Composites Contents

Listing of current literature of interest to the composite community as a service to our readers.

Introduction

In this section, the relevant portions of the tables of contents of current journals which publish composites articles will be reproduced. The entire tables of contents will be reproduced for dedicated composites journals, but in order to conserve space and reduce printing costs, only the composites-related contents of non-dedicated journals will be reproduced. At this time, permission to reproduce the tables of contents has been granted by the following journals:

- AIAA Journal
- Composite Science and Technology
- Composite Structures
- Composites
- Computers and Structures
- Engineering Fracture Mechanics
- Experimental Mechanics
- Experimental Techniques
- International Journal of Analytical and Experimental Model Analysis
- International Journal of Cement Composites
- International Journal of Fracture
- International Journal of Solids and Structures
- Journal of Adhesion
- Journal of Applied Mechanics
- Journal of Composite Materials
- Journal of Engineering Materials and Technology
- Journal of Materials Science
- Journal of Reinforced Plastics and Composites
- Journal of Sound and Vibration
- Journal of Testing and Evaluation
- Mechanics of Composite Materials
- Polymer Composites
- SAMPE Journal
- SAMPE Quarterly
- Shock and Vibration Digest

The Editor welcomes suggestions for improvements to "Composites Contents," although library acquisition and accessibility may prevent some additions to the list of journals surveyed.

Dr. Ronald F. Gibson, *Contents Editor*
Advanced Composites Research Laboratory
Department of Mechanical Engineering
Wayne State University
Detroit, MI 48202

AIAA Journal

Vol. 27, No. 12, Dec. 1989

Vol. 28, No. 1, Jan. 1990

Vol. 28, No. 2, Feb. 1990

Vol. 28, No. 3, March 1990

Vol. 28, No. 5, May 1990

Composite Structures

Vol. 13, No. 3, 1989

Vol. 13, No. 4, 1989

Vol. 14, No. 1, 1990

Vol. 14, No. 2, 1990

Vol. 14, No. 3, 1990

Vol. 14, No. 4, 1990

Composites

Vol. 21, No. 1, Jan. 1990

Vol. 21, No. 2, March 1990

Composites Science and Technology

Vol. 36, No. 4, 1989

Vol. 37, No. 1 to 3, 1990

Vol. 37, No. 4, 1990

Vol. 38, No. 1, 1990

Amination of Ultra-High Strength Polytehylene using Ammonia Plasma—S. Holmes and P. Schwartz, pp. 1–22

A Model for Stress Corrosion Crack Growth in Glass Reinforced Plastics—P. J. Hogg, pp. 23–42

Strength Loss in Composites from Lateral Contact Loads—S. R. Swanson and H. G. Rezaee, pp. 43–54

Effect of Residual Shear Strain on the Cured Shape of Unsymmetric Cross-Ply Thin Laminates—W. J. Jun and C. S. Hong, pp. 55–68

Strength of Ceramic Matrix-Metal Fibre Composites—V. I. Kazmin, S. T. Mileiko and V. V. Tvardovsky, pp. 69–84

Poisson's Ratio as a Damage Parameter in the Static Tensile Loading of Simple Crossply Laminates—P. A. Smith, and J. R. Wood, pp. 85–94

Vol. 38, No. 2, 1990

Accelerated Characterization of Creep Response of an Off-Axis Composite Material—S.-C. Yen and F. L. Williamson, pp. 103–118

Impact Perforation of Carbon Fibre Reinforced Plastic—W. J. Cantwell and J. Morton, pp. 119–142

Effects of a 90° Ply on Matrix Cracks and Edge Delamination in Composite Laminates—W. S. Chan and A. S. D. Wang, pp. 143–158

Microbuckling Compression Failure of a Radiation-Induced Wood/Polymer Composite—F. Y. C. Boey, pp. 159–174

Fracture Toughness of Unidirectional Short-Fiber Reinforced Epoxy Composites—K. Nikpur, Y. F. Chen and J. L. Kardos, pp. 175–192

Vol. 38, No. 3, 1990

A Model of Transverse Thermal Conductivity in Unidirectional Fibre-Reinforced Composites—S. M. Gove, pp. 199–210

Glass/Nylon-6.6 Composites: Delamination Resistance Testing—P. Davies and D. R. Moore, pp. 211–228

An Analytical Model for the Elastic Properties of Fibrous Composites with Anisotropic Constituents—W.-C. Zhang and K. E. Evans, pp. 229–246

Thermo-Elastic Model for Multidirectional Coated-Fiber Composites: Traction Formulation—N. J. Pagano and G. P. Tandon, pp. 247–270

Fibre/Matrix Load Transfer in Thermoset and Thermoplastic Composites - Single Fibre Models and Hole Sensitivity of Laminates—P. Vautey and J.-P. Favre, pp. 271–288

Computers and Structures

Vol. 33, No. 4, 1989

Stress Analysis Around Circular Holes in FRP Laminates Under Transverse Load—T. K. Paul and K. M. Rao, pp. 929–938

An Interface Continuous Stress Penalty Formulation for the Finite Element Analysis of Composite Media—A. Shirazi-Adl, pp. 951–956

Vol. 33, No. 5, 1989

Nonlinear Dynamic Damped Response of an Orthotropic Circular Plate—G. Chandrasekharappa and H. R. Srirangarajan, pp. 1163–1166

Higher-Order Theories for Composite and Sandwich Cylindrical Shells with C° Finite Element—T. Kant and M. P. Menon, pp. 1191–1204

p-Approximation Axisymmetric Shell Elements for Heat Conduction in Laminated Composites—K. S. Surana and N. J. Orth, pp. 1251–1266

A Three-Dimensional Finite Strain Constitutive Theory for Elastomer Composites—D. Fritzson, pp. 1267–1288

Vol. 33, No. 6, 1989

Dynamic Stability Analysis of a Composite Material Planar Mechanism by the Finite Element Method—L.-W. Chen and D.-M. Ku, pp. 1333–1342

Optimum Design of Honeycomb Sandwich Constructions with Buckling Constraints—Y. Ding, pp. 1355–1364

Free Vibration Analysis of Orthotropic Plates by the Initial Value Method—H. Al-Khaiat, pp. 1431–1436

Compromise: An Effective Approach for the Design of Pressure Vessels Using Composite Materials—H. Karandikar, R. Srinivasan, F. Mistree and W. J. Fuchs, pp. 1465–1478

Optimum Design of Structures Composed of Metal and Composite Materials—Y. Ding, J. Yu and B. Xiong, pp. 1479–1494

Vol. 34, No. 1, 1990

Solution of Orthotropic Plates Based on p-Extension of the Hybrid-Trefftz Finite Element Model—J. Jirousek and M. N'Diaye, pp. 51–62

Thermal Buckling Analysis of Laminated Cylindrical Plates by the Finite Element Method—L.-W. Chen and L.-Y. Chen, pp. 71–78

Vol. 34, No. 2, 1990

Free Vibrations of Rectangular Orthotropic Plates with a Pair of Parallel Edges Simply Supported—G. Jayaraman, P. Chen and V. W. Snyder, pp. 203–214

Estimation of Mechanical Parameter Values of Composites with the Use of Finite Element and System Identification Techniques—W. M. G. Courage, P. J. G. Schreurs and J. D. Janssen, pp. 231–238

A General Solution of the Orthotropic Continuous Rectangular Plate—H. Dao-an, pp. 273–280

Vol. 34, No. 3, 1990

Study of the Behavior of a Composite Multi-Bolt Joint—L. Yang and L. Y. Ye, pp. 493–498

Vol. 34, No. 4, 1990

Optimal Design of Sandwich Beams—N. Paydar and G.-J. Park, pp. 523–526

International Journal of Solids and Structures

Vol. 25, No. 12, 1989

Vol. 26, No. 1, 1990

Vol. 26, No. 2, 1990

Vol. 26, No. 3, 1990

Vol. 26, No. 4, 1990

Vol. 26, No. 5 and 6, 1990

Vol. 26, No. 7, 1990

The Journal of Adhesion

Vol. 30, No. 1–4, 1989

Vol. 31, No. 1, 1989

Journal of Applied Mechanics

Vol. 56, No. 4, Dec. 1989

Journal of Composite Materials

Vol. 24, No. 1, Jan. 1990

Vol. 24, No. 2, Feb. 1990

Vol. 24, No. 3, March 1990

Journal of Engineering Materials and Technology

Journal of Materials Science

Vol. 25, No. 2A, Feb. 1990

Vol. 25, No. 2B, Feb. 1990

Vol. 25, No. 3, March 1990

Vol. 25, No. 4, April 1990

Journal of Reinforced Plastics and Composites

Vol. 9, No. 1, Jan. 1990

Effects of Coating Treatments on the Mechanical Behavior of Wood Fiber-Filled Polystyrene Composites. II. Use of Inorganic Salt/Polyvinyl Chloride and Isocyanate as Coating Components—D. Maldas and B. V. Kokta, pp. 2–12

The Nonlinear Behavior of Unidirectional and Laminated Composites - A Micromechanical Approach—J. Aboudi, pp. 13–32

Determination of Interlaminar Stresses in Composite Laminates under Combined Loads—C. Kassapoglou, pp. 33–58

Delamination Resistance in Stitched and Unstitched Composite Plates Subjected to Impact Loading—D. Liu, pp. 59–69

Properties and Formability of an Aligned Discontinuous Fiber Thermoplastic Composite Sheet—R. K. Okine, D. H. Edison and N. K. Little, pp. 70–90

Fracture Mechanics of Unidirectional Composites—J. A. Nairn, p. 91

Vol. 9, No. 2, March 1990

Simulation of Matrix Cracks in Composite Laminates Containing a Small Hole—E. S. Reddy, A. S. D. Wang and Y. Zhong, pp. 104–117

Deflection of Thin-Walled Fiber-Reinforced Composite Beams—L. C. Bank and P. J. Bednarczyk, pp. 118–126

Tensile Stress Acoustic Constants of Unidirectional Graphite/Epoxy Composites—W. H. Prosser, pp. 127–133

Three-Dimensional Simulation of Crack Growth in Notched Laminates—A. S. D. Wang, E. S. Reddy and Y. Zhong, pp. 134–150

