COMPOSITE MATERIALS

FATIGUE AND FRACTURE

FIFTH VOLUME

RODERICK H. MARTIN
EDITOR

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Composite Materials: Fatigue and Fracture—Fifth Volume

Roderick H. Martin, editor

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Peer Review Policy

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The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

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Foreword

This publication, *Composite Materials: Fatigue and Fracture—Fifth Volume*, contains papers presented at the Fifth Symposium on Composite Materials: Fatigue and Fracture, which was held in Atlanta, Georgia, 4–6 May 1993. The symposium was sponsored by ASTM Committee D-30 on High Modulus Fibers and Their Composites. Roderick H. Martin, Materials Engineering Research Laboratory, Ltd., Hertford, England, presided as symposium chairman.

Contents

Overview

The Fifth Symposium on Composite Materials: Fatigue and Fracture, sponsored by ASTM Committee D30, was held in May 1993 in Atlanta, Georgia. The symposium was the fifth in a biannual series of symposia that addresses current issues in the field of damage mechanics of high modulus fibers and their composites. The special technical publication (STP) number and the editors of the previous symposia on fatigue and fracture of composites are listed below:

1st Volume:	ASTM STP 907	Publication year 1986	H. Thomas Hahn, Editor
2nd Volume:	ASTM STP 1012	Publication year 1989	Paul Lagace, Editor
3rd Volume:	ASTM STP 1110	Publication year 1991	T. Kevin O'Brien, Editor
4th Volume:	ASTM STP 1156	Publication year 1993	Wayne Stinchcomb & Noel Ashbaugh, Editors

The objective of these symposia is to increase the understanding of how composite materials and composite material structures fail and to develop analyses and test methods to predict this failure. Topics of these symposia include:

1. Micromechanics where analysis methods to determine the interfacial stresses between the fiber and the matrix are developed and evaluated and tests which determine the strength and toughness of the interface are developed.
2. Fracture mechanics for analytical and experimental characterization of pure and mixed-mode delamination and crack growth to rank materials an . to design durable and damage-tolerant structural parts are covered.
3. Effects of different environments and loadings such as e posure to temperature, liquids, fatigue loads, or impact events on material properties anc structural failure.
4. Characterization of new types of material forms such as in erlaminar-toughened materials and stitched or braided composites or ceramic or metal m trix composites.
5. Fatigue and fracture of composites in structural configura ons.

Over 30 papers were presented at the fifth symposium, adc essing items from the topics listed above. The symposium had eight sessions, listed below alc g with the session chairmen:

1. *Delamination Characterization A*—Anoush Poursartip, Uni ersity of British Columbia.
2. *Damage Modeling*—John Fish, Lockheed Advanced Devel ment Company.
3. *Damage Growth*—Wayne Stinchcomb (deceased), Virgi Polytechnic Institute and State University.
4. *Factors Affecting Fatigue Response*—Steven Hooper, Wich a State University.
5. *Damage Prediction*—Erian Armanios, Georgia Institute of T chnology.
6. *Impact*—John Masters, Lockheed Engineering and Sciences Company.
7. *Damage in Structural Configurations*—Kevin O'Brien, U.S. Army.
8. *Delamination Characterization B*—Kazuro Kageyama, University of Tokyo.

For this publication, the papers have been reorganized into five sections.

Delamination Characterization

Papers in the first section cover the topic of characterizing delamination fracture of laminated composite materials in terms of their interlaminar fracture toughness. This topic continues to receive much attention as the importance of interlaminar fracture properties gains acceptance in materials ranking and in damage-tolerant design. The papers in this section discuss the specific topics of mixed mode delamination and the generation of a mixed mode failure criteria under static and fatigue loads using the mixed mode bending specimen and some newly developed specimens (Sriram et al. and Gong and Benzeggagh). Also, delamination characterization in interlaminar-toughened materials using interleafs or beads is covered (Kageyama et al., Lee et al., and Armstrong-Carroll and Cochran). Delamination in fracture specimens of nonunidirectional layups is discussed in two papers (Kussmaul et al. and Chou et al.). Also, a Mode III delamination test is presented (Sharif et al.); this paper won the best presentation award at the symposium.

