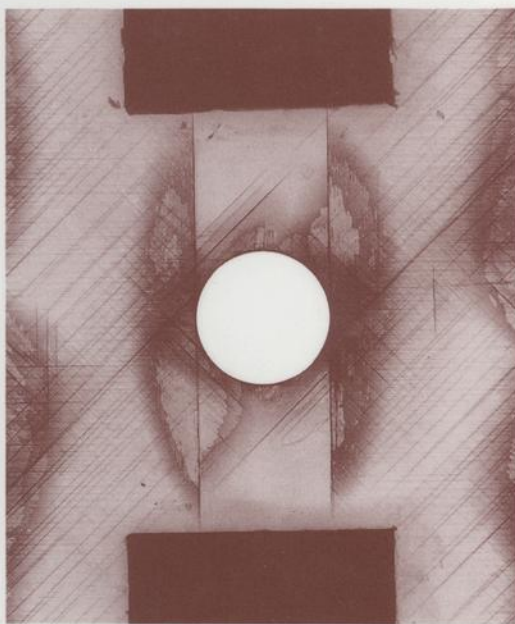


Composite Materials

Fatigue and Fracture



Fourth Volume

Stinchcomb/Ashbaugh, editors



STP 1156

STP 1156

Composite Materials: Fatigue and Fracture, Fourth Volume

Wayne W. Stinchcomb and Noel E. Ashbaugh, editors

ASTM Publication Code Number (PCN)
04-011560-33



ASTM
1916 Race Street
Philadelphia, PA 19103

ASTM Publication Code Number (PCN): 04-011560-33

ISBN: 0-8031-1498-2

ISSN: 1040-3086

Copyright © 1993 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia, PA. Prior editions copyrighted 1991 and earlier by the American Society for Testing and Materials. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

Photocopy Rights

Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by the AMERICAN SOCIETY FOR TESTING AND MATERIALS for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of \$2.50 per copy, plus \$0.50 per page is paid directly to CCC, 27 Congress St., Salem, MA 01970; (508) 744-3350. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Service is 0-8031-1498-2/93 \$2.50 + .50.

Peer Review Policy

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

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.

Printed in Ann Arbor, MI
June 1993

Foreword

This publication, *Composite Materials: Fatigue and Fracture, Fourth Volume*, contains papers presented at the Fourth Symposium on Composite Materials: Fatigue and Fracture, which was held in Indianapolis, Indiana on 6–7 May 1991. The symposium was sponsored by ASTM Committees D-30 on High Modulus Fibers and Their Composites, E-9 on Fatigue, and E-24 on Fracture Testing. Wayne W. Stinchcomb, Virginia Polytechnic Institute and State University, and Noel Ashbaugh, University of Dayton, presided as symposium chairmen and were the editors of this publication.

Contents

Overview	1
 STRENGTH AND FAILURE MODES	
Failure of Graphite/Epoxy Panels with Stiffening Strips—ADAM J. SAWICKI, MICHAEL J. GRAVES, AND PAUL A. LAGACE	5
Failure Initiation and Ultimate Strength of Composite Laminates Containing a Center Hole—G. D. CHU AND C. T. SUN	35
Response of Notched Graphite/Epoxy and Graphite/PEEK Systems—PAUL A. LAGACE, NARENDRA V. BHAT, AND AHMET GUNDOGDU	55
Failure Analysis of Notched Unidirectional Graphite/Epoxy Tubes Under Combined Loading—DEIRDRE A. HIRSCHFELD AND CARL T. HERAKOVICH	72
Matrix Cracking-Induced Delamination Propagation in Graphite/Epoxy Laminated Composites Due to a Transversely Concentrated Load—SHENG LIU, ZAFER KUTLU, AND FU-KUO CHANG	86
 DAMAGE: MEASUREMENT, ANALYSIS, AND MODELING	
Damage Prediction in Cross-Plied Curved Composite Laminates—RODERICK H. MARTIN AND WADE C. JACKSON	105
Evaluation of Impact Damage in Composite Materials Using Acoustic Emission— MANON BOLDUC AND CLERMONT ROY	127
The Change in Thermal Expansion Coefficient as a Damage Parameter During Thermal Cycling of Crossply Laminates—LYNN BONIFACE, STEPHEN L. OGIN, AND PAUL A. SMITH	139
Tensile Deformation of SiC/Ti-15-3 Laminates—BRADLEY A. LERCH AND JAMES F. SALTSMAN	161
Material Modeling for Unidirectional Glass and Glass-Ceramic Matrix Composites with Progressive Matrix Damage—CHIAN-FONG YEN AND KENT W. BUESKING	176
Modeling Ply Crack Growth in Laminates Under Combined Stress States— SAILENDRA N. CHATTERJEE, EDWARD C. J. WUNG, AND CHIAN F. YEN	195
Assessment of Interlayer Shear Slip Theory for Delamination Modeling— XIANQIANG LU AND DAHSIN LIU	218