Development and Characterization of Controlled Interphase Composites (CIC) Materials for Damage Tolerant Applications—R. S. Raghava, pp. 151–161

Characterization of the Nonlinear Elastic Properties of Graphite/Epoxy Composites Using Ultrasound—W. H. Prosser and R. E. Green, Jr., pp. 162–173

A Fracture Mechanics Approach to Interlaminar Failure of Unidirectionally Reinforced Composites—I. Palley, pp. 174–181

An Experimental Comparison of Standard Test Methods for the Determination of Tensile, Compressive and Flexural Properties of "Kevlar" Fibre/Epoxy Laminates—G. Rueda, F. L. Matthews and E. W. Godwin, pp. 182–193

Weldlines in Injection Molded Polypropylene: Effect of Filler Shape—B. Sanschagrin, R. Gauvin, B. Fisa and T. Vu-Khanh, p. 194

Journal of Sound and Vibration

Vol. 136, No. 2, Jan. 1990

On the Strength of a Composite Beam—S. Suzuki, pp. 315–322

Vol. 136, No. 3, Feb. 1990

Natural Frequencies of Cross-Ply Laminates by State Space Approach—S. Chandrashekara and U. Santhosh, pp. 413–424

Vol. 138, No. 1, April 1990

Dynamic Response of Composites with Coulomb Frictional Slippage Between the Phases—J. Aboudi, pp. 35–46

Journal of Testing and Evaluation

Vol. 18, No. 3, May 1990

A Method for Uniform Shear Stress-Strain Analysis of Adhesives—G. W. Wycherley, S. A. Mestan, and I. Grabovac, pp. 203–209

Mechanics of Composite Materials

Vol. 24, No. 6, Nov.-Dec. 1988

Stress Relaxation in Polymeric Materials Under Hydrostatic Pressure—A. Y. Gol'dman, N. P. Demenchuk, and G. K. Murzakhanov, pp. 707–714

Experimental Study of the Elastic and Strength Properties of EDT-10 Epoxy Binder in Conditions of a Complex Stressed State—A. O. Udris and Z. T. Upitis, pp. 715–720

Heat Effects and the Mechanism of Inelastic Deformation of Organic Glassy Polymers—O. B. Salamatina, S. I. Nazarenko, S. N. Rudnev, and E. F. Oleinik, pp. 721–725

Shear Stiffness of Cellular Fillers Made of Corrugated Strip—V. I. Afanasenko, pp. 726–730

Effect of the Nature of the Surface of the Substrate on the Structure and Crack Resistance of Elasticized Adhesives—E. B. Trostyanskaya, A. S. Grabil'nikov, and G. V. Komarov, pp. 731–735

Parameters of Failure of Adhesive Joints in Symmetric Peeling—V. I. Pavlov and V. D. Galich, pp. 736–740

Study of Deformation Characteristics of Interfacial Layer in Organocomposites—A. I. Efremova, L. I. Kuzub, V. M. Lazorenko, V. M. Irzhak and N. I. Shut, pp. 741–745

Computer Simulation of the Fluctuation Initiation of Slipping in a System of Two Weakly Coupled Anharmonic Chains of Atoms—A. I. Mel'ker, A. V. Ivanov, and S. V. Govorov, pp. 746–750

Several Aspects of Determination of the Adequate Model of the Structure of Oriented Fiber-Reinforced Composites—A. E. Kolosov and V. V. Klyavlin, pp. 751–757

Composites Reinforced along the Cube Diagonals. 2. Coefficients of Linear Thermal Expansion—Y. M. Tarnopol'skii, V. A. Polyakov and I. G. Zhigun, pp. 758–764

Viscoelastic Properties of Gradient Interpenetrating Polymer Networks—Y. S. Lipatov, L. M. Sergeeva, L. V. Karabanova, V. F. Rosovitskii, L. A. Gorbach and N. V. Babkina, pp. 765–770

Two-Parameter Model of the Failure of Adhesive Joints—V. L. Pelekh and O. S. Machuga, pp. 771–775

Effect of Elastic Filler on the Fatigue Failure of Thermoplastic Polyurethane Film at Low Temperature—I. V. Grishetskii, V. M. Parfeev, T. A. Erykalova and E. Y. Borisova, pp. 776–781

Effect of Alternating Thermocycling and Humidity on the Strength of Wound Glass-Fiber and Organic-Fiber Plastics—V. N. Bulmanis, N. S. Popov, T. A. Starzhenetskaya, S. A. Kuz'min, G. I. Milyutin and V. I. Polyakov, pp. 782–788

Vol. 25, No. 1, Jan.-Feb. 1989.

Vol. 25, No. 2, Mar.-April 1989

Polymer Composites

Vol. 10, No. 6, Dec. 1989

Sampe Journal

World of Composites

News articles and announcements of interest to the composites technical community

ASTM COMPOSITE ACTIVITIES

Committee D-30 on High Modulus Fibers and Their Composites Awards

Committee D-30 on High Modulus Fibers and Their Composites recently recognized several individuals for their outstanding technical and leadership contributions to ASTM. Chairman Ron Zabora presided over the awards ceremony which was held during the Committee's Spring meeting in San Francisco.

Distinguished Service Awards were presented to three individuals in recognition of their dedicated service to Committee D-30 in leadership positions at the committee and subcommittee levels. Recipients of these awards were:

Dr. Wayne W. Stinchcomb, Virginia Polytechnic Institute
"For Outstanding Leadership of Committee D-30 on High Modulus Fibers and Their Composites for the Years 1982–1988."

Dr. George Sendeckyj, Air Force Wright Research and Development Center
"For Outstanding Leadership of Subcommittee D30.02 on Research and Mechanics Through 1988."

Mr. Dale Wilson, BASF Structural Materials Inc.
"For Outstanding Leadership of Subcommittee D30.03 on Automotive and Industrial Composites for the Years 1982 to 1988."

Certificates of Appreciation were also presented to a number of individuals in recognition of their service to the Committee. Awards were presented to:

Mr. Dale Wilson
BASF Structural Materials Inc.
"For Organizing and Chairing the Symposium *High Modulus Fiber Composites in Ground Transportation and High Volume Applications* and Editing the Resulting Special Technical Publication (STP 873) in a Professional and Timely Fashion."

Dr. W. Steven Johnson
NASA Langley Research Center
"For Organizing and Chairing the Symposium *Delamination and Debonding of Materials* and Editing the Resulting Special Technical Publication (STP 876) in a Professional and Timely Fashion."

Dr. James M. Whitney
Wright Research and Development Center
"For Organizing and Chairing the Seventh Conference on *Composite Materials: Testing and Design* and Editing the Resulting Special Technical Publication (STP 893) in a Professional and Timely Fashion."

Dr. H. Thomas Hahn
Penn State University
"For Organizing and Chairing the First Symposium on *Composite Materials: Fatigue and Fracture* and Editing the Resulting Special Technical Publication (STP 907) in a Professional and Timely Fashion."

Dr. Norman J. Johnston
NASA Langley Research Center
"For Organizing and Chairing the Symposium *Toughened Composites* and Editing the Resulting Special Technical Publication (STP 937) in a Professional and Timely Fashion."

Dr. John E. Masters
American Cyanamid Co.
"For Organizing and Chairing the Symposium *Fractography of Modern Engineering Materials: Composites and Metals* and Editing the Resulting Special Technical Publication (STP 948) in a Professional and Timely Fashion."

Dr. Paul Alfred Lagace
M.I.T.
"For Organizing and Chairing the Second Symposium on *Composite Materials: Fatigue and Fracture* and Editing the Resulting Special Technical Publication (STP 1012) in a Professional and Timely Fashion."

Dr. Kenneth L. Reifsnider
Virginia Tech
"For Outstanding Leadership in Serving as a Co-Editor of the ASTM Journal *Composites Technology Review* from Its Conception in 1978 Until 1988."

Special Technical Publications

The proceedings of two symposia sponsored by Committee D-30 have been published as Special Technical Publications by ASTM in the past year. Overviews and summaries of these volumes are reprinted here.

Composite Materials: Testing and Design (Ninth Symposium), ASTM STP 1059

Samuel P. Garbo, Editor

Overview

The Ninth Symposium on Composite Materials: Testing and Design, upon which this publication is based, was held 27–29 April 1988 in Sparks, Nevada. The symposium was sponsored by ASTM Committee D-30 on High-Modulus Fibers and Their Composites. The focus of the symposium was on significant advances in the area of damage tolerance and durability of composite structures; however, as was true for the previous eight symposia in this series, sufficient theme freedom was permitted to allow papers on other testing and design issues. This Special Technical Publication is based upon that symposium.

Before beginning an overview of the particular papers, the Editor wishes to point out a number of background subthemes which permeated the presentations and discussions at the conference and which are found in these papers. These subthemes provide an additional context for evaluating the contributions in this volume.

One subtheme is associated with the fast-paced (historically unprecedented) development of composite material systems, material forms, and manufacturing processes which has paralleled the expanding use of high-modulus composite materials in commercial and military structural applications. The driving catalysts have been the need to increase structural efficiency markedly and the need to lower dramatically the cost per pound of manufactured composite structures. The advantage of these trends is that the composite structural designer now has virtually unlimited design options. However, there is growing concern as to whether structural designers and analysts (or certifying agencies) can cope with this still-expanding list of composite design options while maintaining historically expected levels of structural integrity and reliability.

This concern is further exacerbated by recent trends in certifying agency requirements and in commercial and military design specifications which require unprecedented and guaranteed levels of structural integrity, efficiency, reliability, maintainability, and durability. Traditional conservative elements of design have been dramatically reduced at the same time that design variables and mechanical behavior phenomena have increased or changed markedly. Thus, corollary concerns are whether traditional, hardware-program, design-development philosophies and schedules are still technically adequate, even for conventional metallic structures, and whether they represent an appropriate basis for assessing business risks when dealing with the development of new composite structures.

A second subtheme is that some of the difficiencies in hardware design, testing, and analysis and some of the structural issues of the past 20 years are still with us today. As composite applications have expanded, the need for mechanics-based studies to provide generic understanding of old, as well as new, application structural failure phenomena have expanded with it.

