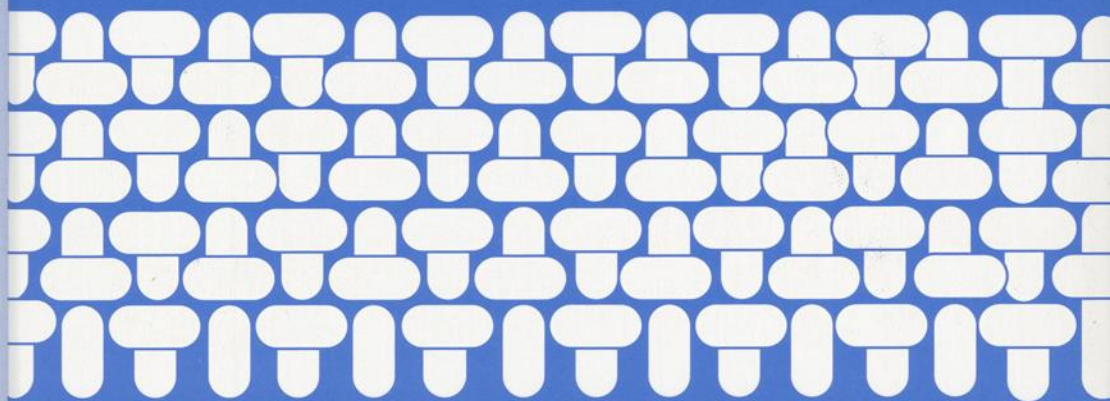


# COMPOSITE MATERIALS



## Testing and Design

Tenth Volume  
Glenn C. Grimes, editor

 STP  
1120

STP 1120

# *Composite Materials: Testing and Design (Tenth Volume)*

*Glenn C. Grimes, editor*

ASTM Publication Code Number (PCN)  
04-011200-33



ASTM  
1916 Race Street  
Philadelphia, PA 19103

ISBN: 0-8031-1426-5  
ASTM Publication Code Number (PCN): 04-011200-33  
ISSN: 0899-1308

Copyright © 1992 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia, PA. 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 0-8031-1426-5-92 \$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.

# Foreword

The Tenth Conference on Composite Materials: Testing and Design was held 24–25 April 1990 in San Francisco, California. ASTM Committee D-30 on High Modulus Fibers and Their Composites sponsored the conference. Glenn C. Grimes, Lockheed Advanced Development Company (The Skunk Works), served as conference chairman and editor of this publication. Most of the papers presented are in this volume, which complements the first through the ninth conference publications with the ASTM STP numbers of 460, 497, 546, 617, 674, 787, 893, 972, and 1059, respectively, all titled *Composite Materials: Testing and Design*. The first Conference was held in 1969 in New Orleans, Louisiana, and has been held approximately every two years since then.

# Acknowledgment

As the Symposium Editor, I wish to express my thanks for the effort put in by the eight Session Chairmen in conducting their sessions in San Francisco, California, getting presentation and technical paper reviewers, mediating differences between authors and reviewers, and writing a short summary of the technical papers in their session. I want to give special thanks to Paul Lagace (Session I), Michael Castelli (Session II), Stephen Swanson (Session III), Robert Croman (Session IV), Tom Duniak (Session V), Karl Steiner (Session VI), Kevin O'Brien (Session VII), and Susan Avery (Session VIII) for their assistance in the accomplishment of this task.

In addition, I must express my appreciation for the approval and support of my endeavor by Robert Goetz, Director of Engineering, and Ben Rich and Sherman Mullin, the immediate past and current Presidents of Lockheed Advanced Development Company (The Skunk Works).

Finally, the help of my secretary, Marylyn Dahlquist, for all the word processing and mailings and the help of my engineering assistant, Edmond Dusablon, for all his telephoning, proofreading, and critical comments are recognized with my sincere appreciation.

*Glenn C. Grimes*

Chairman and Editor,  
10th Symposium on Composite Materials:  
Testing and Design

# Contents

<b>Overview</b>	1
<b>KEYNOTE ADDRESS</b>	
<b>Reflections on the Development of Test Methods for Advanced Composites— JAMES M. WHITNEY</b>	7
<b>SESSION I COMPRESSION TEST METHODOLOGY ANALYSIS AND DEVELOPMENT PAUL A. LAGACE, CHAIRMAN</b>	
<b>Overview</b>	19
<b>The Influence of Fiber Waviness on the Compressive Behavior of Unidirectional Continuous Fiber Composites—ALTON L. HIGHSMITH, JOHN J. DAVIS, AND KAYLEEN L. E. HELMS</b>	20
<b>Open Hole and Postimpact Compressive Fatigue of Stitched and Unstitched Carbon-Epoxy Composites—MARC A. PORTANOVA, CLARENCE C. POE, AND JOHN D. WHITCOMB</b>	37
<b>A Method for Evaluating the High Strain Rate Compressive Properties of Composite Materials—DENISE M. MONTIEL AND CAROL J. WILLIAMS</b>	54
<b>SESSION II GENERAL TEST METHODOLOGY ANALYSIS AND DEVELOPMENT MICHAEL G. CASTELLI, CHAIRMAN</b>	
<b>Overview</b>	69
<b>Thermomechanical Testing of High-Temperature Composites: Thermomechanical Fatigue (TMF) Behavior of SiC(SCS-6)/Ti-15-3—MICHAEL G. CASTELLI, PAUL BARTOLOTTA, AND JOHN R. ELLIS</b>	70
<b>In-Plane Biaxial Compressive Deformation and Failure of E-Glass/Epoxy Laminates—SHIING-HWA DOONG, JAMES E. FAORO, AND DARRELL F. SOCIE</b>	87