INTRALAMINAR AND INTERLAMINAR FRACTURE

Effect of Initial Delamination on Mode I and Mode II Interlaminar Fracture Toughness and Fatigue Fracture Threshold—GRETCHEN B. MURRI AND RODERICK H. MARTIN	239
Damage and Failure Mechanisms in Scaled Angle-Ply Laminates—SOTIRIS KELLAS, JOHN MORTON, AND KAREN E. JACKSON	257
Thickness Effect of Double Cantilever Beam Specimen on Interlaminar Fracture Toughness of AS4/PEEK and T800/Epoxy Laminates—MASAKI HOJO AND TAKAHIRA AOKI	281
The Influence of Interleaf Deformation Behavior and Film-Resin Adhesion on the Fracture Toughness of Interleaved Composites—EILEEN ARMSTRONG-CARROLL, BASSEL ISKANDARANI, IHAB KAMEL, AND THOMAS M. DONNELLAN	299
Effects of Water and Jet Fuel Absorption on Mode I and Mode II Delamination of Graphite/Epoxy—STEVEN J. HOOPER AND RAMASWAMY SUBRAMANIAN	318
Interlaminar Fracture Analysis of Unsymmetrical Laminates—ERIAN A. ARMANIOS AND JIAN LI	341

MICROMECHANICS AND INTERFACES

Some Observations on the Analysis of In-Plane Matrix Failures in Fibrous Composite Laminates—L. J. HART-SMITH	363
Model Composites: A Novel Approach for the Evaluation of Micromechanical Behavior—GREGORY P. CARMAN, JOHN J. LESKO, AHMAD RAZVAN, AND KENNETH L. REIFSNIDER	381
Meso-Indentation Testing of Composite Materials as a Tool for Measuring Interfacial Quality—JOHN J. LESKO, GREGORY P. CARMAN, DAVID A. DILLARD, AND KENNETH L. REIFSNIDER	401
Evaluating Surface Treatment Effects on Interfacial Bond Strength Using Dynamic Mechanical Analysis—D. D. EDIE, J. M. KENNEDY, R. J. CANO, AND R. A. ROSS	419
Micromechanical Analysis of Fiber Fracture—GREGORY P. CARMAN, JOHN J. LESKO, AND KENNETH L. REIFSNIDER	430
Micromechanics of Tensile Strength in Composite Systems—ZHANJUN GAO AND KENNETH L. REIFSNIDER	453

FATIGUE OF POLYMER MATRIX COMPOSITES

Fatigue Damage in Thick, Cross-Ply Laminates with a Center Hole— RICHARD L. WOLTERMAN, JOHN M. KENNEDY, AND GARY L. FARLEY	473
Local Delamination in Laminates with Angle Ply Matrix Cracks, Part I: Tension Tests and Stress Analysis— T. KEVIN O'BRIEN AND STEVEN J. HOOPER	491
Local Delamination in Laminates with Angle Ply Matrix Cracks, Part II: Delamination Fracture Analysis and Fatigue Characterization— T. KEVIN O'BRIEN	507
Effects of Stress Ratio on Edge Delamination Characteristics in Laminated Composites— G. C. SCRIVNER AND W. S. CHAN	538
Effect of Interleaves on the Damage Mechanisms and Residual Strength of Notched Composite Laminates Subjected to Axial Fatigue Loading— R. E. SWAIN, C. E. BAKIS, AND KENNETH L. REIFSNIDER	552
Characterization of Composite Material's Dynamic Response Using Load/Stroke Frequency Response Measurement— MEHRAN ELAHI, AHMAD RAZVAN, AND KENNETH L. REIFSNIDER	575
FATIGUE OF CERAMIC MATRIX, METAL MATRIX, AND SPECIALTY COMPOSITES	
Analysis of Thermomechanical Fatigue of Unidirectional Titanium Metal Matrix Composites— M. MIRDAMADI, W. S. JOHNSON, Y. A. BAHEI-EL-DIN, AND M. G. CASTELLI	591
High-Temperature Tension-Compression Fatigue Behavior of a Unidirectional Tungsten Copper Composite— MICHAEL J. VERRILLI AND TIMOTHY P. GABB	608
Monitoring Fatigue Damage Development in Ceramic Matrix Composite Tubular Specimens by a Thermoelastic Technique— KIN LIAO, THOMAS J. DUNYAK, WAYNE W. STINCHCOMB, AND KENNETH L. REIFSNIDER	620
High-Cycle Fatigue Crack Growth Properties of Aramid-Reinforced Aluminum Laminates— STEFANIE E. STANZL-TSCHEGG, MARIA PAPAKYRIACOU, HERWIG R. MAYER, JAAP SCHIJVE, AND EIMAR K. TSCHEGG	637
Indexes	653

ISBN 0-8031-1498-2