One implication might be that industry will simply increase experimental evaluations in what is referred to as the "building-block" design development approach. However, the reality of the composite technology revolution is that the number of design options (variables) potentially available precludes a predominately experimental approach. The development and verification of mechanics-based analytic models *must significantly expand* to provide the insight needed for properly defined and fully integrated experimental verifications.

Finally, general application discussions in this volume may provide some researchers with a perhaps disturbing awareness of how *overgeneralized* some of their originally *limited* models have become in usage. The counterpoint to this is the awareness that industries (and universities) bear a responsibility to discipline engineers to evaluate not only the mathematical manipulations of structural analysis procedures but also the mechanics-based limitations of foundation assumptions.

With these subthemes in mind, the Editor has chosen to divide the papers of this publication into four subject areas: structural considerations and analysis, delamination initiation and growth analysis, damage mechanisms and test procedures, and other test and design subjects.

Structural Considerations and Analysis

The first category of papers, on structural considerations and analysis, focuses on global structural considerations related to application hardware issues. The eight papers selected cover topics ranging from overall structural qualifications or certification to the adequacy of generic material characterization data in laminate structural analysis. The main feature of this grouping of papers is that the authors are addressing composite *structural* issues, not solely composite material issues. The authors convey a common message that additional mechanistic studies are required to provide a more generic understanding of these application structural issues.

Two papers provide overviews of the current and evolving philosophies regarding the damage tolerance, durability, and qualification or certification of aircraft composite structures. Composite structure delamination-onset and fail-safety procedures are proposed using fracture mechanics, the strain energy release rate threshold criterion, and laminate analysis. Certification testing procedures are also reported which address the significant differences between metal and composite materials and propose approaches for qualification of metal and composite hybrid design concepts.

The issues of damage tolerance and durability and their implications at both the material and structural levels underlie most of the newly proposed procedures. Reported are aircraft industry requirements for increased building-block design development, experimental evaluations of structural coupons, elements, components, material configurations, environmental conditions, and loading interactions. This industry qualification trend emphasizes the large number of design options inherent in current aircraft composite structures and the lack of analytic models for accurately predicting the associated *structural* mechanical behavior. The number of design variables and structural unknowns continues to increase markedly with the growing number of new material systems, material forms, and novel fabrication procedures.

Four papers present experimental and analytic studies for evaluating the mechanical behavior of composite structural design concepts. These papers report on the extensive experimental efforts required to evaluate damage tolerance of structural hardware and the large number of design variables involved. Specific analytic models are proposed to evaluate the effects of low-velocity impact damage on the strength of laminates and stiffened composite panels and the effects of a variety of design variables on the strength of mechanically fastened composite joints.

The lamina-to-laminate analytic model for assessing the effect of impact damage is particularly appealing for industrial design usage because of its minimal input data requirements and general laminate and load condition capabilities. If verified, this model could provide industry with needed analytic insight into the effects of damage on part strength. This insight would permit development of *selective* verification test programs and reduce full-scale qualification test requirements.

While the six papers just described alert readers to new and evolving structural concerns, two other papers remind us that unresolved mechanics-based and strength prediction issues still exist. In particular, these papers question (1) the adequacy and industry acceptance of unidirectional-lamina, mechanical-property databases for use in structural analysis of fibrous composites and (2) the use of one-phase homogenous models of orthotropic lamina for strength predictions. These papers propose alternative characterization test procedures which are better suited to analysis of application laminate mechanical behavior, and a "pseudo-single-phase" strength model is also proposed which permits the fiber or resin phase to dominate, as appropriate, depending on the laminate application stress state.

Delamination Initiation and Growth Analysis

In the second category of papers, on delamination initiation and growth analysis, seven papers were selected which use fracture-mechanics-based strain energy release rates to characterize or predict delamination phenomena in composite materials or structures. The papers document studies concerning geometric or laminate-level effects on the magnitude of the strain energy release rates, the presence and extent of mixed-mode fracture, the adequacy of composite material fracture characterization test procedures, delamination initiation and the growth criterion, and the failure criterion. Results include theoretical correlations with test data obtained from various cracked lap shear, double-side-notched, double-cantilever beam, end-notched flexure, and adhesive joint specimens.

Damage Mechanisms and Test Procedures

In the third category of papers, on damage mechanisms and test procedures, six papers emphasize the continued need to assess our knowledge of basic failure characteristics and the adequacy of the test procedures used to provide generic characterization data. These studies report on experimental procedures used to evaluate the initiation and evolution of failure mechanisms in composite lamina and laminates under static and fatigue load cycles. New results are presented using vibrothermography, temperature measurement, and interrupted-ramp strain-input test techniques to evaluate time-dependent damage mechanisms, as well as to provide further insight into time-independent failure mechanisms.

Laminate and lamina test results of various material system configurations are reported which reveal significant differences in the damage mechanisms being observed in fiber-reinforced material systems that use toughened resin systems. The reported differences emphasize the need for long-term fatigue (>10 E + 5 cycles) evaluations in addition to typical static and short-term life assessments. While research continues, current and future application users are urged to perform both short-term and long-term mechanical property evaluations and to be alert for contradictory indications of property improvements, as well as time-dependent effects.

Other Test and Design Subjects

In the last category of papers, on other test and design subjects, some general interest design and analysis topics are reported. The topics include loading-rate effects, lamina-to-laminate viscoelastic predictions, the nonlinear energy failure criterion, the micromechanics of wavy fibers, torsional-test lamina characterization, and carbon-carbon interlaminar evaluations. The loading-rate and viscoelastic discussions reinforce earlier papers in reporting concerns that new toughened resin systems will require more intensive evlauation of time-dependent mechanical behavior.

In summary, the Editor feels that the papers in this Special Technical Publication indicate that the original conference goals of ASTM Committee D-30 were successfully met. As a most important comment, the Editor wishes gratefully to thank the authors who contributed their research to this conference and especially those who participated in the ardors of the ASTM review process. Important thanks are also directed to the many reviewers who volunteered their time to work with ASTM staff and the Editor to review the contributed papers critically and constructively. Finally, special thanks is expressed for the tireless and often unrewarded efforts and perseverance of ASTM staff, who brought the many facets of the book production to fruition. The combined efforts of all are appreciated sincerely.

Thermomechanical Behavior of Metal Matrix and Ceramic Matrix Composites, ASTM STP 1080

John M. Kennedy, Helen H. Moeller, and W. Steve Johnson, Editors

Overview

In the past twenty five years, Committee D-30 of ASTM has provided a major forum for promoting the transfer of information on advanced composite materials. Similarly, for the past thirty years, Committee E-24 has been involved in fracture testing, both developing standards and transferring information. This publication and the Symposium on Thermal and Mechanical Behavior of Ceramic and Metal Matrix Composites which was held in Atlanta, Georgia on 7–8 November 1989 were sponsored to continue these efforts. Twenty three papers were presented at the symposium, and this publication contains sixteen peer-reviewed articles on the subject.

As history has shown, the advancement of technology in many cases is limited by the availability and understanding of materials.

This is certainly true for today's technology. The government is currently supporting programs such as the National Aerospace Plane which will require new materials with thermal/mechanical operating conditions which are far beyond the capability of materials currently used in production of high-temperature components. To support this program and numerous others, industry and government are developing new material systems which can satisfy the material design requirements. In many cases, it appears that ceramic or metal matrix composites are the only viable material systems. Before these materials can be extensively used in DOD, NASA, and commercial systems, optimized cost effective material processes must be developed. In developing these processes and also after the materials are commercially available, extensive material characterization programs must be conducted to provide a database so that the end user of the material will have confidence in the performance of the material.

Developing test methods and generating design data for materials which will be used in thermomechanical environments is extremely expensive. High-temperature composite materials cost much more than homogenous materials or standard resin matrix composites. Equipment for testing at elevated temperature is highly specialized and very expensive. Specialized test methods must be developed which take into consideration thermal stresses, stress gradients, measurement capabilities, gripping methods and limited material quantities. It is therefore important that test methods be carefully developed and standardized so that accurate data are generated and duplication of test data is avoided in test programs.

The papers contained in this proceedings provide current results of research and development programs on ceramic and metal matrix composites. The papers are divided into four categories:

1. Analysis and Modeling
2. Behavior of Ceramic Matrix Composites
3. Behavior of Metal Matrix Composites
4. Test Methods

The sections include papers which address both continuous and discontinuous ceramic and metal matrix composites. The Analysis and Modeling section includes papers on plasticity analysis of composite laminates during thermomechanical loading, micromechanical stress analysis of continuous reinforced metal matrix composites, creep models for discontinuous and laminated metal matrix composites, and simulation of the cyclic behavior of metal matrix composites. The section on Behavior of Ceramic Matrix Composites includes papers on fracture of whisker reinforced ceramic composites, mechanical characterization of ceramic fibers, frictional stresses at the fiber/matrix interface of ceramic composites, and mechanical behavior of selected ceramic matrix composites. The papers in the section on Behavior of Metal Matrix Composites address mechanical and thermal behavior of continuous and discontinuous reinforced metal matrix composites. Experimental results were reported from static and fatigue tension test programs as well as fracture studies. Another paper presented an indentation test method to derive the optimal manufacturing process of metal matrix composites. The paper included in the section on Test Methods addressed specific test methods and experimental hardware which may be applied to either ceramic or metal matrix composites.

With this symposium and the resulting special technical publication, ASTM has made another stride forward by providing a wealth of information on ceramic and metal matrix composites which will assist the research and design community in better understanding the behavior of these materials. This information will also be invaluable as test methods are developed for ceramic and metal matrix composites.

Summary

Since 1984, ASTM Committee D-30 has aggressively promoted development of test methods for metal matrix composites and transfer of research results related to these materials. In November 1985 ASTM held a symposium on Testing Technology of Metal Matrix Composites in Nashville, Tennessee. The results of that symposium are now archived in *ASTM STP 964* which was edited by DiGiovanni and Adsit. At that symposium, task forces were formed to address test methods for metal matrix composites. At subsequent meetings workshops highlighting the activities of the task forces were held. The objectives of these meetings have been to provide leadership and a focal point for addressing test method development for metal and ceramic matrix composites and to act as a forum for presenting and debating results of research directed toward these materials.

