



TOUGHENED **COMPOSITES**

Norman J. Johnston, editor



STP 937

TOUGHENED COMPOSITES

Symposium on Toughened Composites
sponsored by
ASTM Committee D-30
on High Modulus Fibers
and Their Composites
Houston, Texas, 13-15 March 1985
in cooperation with
NASA-Langley Research Center

ASTM SPECIAL TECHNICAL PUBLICATION 937
Norman J. Johnston, NASA-Langley
Research Center, editor

ASTM Publication Code Number (PCN)
04-937000-33



1916 Race Street, Philadelphia, PA 19103

Library of Congress Cataloging-in-Publication Data

Symposium on Toughened Composites (1985: Houston, Tex.)
Toughened composites.

(ASTM special technical publication; 937)

"ASTM publication code number (PCN) 04-937000-33."

Includes bibliographies and index.

1. Composite materials—Congresses. I. Johnston, Norman J. (Norman Joseph),
1934–. II. ASTM Committee D-30 on High Modulus Fibers and Their Composites.
III. Title. IV. Series.

TA418.9.C6S94 1985 620.1'18 87-1387

ISBN 0-8031-0934-2

Copyright © by American Society for Testing and Materials 1987
Library of Congress Catalog Card Number: 87-1387/

NOTE

The Society is not responsible, as a body,
for the statements and opinions
advanced in this publication.

Foreword

The Symposium on Toughened Composites was held in Houston, Texas, on 13-15 March 1985. ASTM Committee D-30 on High Modulus Fibers and Their Composites was sponsor in cooperation with NASA-Langley Research Center. Norman J. Johnston, NASA-Langley Research Center, served as symposium chairman and has edited this publication.

Related ASTM Publications

Composite Materials: Fatigue and Fracture, STP 907 (1986),
04-907000-33

Elastic-Plastic Fracture Mechanics Technology, STP 896, (1985),
04-896000-30

High Modulus Fiber Composites in Ground Transportation and
High Volume Applications, STP 873 (1985), 04-873000-33

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.

ASTM Committee on Publications

ASTM Editorial Staff

Kathleen A. Peters
Janet R. Schroeder
Kathleen A. Greene
Bill Benzing

Contents

Overview	1
TOUGHENED COMPOSITES: PROSPECTIVES FROM INDUSTRY	
Toughened Composites Selection Criteria — CLIFFORD Y. KAM AND JEFF V. WALKER	9
Damage Tolerance of Toughened Resin Graphite Composites — CHARLES F. GRIFFIN	23
MICROMECHANICS	
The Effect of Resin Toughness and Modulus on Compressive Failure Modes of Quasi-Isotropic Graphite/Epoxy Laminates — MOHSEN M. SOHI, H. THOMAS HAHN, AND JERRY G. WILLIAMS	37
A Comparison of Several Mechanical Tests Used To Evaluate the Toughness of Composites — KEVIN R. HIRSCHBUEHLER	61
Discussion	73
Matrix Resin Effects in Composite Delamination: Mode I Fracture Aspects — DONALD L. HUNSTON, RICHARD J. MOULTON, NORMAN J. JOHNSTON, AND WILLARD D. BASCOM	74
Discussion	93
Micromechanisms of Fracture in Toughened Graphite-Epoxy Laminates — WILLIAM M. JORDAN AND WALTER L. BRADLEY	95
Interlaminar Fracture Toughness and Real-Time Fracture Mechanism of Some Toughened Graphite/Epoxy Composites — MIKE F. HIBBS, MING KWAN TSE, AND WALTER L. BRADLEY	115
Fractographic Analysis of Interlaminar Fracture — WILLARD D. BASCOM, D. J. BOLL, D. L. HUNSTON, BRET FULLER, AND P. J. PHILLIPS	131

Effect of Fiber Coatings on Interlaminar Fracture Toughness of Composites — HERBERT S. SCHWARTZ AND JOHN TIMOTHY HARTNESS	150
Surface Energy Measurements of Graphite and Glass Filaments — MARK WEINBERG	166
Axisymmetric Stress Distribution Around an Isolated Fiber Fragment — JAMES M. WHITNEY AND LAWRENCE T. DRZAL	179

INTERLAMINAR FRACTURE

Comparisons of Various Configurations of the Edge Delamination Test for Interlaminar Fracture Toughness — T. KEVIN O'BRIEN, NORMAN J. JOHNSTON, IVATURY S. RAJU, DON H. MORRIS, AND ROBERT A. SIMONDS	199
The Characterization of Edge Delamination Growth in Laminates Under Fatigue Loading — ANOUSH POURSAARTIP	222
Frequency and Load Ratio Effects on Critical Strain Energy Release Rate G_c Thresholds of Graphite/Epoxy Composites — DONALD F. ADAMS, RICHARD S. ZIMMERMAN, AND EDWIN M. ODOM	242
Rate Effects on Delamination Fracture Toughness of a Toughened Graphite/Epoxy — ISAAC M. DANIEL, IQBAL SHAREEF, AND ABDU A. ALIYU	260
The Effect of Matrix Toughness on Delamination: Static and Fatigue Fracture Under Mode II Shear Loading of Graphite Fiber Composites — ALAN J. RUSSELL AND KEN N. STREET	275
Discussion	293
Influence of the Resin on Interlaminar Mixed-Mode Fracture — W. S. JOHNSON AND P. D. MANGALGIRI	295

THERMOPLASTICS

Ryton®-PPS Carbon Fiber Reinforced Composites: The How, When, and Why of Molding — WILLIAM H. BEEVER, CHARLES L. RYAN, JAMES E. O'CONNOR, AND ALEX Y. LOU	319
--	-----

The Development of Residual Thermal Stresses in Amorphous and Semicrystalline Thermoplastic Matrix Composites—	
JOHN A. NAIRN AND PAUL ZOLLER	328
Mechanical Properties and Morphology of Poly(etheretherketone)—	
PEGGY CEBE, SU-DON HONG, SHIRLEY CHUNG, AND AMITAVA GUPTA	342
Delamination Behavior of Carbon Fiber/Poly(etheretherketone) (PEEK) Composites—	
DAVID C. LEACH, DON C. CURTIS, AND DAVID R. TAMBLIN	358
THERMOSETS	
Modifying Matrix Materials for Tougher Composites—	
F. YEE	383
Discussion	395
Structural Property Improvements Through Hybridized Composites—	
RAMON GARCIA, ROBERT E. EVANS, AND RAYMOND J. PALMER	397
A New Generation of Epoxy Composites for Primary Structural Applications: Materials and Mechanics—	
ROBERT E. EVANS AND JOHN E. MASTERS	413
Discussion	435
Screening of Advanced Matrix Resin Systems for Use in High Performance Aircraft—	
ROBERT H. BOSCHAN, YUJI A. TAJIMA, GUSTAF A. FORSBERG, GLEN HULL, AND JAN HARPER-TERVET	437
A Dicyanate Semi-Interpenetrating Polymer Network (SIPN) Matrix Composite—	
JOHN T. HARTNESS	453
Index	463



ISBN 0-8031-0934-2