Damage Modeling

The ability to model composite damage and to predict the onset of fiber matrix debonding, matrix cracking, delamination, buckling, fiber failure, or some other damage mode such as stiffness reduction is essential, and papers in this section address some of these issues. The topics covered include a closed form method to determine the individual modes of strain energy release rate for an edge delamination (Davidson), a fracture analysis approach to fiber matrix or transverse cracking (Suresh and Wang and Sriram and Armanios), and the consideration of reducing material properties in a finite element analysis to predict damage growth (Shaid and Chang and Slattery).

Material Damage Characterization

This section investigates forms of damage associated with composite materials under environmental exposure and mechanical loads. In many papers in this section, ''material'' damage is a result of the composite being formed into a laminate and, hence, becoming in itself a structure. It is imperative to understand damage growth at this level of a composite material ''structure'' before further structural configurations can be understood. Papers in this section present damage observations in laminates with different layups under tension and compression fatigue loads (Komorowski et al. and Connolly and Davidson), while another paper discusses the effects of thermal cycling as experienced in space on matrix cracking (Knouff et al.). The other topics covered in this section include the effects of marine environments on composite properties (Pomies et al.) and a test method for measuring the compression strength of an impregnated tow (Cairns).

Impact

The maximum benefits derived from utilizing laminated composite materials is severely limited by the inability to predict the performance of composites under impact conditions. This section covers topics such as the damage size in a brittle and tough matrix composite under low and intermediate impact velocities (Delfosse et al.), the post-impact response of stitched and braided composites (Moon and Kennedy and Portanova and Deaton), and the effects of thickness and clamping conditions on the response of a panel under impact (Ambur et al.).

Structural Damage Characterization

Ultimately, information from the materials tests, the modeling, and the materials property evaluation tests must be used to determine structural failure. The papers in this section describe some of the issues of failure or damage in specific structures. One paper covers the growth and arrest of cracks in pressurized composite cylinders such as pipes or aircraft fuselages (Ranniger et al.). Another describes a project investigating the fatigue failures of a graphite torsion spring used indoors on a Boeing 767 aircraft (Bliss et al.), while two other papers investigated stresses and delamination in tapered laminates (Vizzini and Wisnom et al.). The fracture of a laminate under torsion and tension-torsion loads consistent with rotor craft applications (Sen and Fish) was discussed in a further paper.

Papers Not Published

There were five presentations at the symposium whose manuscripts do not appear in this publication. One, entitled ''A Characterization of Fiber-Matrix Interface Strength,'' was presented by Rajiv Naik of Analytical Services and Materials in Virginia. His presentation described the use of a closed form solution to determine fiber matrix stresses and the use of an off-axis flexure test to determine fiber matrix strength under different ratios of transverse and shear stress. Another paper, entitled ''Delamination Growth Under Cyclic Compression in Composite Plates,'' was presented by George Kardomateas of The Georgia Institute of Technology. His presentation described fracture models describing the growth of delaminations from repeated buckling/post-buckling and unloading. A further presentation by John Bakuckas, then of the National Research Council, entitled ''Modelling Fatigue Crack Growth in Cross Ply Titanium Matrix Composites,'' described experimental crack growth data for two TMC composites and used a fiber-bridging model to determine the stress intensity factor at the crack tip. A fourth paper, presented by Wade Jackson of the U.S. Army, entitled ''Effect of Plate Size on Impact Damage,'' compared the damage area from static indentation tests and low-velocity impact tests on plates of different dimensions. The fifth paper presented but not published was entitled ''Evaluation of the Long-Term Behavior of a Notched Thermoplastic Laminate,'' given by W. S. Kohl, then of Virginia Polytechnic Institute. This paper used NDE techniques and DMA tests to investigate changes in the viscoelastic nature of fatigue damage in notched laminates. The paper was co-authored by the late Wayne Stinchcomb.

This STP is a result of hard work by many people, and the editor would like to acknowledge and thank these people: The ASTM staff: Dorothy Savini, Kathie Schaaf, Kathy Dernoga, Rita Hippensteel, David Jones, and Therese Pravitz; the session chairman, listed above; the reviewers, approximately 100 of them; and finally the authors for their papers and presentations.

Roderick H. Martin

Materials Engineering Research Laboratory, Ltd. (MERL), Hertford, England; symposium chairman and editor

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