Subcommittee E24.07 has recently been given the charter to focus on advanced materials including metal matrix and ceramic matrix composites. The primary emphasis is on fracture of these materials. Since 1987, E-24 and D-30 have been combining the composites technology of D-30 with the fracture knowledge of E-24 to study and understand composite materials.

During 1988 ASTM sponsored two symposia on metal and ceramic matrix composites as well as several workshops and task force meetings. The first symposia, Metal Matrix Composites: Testing, Analysis, and Failure Modes was held in Sparks, Nevada, on 25–26 April 1988. The symposia and the resulting special technical publication, *ASTM STP 1032* (editor: Johnson) were a comprehensive review of the state of the art in testing and analyzing continuous fiber reinforced metal matrix composites. Additional papers dealt with failure of these materials. The second symposia, Thermal and Mechanical Behavior of Ceramic and Metal Matrix Composites was held in Atlanta, Georgia, on 7–8 November 1988. The presentations and the collection of papers in this special technical publication, *ASTM STP 1080* are results of recent research and development programs for ceramic and metal matrix composites.

The papers in this special technical publication are a significant contribution to the development and understanding of the behavior of ceramic and metal matrix composites. Each of the papers in the four sections is briefly summarized in the following paragraphs with some perspective on the significance of the work.

Analysis and Modeling

"Local Stresses in Metal Matrix Composites Subjected to Thermal and Mechanical Loading" by Highsmith, Shin, and Naik—This paper developed a micromechanics model and presented results for the stress state at the fiber matrix interface due to thermal and mechanical loading. The results provide a clear understanding of the strength requirements necessary to maintain integrity at the interface.

"Plasticity Analysis of Fibrous Composite Laminates Under Thermomechanical Loads" by Bahei-El-Din—An elastic-plastic thermomechanical micromechanics analysis was developed which included temperature depended mechanical properties of the fiber and matrix.

"Thermomechanical, Time-Dependent Analysis of Layered Metal Matrix Composites" by Lee and Krempl—At elevated temperatures, inelastic deformations such as creep, relaxation, and rate sensitivity cannot be neglected. This paper proposes a modified laminated plate theory which includes time dependent effects.

"Computational Simulation of High-Temperature Metal Matrix Composites Cyclic Behavior" by Chamis, Murthy, and Hopkins—The authors have developed a numerical procedure to model the cyclic behavior of metal matrix composites and the associated degradation in material properties. The model accounts for the interphase. The results show that the combined thermomechanical cycling degrades the composite faster than superposition of the two individual effects. This model may be useful for predicting the useful life of metal matrix composites in thermomechanical environments.

"Effects of Environmental and Microstructural Variables on the Plastic Deformation of Metal Matrix Composites Under Changing Temperature Conditions" by Daehn—An elastic-plastic model for the deformation of aligned, whisker reinforced metal matrix composites is developed. This model shows that these materials will degrade during thermal cycling at stresses far below the yield strength of the composite.

"Analysis of a Ceramic Matrix Composite Flexure Specimen" by Dharani—A detailed stress analysis of the three- and four-point bend tests was conducted to predict the behavior of ceramic matrix composites with multiple cracks. The analysis shows that the stresses are substantially different than those predicted by beam theory. The analysis can also predict the failure mode.

Behavior of Ceramic Matrix Composites

"Toughness Models of Whisker Reinforced Ceramic Matrix Composites" by Chiang and Chou—Unlike homogeneous metals, whisker reinforced ceramic and metal matrix composites have anisotropic fracture properties. A model is presented to predict the critical strain energy release rate for ceramic matrix composites.

"Comparison of High-Temperature Tension Testing Results of Ceramic Fibers" by Rigdon and Hong—The authors have collected tensile strength and elastic property data for three different ceramic matrix composites and compared the results. Substantial differences in the test results were obtained for the different test methods utilized. The differences in results highlights the need for standard test methods for these materials to avoid variation in the test results due to differences in the test method.

"Comparison of Methods for Determining Fiber/Matrix Interface Frictional Stresses in Ceramic Matrix Composites" by Cranmer, Deshmukh, and Coyle—Fiber indentation tests and single fiber pull-out tests were conducted on two ceramic matrix composite material systems. The authors recommend the fiber indentation push-out test for characterizing the bonding between the fiber and the matrix.

"Monotonic and Cyclic Behavior of Silicon Carbide/Calcium-Aluminosilicate Ceramic Composite" by Rousseau—An experimental investigation at elevated and room temperature identified the basic elements of laminate response and damage due to monotonic and cyclic loading. Degradation in material properties was due to damage in off-axis plies and embrittlement of the fiber/matrix interface.

Behavior of Metal Matrix Composites

"Mechanical and Thermal Properties of Silicon-Carbide Particle-Reinforced Aluminum" by Schmidt, Zweben, and Arsenault—Particle reinforced aluminum is being considered as a replacement material for homogeneous metals in electronics packaging. An experimental program to determine key material properties showed that these materials are viable electronics packaging materials because of their low thermal coefficient of expansion, high thermal conductivity, and low density. However, the fracture toughness is low and limits the applications in fracture critical application.

"Temperature-Dependent Tensile and Shear Response of P100/6061 Graphite-Aluminum" by Fujita, Pindera, and Herakovich—Experiments were conducted to the elastic and strength properties in tension and shear. Elastic properties did not change appreciably over the temperature range at which tests were conducted. Strength properties changed substantially over the same range. However, the changes in strength properties did not follow that of the bulk aluminum. Evaluation of the thermal residual stresses explained the variation in the strength properties, in particular the yield strength.

"The Bonding Strength at the Fiber/Matrix Interface of Metal Matrix Composites" by Kim, Lee, and Jun—The fiber indentation test method was used to obtain the optimal manufacturing process parameters for continuous fiber reinforced metal matrix composites produced by squeeze casting. It was assumed that the fiber matrix interface is the critical element in producing a mechanically attractive composite. Using the fiber indentation test enabled the authors to determine an optimal manufacturing process map which can substantially reduce the time to determine the optimal manufacturing process.

"Mechanical Characterization of Unnotched SCS_6/Ti-15-3 Metal Matrix Composites at Room Temperature" by Johnson, Lubowinski, and Highsmith—Five laminates of silicon carbide reinforced titanium were tested in tension to characterize the elastic properties and the failure modes. Analytical models predicted the elastic properties and strengths accurately. Fatigue tests showed that most of the damage occurs in the first few cycles due to the low strength of the fiber/matrix interface.

"Fatigue Crack Growth in an Al_2O_3 Short Fiber Reinforced Al-2Mg Alloy" by Preston, Melander, Groth, and Blom—Fatigue crack growth experiments were conducted to determine the fundamental crack growth mechanisms. The initial damage was traced back to the manufacturing process. The small initial flaws linked up to form a dominant crack. Damage growth could be correlated using measurements of crack closure.

Test Methods

"Ceramics Tensile Grip" by Larsen—Alignment is critical when testing ceramic materials including ceramic composites. A new gripping technique for tensile testing ceramic is discussed. The grip is designed to differentiate bending due to alignment and bending due to test specimen eccentricities. The grip is capable of producing accurate results for brittle materials.

CALL FOR PAPERS

Symposium on High Temperature and Environmental Effects on Polymeric Composites

Papers are invited for a Symposium on High Temperature and Environmental Effects on Polymeric Composites sponsored by ASTM Committee D-30. The symposium will be held 15–16 Oct. 1991 in San Diego, California, in conjunction with the 15–17 Oct. 1991 standards development meetings of Committee D-30.

Previously unpublished papers are requested covering the effects of high temperature and other environmental effects on the behavior of fiber-reinforced polymeric composite materials, components, and structures. Topics of particular interest include:

- Physical and Chemical Aging
- Combined Effects
- Thermomechanical Fatigue
- Measurement Techniques
- Long-Term Durability
- Accelerated Test Methods
- Damage Mechanisms and Failure
- Constitutive Models
- Life Prediction Methodology

Prospective authors are requested to submit a title, a 300–500 word abstract, and the ASTM Paper Submittal Form below by 17 Dec. 1990 to Dorothy Savini, Symposia Operations, ASTM, 1916 Race St., Philadelphia, PA 19103-1187, telephone: 215/299-5413. Additional Paper Submittal Forms are available from Ms. Savini.

A Special Technical Publication (STP) based on the symposium proceedings is anticipated by ASTM. Main authors will receive a complimentary copy of the volume(s) containing their papers. The main author is the author corresponding with the ASTM publications staff. All published authors may purchase reprints of the papers at cost. Authors will be notified of their acceptance for presentation by 1 Feb. 1991 by the symposium chairmen.

Final manuscripts for the STP based on this symposium are due by 16 Aug. 1991. This deadline will be rigidly enforced. All papers not submitted to ASTM by this deadline may be forwarded to the appropriate ASTM journal to be considered for publication. Papers presented at the symposium will be included in the STP if they are approved through the ASTM peer-review process. ASTM may print and distribute accepted abstracts with the approval of the symposium chairman.

More information is available from Symposium Co-Chairmen Dr. Charles E. Harris or Dr. Thomas S. Gates, NASA Langley Research Center, Mail Stop 188E, Hampton, VA 23665-5225, telephone: 804/864-3449, FAX: 804/864-7729.

SUPPLIERS OF ADVANCED COMPOSITE MATERIALS ASSOCIATION

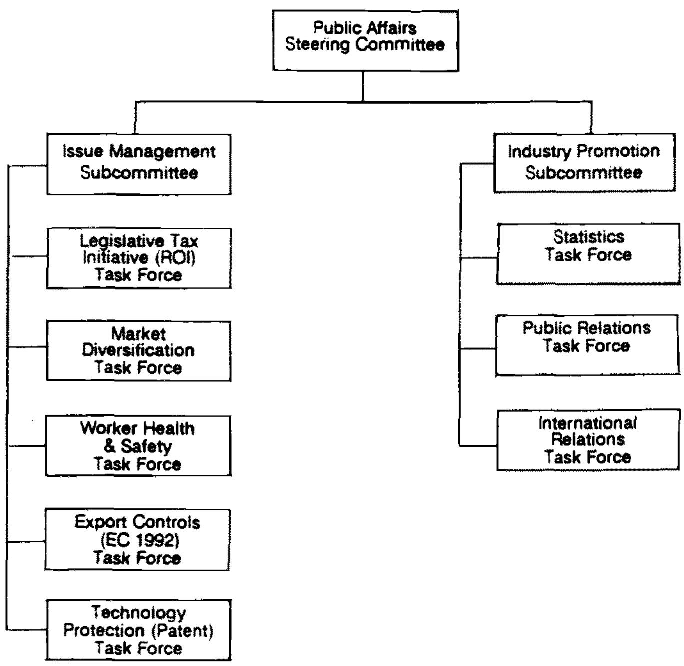
Public Affairs Steering Committee

The Suppliers of Advanced Composite Materials Association, commonly known as SACMA, is a nonprofit, international trade association of manufacturers that produce materials used in the construction of fiber-reinforced products as well as composite parts manufacturers and other interested organizations which provide ancillary support and service to the advanced composite materials industry.