<b>The Effect of Tab Orientation on the Distribution of Strains in Composite Specimens—</b> BRYAN C. FOOS, WILLIAM E. WOLFE, AND RAGHBIR S. SANDHU	103
--	-----

SESSION III  
MATERIAL MECHANICAL PROPERTIES AND FAILURE CRITERIA  
STEPHEN R. SWANSON, CHAIRMAN

<b>Overview</b>	117
<b>Characterization of IM7 Graphite/Thermoplastic Polyetheretherketone (PEEK) for Spacecraft Structural Applications—</b> EDWARD M. SILVERMAN, CHRIS R. WIACEK, AND RICHARD A. GRIESE	118
<b>Hot/Wet Testing of Celion 3000/PMR-15 Coupon Specimens—</b> ELIZABETH BLOUNT KINMAN	131
<b>A Scientific Approach to Composite Laminate Strength Prediction—</b> L. J. HART-SMITH	142

SESSION IV  
ADVANCED MATERIALS ANALYSIS AND TEST  
ROBERT B. CROMAN, CHAIRMAN

<b>Overview</b>	173
<b>Characterization of Unnotched SCS-6/Ti-15-3 Metal Matrix Composites at 650°—</b> WILLIAM D. POLLOCK AND W. STEVEN JOHNSON	175
<b>High-Temperature Fatigue Behavior of a SiC/Ti-24Al-11Nb Composite—</b> PAUL A. BARTOLOTTA AND PAMELA K. BRINDLEY	192
<b>Deformation and Failure of Longitudinally Loaded Brittle-Matrix Composites—</b> J.-W. LEE AND I. M. DANIEL	204
<b>A Macro-Micromechanics Analysis of a Notched Metal Matrix Composite—</b> CATHERINE A. BIGELOW AND RAJIV A. NAIK	222

SESSION V  
ANALYSIS, TEST, AND CERTIFICATION OF STRUCTURE  
THOMAS J. DUNYAK, CHAIRMAN

<b>Overview</b>	237
<b>Analysis and Test Techniques for Composite Structures Subjected to Out-of-Plane Loads—</b> PHILIP C. PAUL, CHARLES R. SAFF, KENNETH B. SANGER, MARY A. MAHLER, HAN-PIN KAN, AND EDWARD F. KAUTZ	238
<b>Analysis and Testing of a Composite Sandwich Shell Horizontal Tail—</b> MARK A. SHERROUSE AND JOHN C. McWHORTER, III	253

<b>Composite Material Stub-Blade Wing Joint—</b> WALTER M. FRANKLIN AND BRYAN W. KREIMENDAHL	264
<b>Temperature and Load Cycling of a Thick Polyimide Quartz Laminate—</b> RENE E. LAURENCOT AND LAURA M. KEEN	279

SESSION VI  
QUALITY ASSURANCE AND PROCESS CONTROL  
KARL V. STEINER, CHAIRMAN

<b>Overview</b>	291
<b>Effects of Processing Variables on the Quality of Co-Cured Sandwich Panels—</b> PIERRE JOUIN, DAVID POLLOCK, AND ED RUDISILL	293
<b>An Evaluation of the Current Status of Automated Process Control for Thermosetting Composites—</b> MICHAEL W. HOLL AND LAWRENCE W. REHFELD	308
<b>Analysis of Composite Material Containing Defects—</b> ROBERT S. FRANKLE, DONALD R. JONES, BARON L. ROBERTS, AND LISA M. SHUSTO	320
<b>Image Enhancement Techniques for Ultrasonic NDE Applications—</b> KARL V. STEINER	330

SESSION VII  
INTERLAMINAR FRACTURE ANALYSIS AND TEST  
T. KEVIN O'BRIEN, CHAIRMAN

<b>Overview</b>	347
<b>Free-Edge Stress Analysis of Glass-Epoxy Laminates with Matrix Cracks—</b> JOHN C. FISH AND T. KEVIN O'BRIEN	348
<b>Delamination Failure in a Unidirectional Curved Composite Laminate—</b> RODERICK H. MARTIN	365
<b>Efficient Use of Film Adhesive Interlayers to Suppress Delamination—</b> PAUL A. LAGACE AND NARENDRA V. BHAT	384

SESSION VIII  
DAMAGE, FLAWS, AND REPAIR  
SUSAN S. AVERY, CHAIRMAN

<b>Overview</b>	399
<b>Damage Tolerance of Three-Dimensional Commingled PEEK/Carbon Composites—</b> CAM T. HUA, JIA-NI CHU, AND FRANK K. KO	400



<b>Damage Accumulation and Fracture of Notched Composite Laminates Under Tensile and Compressive Loading—SENG C. TAN AND RAN Y. KIM</b>	414
<b>Advances in Thermographic Stress Analysis and Evaluation of Damage in Composites—DAQING ZHANG AND BELA I. SANDOR</b>	428
<b>Stress Field Sensitivity of a Composite Patch Repair as a Result of Varying Patch Thickness—MICHAEL P. SIENER</b>	444
<b>Index</b>	465

ISBN 0-8031-1426-5