly was more severe than expected from current manufacturing processes. In all cases, defects that resulted in strength reductions greater than 15% would have been detected using current industry inspection techniques and would have been rejected or repaired to meet current acceptance criteria.

Tests were performed to determine the effects on static strength, fatigue strength, and hole wear.

Static Strength

The effect on static strength was evaluated by comparing static strength of joints with a particular defect with the static strength of specimens with no defect. All static strength test specimens were fabricated from 20-ply laminates, with a per ply thickness of 0.0104 in. (0.208 in. total thickness).

Specimens were tested to failure in tension and compression at three environmental conditions: room temperature dry (RTD), room temperature wet (RTW), and elevated temperature wet (ETW). The ETW tests were conducted at 250°F with specimen moisture contents of approximately 0.80% by weight. Hercules AS/3501-6 carbon/epoxy was used for fabrication of test specimens.

Results are summarized in Table 1. Indicated percentages of increased or decreased strength are based on a comparison with baseline specimens. Detailed results are discussed in the following paragraphs.

Out-of-Round Holes—Effects of out-of-round holes on joint strength were evaluated by drilling a second set of holes offset from the first holes by 0.004 in. as shown in Fig. 1. Test results of specimens from two laminates (50/40/10

TABLE 1—*Strength reduction summary.*

	RTD Tension	Compression	
		RT[a]	250°F[a]
Out-of-round holes			
50/40/10 laminate	[b]	...	...
30/60/10 laminate	−4.8	...	...
Broken fibers exit side of hole			
Severe	−7.3	−8.4	−9.2
Moderate	−1.4	−3.2	−4.2
Porosity around hole			
Severe	[b]	−10.3	−30.8
Severe with freeze-thaw	...	−11.6	...
Moderate	...	−7.1	−13.3
Moderate with freeze-thaw	...	−8.4	...
Improper fastener seating depth			
80% thickness	−16.4	...	...
100% thickness	−34.3	...	...
Tilted countersinks			
Away from bearing surface	[b]	...	−16.7
Toward bearing surface	−21.4	...	−16.7
Interference fit tolerances (in.)			
50/40/10 @ 0.003	[b]	...	+9.1[c]
@ 0.008	[b]	...	+9.1[c]
30/60/10 @ 0.003	[b]	...	[b,c]
@ 0.008	[b]	...	[b,c]
Fastener removal and reinstallation			
100 cycles	[b]	...	−8.3

[a]Moisture content = 0.86%
[b]Less than 2% change.
[c]Tensile loading
NOTE—Three dots indicate no test. See appendix for SI equivalents.

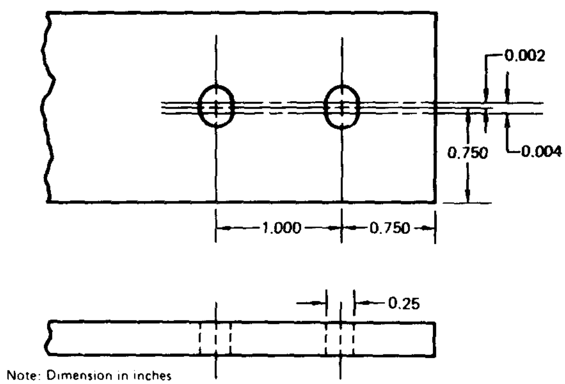

FIG. 1—*Out-of-round holes—specimen.*