In the Fall publication of this journal, a report on SACMA's Environmental, Health & Safety initiatives were highlighted. This column will focus on the organization (figure), objectives, and current activities of SACMA's Public Affairs Steering Committee.

SACMA's Public Affairs Steering Committee objectives are to:

- promote growth and improve profitability of advanced composites industry;
- promote value and increase understanding of advanced composites in public, private, and federal sectors;
- expand and diversify advanced composites market base; and
- provide industry forum to facilitate awareness of key issues affecting advanced composites.



Issue Management

Given the interplay between public sector policies and private sector competitiveness, SACMA recently formed an Issue Management Subcommittee to keep its members out in front and up to speed on relevant Congressional and Administrative initiatives. An integral component of their efforts will be to develop a greater awareness and better understanding of critical business issues confronting the advanced composites industry—prerequisites to informed decision making and sound national materials policies.

Based on member input, five areas were identified for in-depth examination and, where deemed appropriate, legislative redress. Specifically they are:

- export controls,
- legislative tex initiatives,
- worker health and safety,
- technology ownership, and
- market diversification.

Working groups have been formed and specific charges have been formulated in each of the aforementioned areas.

Industry Promotion

While price and performance are fundamental determinants in the commercial sales equation, public awareness and buyer perceptions also play a tangible role in market development. SACMA's Industry Promotion Subcommittee is working toward creating an image for advanced composites and building a knowledge bridge that conveys to target markets that advanced composite materials are user friendly and cost-effective. Specific activities include:

- Collection of worldwide statistical data on fiber and prepreg shipments. The program will be expanded to include matrix resin shipments in 1991.
- Publication of timely articles in trade journals on SACMA programs and industry initiatives.
- Formation of a proactive Speakers Bureau to address allied interest groups on SACMA activities and important industry concerns, for example, environmental, health, and safety.
- Sponsorship of briefings and conferences on issues of contemporary interest, for example, competitiveness, standardization, and so forth.
- Establishment of a mechanism to broadcast SACMA programs within other allied international organizations as well as to monitor worldwide events and allied organization initiatives which may impact on industry.

In summary, this is what SACMA has done or plans to do in the public affairs arena.

For additional information on these programs, please contact Gigi Healy, SACMA Director of Public Affairs, 1600 Wilson Blvd., Suite 1008, Arlington, VA 22209; telephone: (703) 841-1556.

CENTER FOR COMPOSITE MATERIALS

Research Overview: Joining

The area of joining has assumed increased importance as composites are used more extensively in automotive, military, and aerospace structural applications. Welding represents a unique technology for joining and repair of thermoplastic composite components in addition to traditional thermoset adhesives and mechanical fasteners. Recent efforts at the University of Delaware's Center for Composite Materials (CCM) have focused on the use of various welding technologies for thermoplastic composites. Research has also been conducted to investigate the fundamental role of molecular mobility in the bonding and consolidation of composites. The following summarizes those projects and lists the sponsoring agencies and focal points. Further information is available from the designated faculty members and the University of Delaware's Center for Composite Materials.

Fusion Bonding of Thermoplastic Composites by Induction Heating

In a project supported by the U.S. Army, the Du Pont Company, and Lockheed Aeronautical Systems Company, researchers are examining fusion bonding of thermoplastic composites by induction heating. This joining technique uses an externally applied alternating inductive field creating localized heating at the bond interface. The localization of heating is the result of preferential heating in a magnetic and/or electrically conductive susceptor placed at the interface. The goal of this research is first to develop a fundamental understanding of the heating mechanisms and the bonding phenomena in various susceptor materials. This will lead to the development of a process model supported by experimental verification. Such a model requires identification of the susceptor design, coil design, power levels, and frequency levels most suited for joining of thermoplastic composites in possible Army field repair applications. The various materials, dimensional, and environmental limitations will also be investigated.

Cpt. Bruce Fink, U.S. Army
John W. Gillespie, Jr., E. I. du Pont de Nemours & Company, Inc.
Roy L. McCullough, Lockheed Aeronautical Systems Company

Manufacture and Performance of Resistance Welded Graphite-Reinforced Thermoplastic Composite Structural Elements

The influence of manufacturing on the design and performance of resistance welded thermoplastic composite skin/core structural elements is investigated. Manufacturing results focus on techniques for consolidation of thermoplastic cores and resistance welding of the core to the face sheets. Performance results include flexural testing of structural elements and coupon tests to quantify design allowables. Experimentally validated models are presented to predict in-situ strength and toughness of resistance welded thermoplastic joints in composite structures as a function of process history. Experimental studies on welding graphite (AS4) polyetheretherketone (PEEK) thermoplastic composites (APC-2 and BASF commingled prepregs) using PEEK film and polyetherimide (PEI) (amorphous polymer bonding technology) have shown that in-situ lap shear strength and Modes I and II interlaminar fracture toughness are extremely sensitive to the nonisothermal process history. These predictive models enable design and manufacturing trade-off studies to be conducted. The methodology is demonstrated by predicting joint failures in the skin/core structure for various welding conditions by combining traditional stress analysis and interlaminar fracture mechanics with our nonisothermal process models for strength and toughness. Predictions will be correlated with experimental results.

Laurent Bastien   Aluminum Company of America
Ian Howie
Roderic C. Don
Scott Holmes
John W. Gillespie, Jr.

Nonisothermal Model for Fusion Bonding of Thermoplastic Composites

A model based on the reptation and healing theory for amorphous polymers is proposed to predict strength and interlaminar fracture toughness as a function of nonisothermal process history in this project which is supported by the Aluminum Company of America (ALCOA). Techniques for quantifying diffusion coefficients have been developed and evaluated experimentally. Temperature dependance has been successfully represented by an Arrhenius law for a large range of process temperatures for fusion bonding graphite/PEEK composites using amorphous film technology. The influence of processing on fusion bonding of graphite (AS4) polyetheretherketone (PEEK) thermoplastic composites (BASF commingled PEEK/graphite NCS woven fabric) using a polyetherimide (PEI) film at the interface (amorphous bonding technology) is investigated. Joint performance is quantified experimentally through lap shear and Modes I and II interlaminar fracture testing. The influence of bondline thickness and crack growth resistance is studied. The role of consolidation pressure during the fusion bonding process has also been considered. Model predictions are correlated with experimental data for various nonisothermal process conditions measured in the hot press. Model predictions have been correlated successfully with experimental data. The model is used to investigate the process time required to reach maximum strength and toughness at other isothermal temperatures. Application of the model to resistance welding using dual film technology is presented for this highly nonisothermal joining technique. A two-dimensional (2-D) transient anisotropic heat transfer model of a resistance welded lap shear specimen provides typical transient temperature profiles of the interface that is fundamental input to the strength model. Model predictions show that optimum strength and toughness are achievable in relatively short process times with appropriate welding conditions.

Laurent Bastien   Aluminum Company of America
Min Chao
Roderic Don
John W. Gillespie, Jr.

Two-Dimensional Thermal Analysis of Resistance Welded Thermoplastic Composites

SCS Dukadan and ALCOA are jointly sponsoring this work to develop a transient two-dimensional thermal model for resistance welding of thermoplastic composites. A heat generation term is introduced to include joule heating within the heating element. A generalized boundary condition formulation is used so that Direlect, Neumann, or mixed conditions can be specified on domain boundaries in a straightforward manner. The boundary fitted coordinate system (BFCS) transformation technique is combined with the alternating direction explicit (ADE) method for finite difference solution to calculate transient thermal histories in geometries of arbitrary cross sections. A parametric study is conducted that yields insight into the welding process, enabling some critical process and material parameters to be identified. Optimum process times for maximum performance are shown to be extremely sensitive to the resistivity of the heating element and heat loss to the tooling. Time to melt is predicted by the model and is successfully compared to experimental observations. Local heating and melt-through at the ends of the joint that may lead to current leakage and insufficient welding have been investigated. The results of the transient thermal model are in good agreement with experimental observations.

T. B. Jakobsen, SCS Dukadan AS
J. W. Gillespie, Jr., Aluminum Company of America

Automated Welding of Thermoplastic Composites by Resistance Heating

An apparatus for automated resistance welding of thermoplastic composites has been designed and fabricated as a senior design project. The computer-controlled apparatus enables large area joints (4- by 24-in. [10- by 61-cm]) to be welded sequentially. Key features of the apparatus include (1) automation of the process, (2) computer control for three heating stations with independent pressure control, (3) constant power welding using continuous feedback, (4) ultrasonic detection for melt and process control, (5) a cooling system to minimize localized heating, (6) a motion system for automated sequential welding, and (7) computer storage and display of all process history parameters during welding. The apparatus is now being used in our research to investigate scale-up issues that must be overcome before widespread use of this technology is possible. Current research activities include experimentation using the constant pressure process and cooling system to eliminate excessive melting and fiber motion in the laminates to be welded. Studies correlating the role of pressure on strength indicate that relatively low consolidation pressures may be sufficient. Optimum preheat times to ensure intimate contact before high power welding will be investigated. Higher power welding will be studied to further reduce weld times from current levels.

Scott Holmes   Aluminum Company of America
Roderic Don
John W. Gillespie, Jr.

COMPOSITE MECHANICS LABORATORY, UNIVERSITY OF VIRGINIA

Purpose and Capabilities

The Composite Mechanics Laboratory is dedicated to theoretical and experimental research on the thermomechanical response and structural application of fibrous composite materials. Theoretical modeling work is conducted on problems ranging in scale from the micromechanics of the fiber and matrix to full-scale structural components. Analytical and numerical methods are used as appropriate.

Laboratory facilities include four testing machines with load cells ranging from 50 to 120 000 lbs (23 to 54 432 kg). Two machines are servo-hydraulic with fatigue capability, one of which is a combined axial/torsional machine. A system for internal pressurization is available for use on any of the machines. Environmental chambers, quartz lamp, induction heating, and associated measurement devices are available for testing in the temperature range −190 to 1700°C. A long-range microscope with attached video and tape recording system and a real-time X-ray system are available for high-level observation of events. Thermal expansion coefficients can be measured in air, vacuum, or other gases over the temperature range −190 to 1600°C using a differential dilatometer. A vacuum oven, analytic balance, ultrasonic drill, precision saws, and strain-gaging station are available for specimen preparation. Inhouse-developed computerized data acquisition hardware and software complete the laboratory facilities.

Computing facilities include Sun3 and Sun4 workstations, IBM compatible PCs, Apple Macintosh II, and access to a variety of high-speed mainframes including a CRAY.

History

The Composite Mechanics Laboratory was founded in September 1987 with the appointment of Professor Carl T. Herakovich to the faculty of Civil Engineering. Primary funding for the laboratory equipment was provided by the School of Engineering and Applied Science and the National Science Foundation. Space was provided by the Civil Engineering Department, and renovation of the space was provided by the University, School, and Department.

Faculty

- **Carl T. Herakovich,** Henry L. Kinnier Professor of Civil Engineering and Director of the Applied Mechanics Program in the School of Engineering and Applied Science. **Research interests:** interlaminar stresses, failure, fracture, damage, material response, micromechanics, thermal stresses, dimensional stability, finite element stress analysis, structural mechanics, optimum design, test methods.
- **Marek-Jerzy Pindera,** Assistant professor of Civil Engineering. **Research interests:** micromechanics, inelastic and rate dependent response, test methods, anisotropic elasticity.
- **J. Mark Duva,** Assistant professor of Applied Mathematics. **Research interests:** micromechanics, beam and plate theories, fracture, probabilistic mechanics, constitutive response, finite elements.
- **Furman W. Barton,** Professor and Chairman of Civil Engineering. **Research interests:** structural mechanics, optimum design.
- **Jacob Aboudi,** Adjunct professor of Civil Engineering (permanent position, Professor and Dean of Engineering, Tel Aviv University. **Research interests:** Micromechanics, inelastic response, analytical methods, damage, wave propagation.
- **Cornelius O. Horgan,** Professor of Applied Mathematics. **Research interests:** nonlinear elasticity, anisotropic elasticity, end effects in composites, large deformations in composites.
- **Thomas T. Baber,** Associate professor of Civil Engineering. **Research interests:** structural mechanics, vibrations.
- **James G. Simmonds,** Lawrence R. Quarles Professor of Engineering and Applied Mathematics. **Research interests:** laminated shells, end effects.
- **Farshad Mirzadeh,** Research Assistant Professor of Civil Engineering. **Research interests:** material response, structural analysis and design, fatigue, test methods.

Current Research Projects

Researchers in the laboratory have experience with a wide variety of fibrous composite systems. Current research projects are listed below. Sponsoring agencies are listed in parentheses.

- Notch sensitivity of ARALL laminates (Alcoa)
- Out-of-plane gradients in laminated composites (NASA)
- Characterization of pultruded graphite-epoxy (CIT)
- Failure and fracture of fibrous composites (Hercules)
- Thermomechanical characterization of unidirectional and multidirectional laminates (CIT)
- Fiber morphology and composite properties (NSF)
- Micromechanical modeling of metal-matrix composites (General Electric)
- Optimum Design of pultruded beams (Morrison Molded Fiber Glass and CIT)
- Response of metal-matrix composites under combined loading (NASA)
- Stress wave propagation in laminated cylinders (Materials Sciences Corp.)
- Fracture of metal-matrix composites (Center for Light Thermal Structures)
- Optimum design of metal-matrix composites (Center for Light Thermal Structures)
- High-temperature laboratory equipment (NSF)

Recent Publications

- Herakovich, C. T., "Free Edge Effects in Laminated Composites," in *Handbook of Composites,* Vol. 2, Structures and Design, Herakovich and Tarnopol'skii, Eds., North Holland, 1989.
- Pindera, M. J. and Herakovich, C. T., "Shear Characterization of Unidirectional Composites with the Off-Axis Tension Test," *Experimental Mechanics,* Vol. 26, No. 1, 1986, pp. 103–111.
- Avery, W. B. and Herakovich, C. T., "Effect of Fiber Anisotropy on Thermal Stresses in Fibrous Composites," *Journal of Applied Mechanics,* Vol. 53, No. 4, Dec. 1986, pp. 751–756.
- Gurdal, Z. and Herakovich, C. T., "Effect of Initial Flaw Shape on Crack Extension in Orthotropic Composite Materials,"

Theoretical and Applied Fracture Mechanics, Vol. 8, 1987, pp. 59–75.
• Pindera, M. J., Choksi, G. N., Hidde, J. S., and Herakovich, C. T., "A Methodology for Accurate Shear Characterization of Unidirectional Composites," *Journal of Composite Materials,* Vol. 21, No. 12, Dec. 1987.
• Pindera, M. J., Herakovich, C. T., Aboudi, J., and Becker, W., "Nonlinear Response of Unidirectional Boron/Aluminum," *Journal of Composite Materials.*
• Aboudi, J., Lee, S. W., and Herakovich, C. T., "Three-Dimensional Analysis of Laminates with Cross Cracks," *Journal of Applied Mechanics.*
• Herakovich, C. T., Aboudi, J., Lee, S. W., and Strauss, E. A., "Damage in Composite Laminates: Effects of Transverse Cracks," *Mechanics of Materials,* in press.
• Herakovich, C. T., Aboudi, J., Strauss, E. A., and Lee, S. W., "Property Degradation in Cross-Ply Laminates with Transverse Cracks," Symposium on Mechanics of Composite Materials 1988, ASME/SES First Joint Meeting, Berkeley, June, 1988 (accepted for publication).
• Pindera, J. T. and Pindera, M. J., "On the Methodologies of Stress Analysis of Composite Structures. Part I: State of the Art-Phenomenological and Physical Methodologies," *Journal Theoretical and Applied Fracture Mechanics,* Vol. 6, No. 3, Dec. 1986, p. 139.
• Pindera, J. T. and Pindera, M. J., "On the Methodologies of Stress Analysis of Composite Structures. Part II: New Experimental Approaches," *Journal Theoretical and Applied Fracture Mechanics,* Vol. 6, No. 3, Dec. 1986, p. 153.
• Pindera, M. J. and Aboudi, J., "Micromechanical Analysis of Yielding of Metal Matrix Composites," *International Journal of Plasticity,* in press.
• Horgan, C. O. and Pence, T. J., "Void Nucleation in Tensile Dead-loading of a Composite Incompressible Nonlinearly Elastic Sphere," *Journal Elasticity,* Vol. 21, 1989, pp. 61–82.
• Horgan, C. O. and Pence, T. J., "Cavity Formation at the Center of a Composite Incompressible Nonlinearly Elastic Sphere," *Journal of Applied Mechanics,* Vol. 56, 1989, pp. 302–308.

Additional Information

For additional information contact any of the listed faculty or: Prof. Carl T. Herakovich, Rm B122, Thornton Hall, Civil Engineering Department, University of Virginia, Charlottesville, VA 22903; phone: (804) 924-3605 and Fax: (804) 924-6270.

RECENT COMPOSITES PUBLICATIONS

Specifications and Standards for Plastics and Composites

REFERENCE: Traceski, F. T., *Specifications and Standards for Plastics and Composites,* ASM International, Member/Customer Service Center, Materials Park, OH 44073, Telephone: 216-338-5151, Fax: 216-338-4634, 1990, 224 pp.

A reference source of current technical specifications and standards for plastics and composites is available from ASM International, the materials information society.

Specifications and Standards for Plastics and Composites is a 224-page book written by Frank T. Traceski, currently a staff engineer with the Organization of the Secretary of Defense (OSD). The publication was created to aid materials engineers in searching for and identifying specifications and standards for testing, quality assurance, screening, or qualification of new materials, procurement, and many other similar uses.

More than 2000 standards from leading organizations such as ASTM, DoD, SAE, ISO, NASA, NIST, AIA, SACMA, ANSI, CMC, NMAB, SPE, SPI, VAMAS, BSI, JSA, DIN, ANFOR, and AECMA are identified. Also included are other U.S. and European standards-related organizations.

This volume identifies specifications and standards by number and title for quick reference and includes procedures and test methods of domestic, foreign, and international organizations. An explanation of each standards-developing body includes the organization's scope; address for obtaining hard copies of standards; and telephone, telex, and facsimile numbers for ease and expedition of requests.

Areas covered in the publication include: Classification of Plastics and Composites, Military System of Specifications and Standards, ASTM Standards, Aerospace Material Specifications (AMS), Other Government/Industry Standards, International (ISO) Standards, Foreign Standards, and Military Applications.

Delaware Composites Design Encyclopedia, Volume Five Published

REFERENCE: Kedward, K. T. and Whitney, J. M., *Delaware Composites Design Encyclopedia: Volume 5/Design Studies,* Technomic Publishing Company, 851 New Holland Ave., Box 3535, Lancaster, PA 17604, Telephone: 800-233-9936, Fax: 717-295-4538, 1990, ISBN: 0-87762-703-7, 170 pp.

The fifth volume is now available in a new six-volume design encyclopedia for advanced composite materials and components. The *Delaware Composites Design Encyclopedia* will provide users with basic knowledge about the design and analysis of composite materials and structures. It is intended for use by engineers, material scientists, designers, and other technical personnel involved in the applications of composite materials to industrial products.

The material contained in the encyclopedia was written by international experts in the field and compiled at the University of Delaware's Center for Composite Materials (CCM). The CCM is supported by a university/industry consortium and several U.S. federal research agencies.

Volume 5/Design Studies examines composites design procedures. Although they parallel those used for metallic structures, these procedures are more fundamental and can be used to model and predict accurately both primary and secondary stresses.

The volume begins with an examination of a typical composites design and basic configurations (straight and curved beams, thin plates, and so forth). The middle chapters deal with the application of numerical methods to composite structures and provide an in-depth treatment of lamination theory and free edge stress analysis, strength analysis, anisotropic plate and beam theory, and one-dimensional theory of anisotropic plates and beams. This volume concludes with solutions to laminated plate problems and presents some example design studies.

Volume 5 is authored by Keith T. Kedward, Alcoa Defense Systems, and Dr. James M. Whitney, Materials Laboratory, Wright-Patterson AFB and the University of Dayton.

The remaining volume of the encyclopedia, *Volume 6/Test Methods* (ISBN: 0-87762-704-5), and an index to Volumes 1–6 (ISBN: 0-87762-705-3) will be published later this year.

Smart Autoclave Cure of Composites

REFERENCE: Ciriscioli, P. R. and Springer, G. S., *Smart Autoclave Cure of Composites,* Technomic Publishing Company, 851 New Holland Ave., Box 3535, Lancaster, PA 17604, Telephone: 800-233-9936, Fax: 717-295-4538, 1990, ISBN: 0-87762-802-5, 176 pp.

Traditional empirical methods used to manufacture composites in an autoclave are expensive and time-consuming. Recent interest in real-time control of the autoclave pressure and temperature has led to the development of expert systems capable of controlling the manufacturing process. It has been found that these systems require little initial information about the material, can be used for complex shapes, provide instantaneous feedback control of the autoclave conditions, and result in the shortest curing times necessary to produce high quality parts.

A new book, *Smart Autoclave Cure of Composites,* is a unified presentation of process models for both thermosetting and thermoplastic matrix composites. Admittedly only the first step towards a complete solution, these models are presented in sufficient detail to acquaint the reader with the rationale behind the models, the rules and numerical procedures, and the model software and hardware.

The book also includes details and specifications on an expert system applicable to the autoclave curing of thermosetting matrix composites. *Smart Autoclave Cure of Composites* contains seven helpful appendices that include physical and experimental data and computer simulation results.

Calendar on Composites

The following meetings may be of interest to researchers in the field of composite materials.

2–4 January 1991
International Seminar on DYNAMIC FAILURE OF MATERIALS Theory, Experiments and Numerics
Vienna, Austria
Contact: Doz. Dr. H. P. Rossmanith, Institute of Mechanics, Technical University of Vienna, Wiedner Hauptstraße 8-10/325, A-1040 Vienna, Austria; Telephone: 0222-58801-5514, 5519, Ttx: 61-3222467 = TUW, Telefax: 0222-5871020

2–5 January 1991
The Second Pan American Congress of Applied Mechanics (PACAM II)
Valparaiso, Chile
Contact: Professor D. Mook, Department of Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA 24061-0219; Telephone: 703-231-6841

7–12 January 1991
Third International Conference on Constitutive Laws for Engineering Materials: Theory and Applications and Workshop on Innovative Use of Materials in Industrial and Infrastructure Design and Manufacturing
Tucson, AZ
Contact: Professor Chandra S. Desai, Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ 85721; Telephone: 602-621-2266; FAX: 602-621-2550

13–15 February 1991
DAMPING '91
San Diego, CA
Contact: CSA Engineering, Inc., Attn: Damping '91 Administrative Chairman, 560 San Antonio Road, Suite 101, Palo Alto, CA 94306-4682

20–21 February 1991
32nd Israel Annual Conference on Aviation and Astronautics
Tel Aviv, Israel
Contact: Dr. Alon Dumanis, Chairman, Program Committee, 32nd Israel Annual Conference on Aviation and Astronautics, Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, Israel; Telephone: 00972-3-5414541; FAX: 09972-3-5414540

12–13 March 1991
Bonding and Repair of Composites II
Zurich, Switzerland
Contact: Kay Royle, Conference Coordinator, Rapra Technology Limited, Shawbury, Shrewsbury, Shropshire SY4 4NR, ENGLAND; Telephone: 0939-250383; FAX: 0939-251118

13–15 March 1991
Symposium on M^3D: Mechanics and Mechanisms of Material Damping
Baltimore, MD
Contact: Dr. Vikram K. Kinra, Texas A & M University, Department of Aerospace Engineering, College Station, TX 77843; Telephone: 409-845-1667

17–21 March 1991
International Exhibitions for Plastics and Rubber and Packaging Products "PLASTO ISPACK"
Tel Aviv, Israel
Contact: Mr. Izhak Rozen, Director, The Plastics and Packaging Center, Israel Export Institute, POB 50084, Tel Aviv 68125, Israel; Telephone: 972-3-514857; 5142830; FAX: 972-3-5142902

25–27 March 1991
1st International Conference on Deformation and Fracture of Composites
Manchester, United Kingdom
Contact: Conference Department G00325, Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0HL, United Kingdom; Telephone: 01-245-9555; Telex: 915719 PRIUK G.; FAX: 01-823-1379

1–4 April 1991
8th International Conference on Mathematical and Computer Modelling
College Park, Maryland
Contact: Dr. Xavier J. R. Avula, Chairman, Eighth ICMCM, P. O. Box 1488, Rolla, MO 65401; Telephone: 314-341-4585; FAX: 314-341-6026

8–10 April 1991
AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics and Materials (SDM) Conference
Baltimore, MD
Contact: Ron Kollmansberger, 16761 Via Del Campo Court, San Diego, CA; Telephone: 619-592-2423

14–18 April 1991
IMAC 9th International Modal Analysis Conference and Exhibit
Florence, Italy
Contact: Dominick J. DeMichele, Union College, Graduate & Continuing Studies, Wells House - 1 Union Avenue, Schenectady, NY 12308-363; Telephone: 518-370-6673; FAX: 518-370-6875

15–17 April 1991
Recent Advances in Active Control of Sound and Vibration
Blacksburg, VA
Contact: Ms. Nancy Feuerbach, Smart Materials & Structures Laboratory, Mechanical Engineering Department, Randolph

Hall, Virginia Tech, Blacksburg, VA 24061-0238; Telephone: 703-231-3365; FAX: 703-231-9100

15–18 April 1991
Thirty-Sixth International SAMPE Symposium and Exhibition—Advanced Materials: How Concepts Become Reality
San Diego, CA
Contact: SAMPE, P.O. Box 2459, Covina, CA 91722; Telephone: 818-331-0616; FAX: 818-332-8929

16–18 April 1991
Third International Symposium Mechanics of Polymer Composites "MPC '91"
Prague, Czechoslovakia
Contact: Secretariat of the MPC '91, c/o Institute of Theoretical and Applied Mechanics, Czecchoslovak Academy of Sciences, Vyšehradská 49, 128 49 Praha 2, Czechoslovakia; Telephone: 29 64 51, 29 91 71, 29 75 78.

21–25 April 1991
(ICES '91) International Conference on Computational Engineering Science
Patras, Greece
Contact: ICES '91 Secretariat, % Professor S. N. Atluri, Computational Mechanics Center, Georgia Institute of Technology, Atlanta, Georgia 30332-0356

23–24 April 1991
Symposium on Constraint Effects in Fracture
Indianapolis, IN
Contact: Symposium Chairman E. M. Hackett, David Taylor Research Center, Code 2814, Annapolis, MD 21402; Telephone: 301-267-3755

6–7 May 1991
Fourth ASTM Symposium on Composite Materials: Fatigue and Fracture
Indianapolis, IN
Contact: Dr. Wayne W. Stinchcomb, Engineering Science & Mechanics Department, 227 Norris Hall, VPI & SU, Blacksburg, VA 24061-0219; Telephone: 703-231-5316; FAX: 703-231-9452

12–16 May 1991
International Aerospace Congress 1991: Focus on the Future
Melbourne, Australia
Contact: Secretariat, International Aerospace Congress 1991, GPO Box 358F, Melbourne Victoria 3001 Australia; Telephone: 061 03 654 7533 or 061 03 654 8799; FAX: 03 654 8540

14–16 May 1991
2nd Annual BCC Conference on Recent Advances in Flame Retardancy of Polymeric Materials: Materials Applications, Industry Developments, Markets
Stamford, CT
Contact: Program Co-Chairman, G. S. Kirshenbaum, Manager, Standards, Codes, and Technical Support, Engineering Plastics Division, Hoechst Celanese, 26 Main St., Chatham, NJ 07928; Telephone: 201-635-4217; FAX: 201-635-4330

20–24 May 1991
AeroMat '91: Advanced Aerospace Materials/Processes Conference and Exposition
Long Beach, CA
Contact: ASM International, Materials Park, OH 44073; Telephone: 216-338-5151; Telex: 98-0619 ASMINT; FAX: 216-338-4634

Summer 1991
American Society of Composites 6th Technical Conference
Telephone: 513-255-9080

16–19 June 1991
Symposium on Dynamics of Bubbles and Vortices Near a Free Surface
Columbus, OH
Contact: Iskender Sahin, Department of Mechanical Engineering, Western Michigan University, Kalamazoo, MI 49008; Telephone: 616-387-3376

17–20 June 1991
European Joint Conference on Engineering Systems Design and Analysis
Istanbul, Turkey
Contact: Dr. Jahan Rasty, Department of Mechanical Engineering, Texas Tech University, P.O. Box 4289 MS1021, Lubbock, TX 79409

18–20 June 1991
ASTM 23rd National Symposium on Fracture Mechanics
College Station, TX
Contact: Dr. Ravinder Chona, Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123; Telephone: 409-845-1531; FAX: 409-845-3081

8–10 July 1991
The 6th International Conference in Australia on Finite Element Methods
Sydney, Australia
Contact: Dr. Colin McIvor, Organising Committee, Department of Aeronautical Engineering, The University of Sydney, Sydney, NSW 2006, Australia; Telephone: 02-692-2850; FAX: 02-692-2012

8–12 July 1991
The 7th International Conference on Numerical Methods for Thermal Problems
Stanford, CA
Contact: Meeting Coordinator, Mrs. Lindi Bauman, Thermal Conference, Department of Chemical Engineering, Stanford University, Stanford, CA 94305-5025; Telephone: 415-723-0153; FAX: 415-725-7294; E-Mail: LINDI@DELLA.STANFORD.EDU"

15–17 July 1991
International Conference on Mixed-Mode Fracture and Fatigue
Vienna, Austria
Contact: Doz. Dr. H. P. Rossmanith, Institute of Mechanics, Technical University of Vienna, Wiedner Hauptstraße 8-10/325, A-1040 Vienna, Austria; Telephone: 0222-58801-5514, 5519; Ttx: 61-3222467 = TUW; Telefax: 0222-5871020

15–19 July 1991
The Eighth International Conference on Composite Materials (ICCM/VIII)
Honolulu, HI
Contact: Profs. Stephen W. Tsai and George S. Springer, Department of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305; Telephone: 415-725-3305; FAX: 415-725-3377

15–19 July 1991
The 7th International Conference on Numerical Methods in Laminar and Turbulent Flow
Stanford, CA

Contact: Meeting Coordinator, Mrs. Lindi Bauman, Thermal Conference, Department of Chemical Engineering, Stanford University, Stanford, CA 94305-5025; Telephone: 415-723-0153; FAX: 415-725-7294; E-Mail: LINDI@DELLA.STANFORD.EDU"

21–24 July 1991
First U.S. National Congress on Computational Mechanics
Chicago, IL
Contact: Professor Wing Kam Liu, Department of Mechanical Engineering, Robert R. McCormick School of Engineering and Applied Science, The Technological Institute, Northwestern University, Evanston, IL 60208-3111

24–26 July 1991
The Third International Conference on Residual Stresses (ICRS - 3)
Tokushima, Japan
Contact: Prof. R. W. Hendricks, Department of Materials Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061; Telephone: 703-231-6917; E-MAIL: HENDRXRW@VTVM1.CC.VT.EDU

29 July–2 August 1991
The Sixth International Conference on Mechanical Behaviour of Materials (ICM - 6)
Kyoto, Japan
Contact: The Society of Materials Science, Japan, Att. Prof. T. Inoue, Secretary General, ICM-6, Yoshida-Izumidono-cho 1-101, Sakyo-ku, 606 Kyoto, Japan; Telefax: 075-761-5325

6–8 August 1991
Joint ICF/FEFG International Conference on Fracture of Engineering Materials and Structures
National University of Singapore
Contact: Dr. S. H. Teoh, Conference Director, Dept. of Mechanical & Production Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 0511; Telephone: 65-7722212; FAX: 65-7791459; Tlx: UNISPORE RS33943; Tlgm: UNIVSPORE

12–16 August 1991
Plasticity '91 Symposium
Grenoble, France
Contact: Professor Akhtar S. Khan, School of Aerospace and Mechanical Engineering, The University of Oklahoma, 865 Asp Avenue, Room 212, Norman, Oklahoma 73019-0601; Telephone: 405-325-5011; FAX: 405-325-1088 or 405-325-5068

20–22 August 1991
Computational Structures Technology
Edinburgh, Scotland
Contact: Professor B. H. V. Topping, Department of Civil Engineering, Heriot-Watt University, Riccarton, Edinburgh EH14 4AS, United Kingdom; Telephone: 031-449-5111; FAX: 031-451-3170

20–22 August 1991
Conference on Materials for Electronic Packaging
Buffalo, NY
Contact: Professor D. D. L. Chung, Department of Mechanical and Aerospace Engineering, State University of New York at Buffalo, Buffalo, NY 14260; Telephone: 716-636-2520

4–6 September 1991
First Canadian International Composites Conference and Exhibition
Montreal, Quebec, Canada
Contact: Dr. S. V. Hoa, Conference Chairperson, Department of Mechanical Engineering, Concordia University, 1455 de Maisonneuve Blvd. West, H 929-11, Montreal, Quebec, Canada H3G 1M8; Telephone: 514-848-3139; FAX: 514-848-3494

9–11 September 1991
Sixth International Conference on Composite Structure (ICCS/6)
Paisley, Scotland
Contact: Dr. I. H. Marshall, Department of Mechanical and Production Engineering, Paisley College of Technology, High Street, Paisley PA1 2BE, Scotland; Telephone: 041-887-1241; FAX: 041-887-0812

9–11 September 1991
Third ASTM International Symposium on Computerization and Use of Materials Property Data
Cambridge, England
Contact: Keith W. Reynard, Symposium Co-Chairman, Wilkinson Consultancy Services, Stable Cottage, Broad Lane, Newdigate, Surry RH5 5AT, United Kingdom; Telephone: 44(0)-306-77247; FAX: 44(0)-306-77247

16–20 September 1991
International Conference of Nonlinear Engineering Computations
Split, Yugoslavia
Contact: P. Marovic, Gradevinski Fakultet Split, V. Maslese b.b., 58000 Split, Yugoslavia; Telephone: 058-523-333 or 058-551-475; Telex: 26-433-YU-GIFGT; Telefax: 058-551-152

17–19 September 1991
Interfacial Phenomena in Composite Materials (IPCM '91)
Leuven, Belgium
Contact: Janet Miles, Conference Organiser, Butterworth Scientific Ltd., P.O. Box 63, Westbury House, Bury Street, Guildford, Surrey GU2 5BH, United Kingdom; Telephone: 0483 300966; Telex: 859556 SCITEC G; FAX: 0483 301563

7–9 October 1991
6th American Society of Composites Technical Conference on Composite Materials
Troy, NY
Contact: Professor Sanford S. Sternstein, Rensselaer Polytechnic Institute, Center for Composite Materials and Structures, JEC 5007, Troy, NY 12180; Telephone: 518-276-2792

7–9 October 1991
22nd Midwestern Mechanics Conference
Rolla, MO
Contact: Professor Romesh C. Batra, Department of Mechanical and Aerospace Engineering and Engineering Mechanics, University of Missouri-Rolla, Rolla, MO 65401-0249; Telephone: 314-341-4589

9–11 October 1991
3rd International Exhibition and Congress on the Entire Composite Technology
"VERBUNDWERK 91"
Wiesbaden, West Germany
Contact: Diana Schnabel, DEMAT, Postbox 110 611, 600 Frankfurt 11, West Germany; Telephone: 069/ 23 43 31; FAX: 069/25 30 71

14–15 October 1991
Symposium on Multiaxial Fatigue (ASTM)
San Diego, CA
Contact: Professor David L. McDowell, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405; Telephone: 404-894-5128 or Rod Ellis, NASA Lewis Research Center, MS 49/7, 21000 Brookpark Road, Cleveland, OH 44135; Telephone: 216-433-3340

16 October 1991
Symposium on Thermo-Mechanical Fatigue Behavior of Materials
San Diego, CA
Contact: Professor Huseyin Sehitoglu, Department of Mechanical Engineering, University of Illinois, 1206 W. Green, Urbana, IL 61801; Telephone: 217-333-4112

22–24 October 1991
Twenty-Third International SAMPE Technical Conference: Advanced Materials/Affordable Processes
Kiamesha Lake, NY
Contact: SAMPE International Headquarters, P. O. Box 2459, Covina, CA 91722; Telephone: 818-331-0616; FAX: 818-332-8929

27 October–1 November 1991
IUTAM Symposium on Local Mechanics Concepts for Composite Materials Systems
Blacksburg, VA
Contact: J. N. Reedy and K. L. Reifsnider, Department of Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA 24061-0219; Telephone: 703-231-6744; FAX: 703-231-4574

6–8 November 1991
28th Annual Meeting of the Society of Engineering Science
Gainesville, FL
Contact: Dr. Martin A. Eisenberg or Dr. Bhavani V. Sankar, Department of Aerospace Engineering, Mechanics & Engineering Science, 231 Aerospace Building, University of Florida, Gainesville, FL 32611-2031; Telephone: 904-392-0961; FAX: 904-392-7303

1–6 December 1991
Recent Developments in Elasticity: ASME Winter Annual Meeting
Atlanta, GA
Contact: Prof. R. C. Batra, Dept. Mech. & Aero. Engr. & Engr. Mechanics, University of Missouri-Rolla, Rolla, MO 65401-0249; Telephone: 314-341-4589

Summer 1992
6th US-Japan Conference on Composite Materials
San Diego, CA
Contact: Kenneth L. Reifsnider or M. W. Hyer, Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0219; Telephone: 703-231-5077 or 703-231-5372; FAX: 703-231-4574

Summer 1992
American Society of Composites 7th Technical Conference
Telephone: 513-255-9080

22–28 August 1992
18th International Congress of Theoretical and Applied Mechanics
Haifa, Israel
Contact: Professor A. Solan, Secretary ICTAM 1992, Faculty of Mechanical Engineering, Technion - Israel Institute of Technology, Haifa 32000, Israel; Telephone: 04-292111; FAX: 04-324533 or 04-221581

8–13 November 1992
ASME Winter Annual Meeting
Anaheim, MI
Contact: ASME, 345 East 47th St., New York, NY 10017; Telephone: 212-705-7722

28 November–3 December 1993
ASME Winter Annual Meeting
New Orleans, LA
Contact: ASME, 345 East 47th St., New York, NY 10017; Telephone: 212-705-7722

13–18 November 1994
ASME Winter Annual Meeting
Chicago, IL
Contact: ASME, 345 East 47th St., New York, NY 10017; Telephone: 212-705-7722

12–17 November 1995
ASME Winter Annual Meeting
San Francisco, CA
Contact: ASME, 345 East 47th St., New York, NY 10017; Telephone: 212-705-7722

17–22 November 1996
ASME Winter Annual Meeting
Atlanta, GA
Contact: ASME, 345 East 47th St., New York, NY 10017; Telephone: 212-705-7722

Send items for this calendar to:
Prof. M. W. Hyer, Department of Engineering Science and Mechanics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0219
Telephone: (703) 231-5372
FAX: (703) 231-4574

Guest Commentaries

EDITOR'S NOTE:
We are privileged to bring to you two Guest Commentaries in this issue. Both commentaries are written by highly respected scientists from the United States Air Force Aeronautics Systems Division. Dr. Jack Lincoln discusses material competitiveness and Dr. John Halpin discusses the need for total process control for composite materials. Enjoy!

Material Competitiveness

by John W. Lincoln, Technical Expert, Aeronautical Systems Division at Wright-Patterson Air Force Base

The United States Air Force Aeronautical Systems Division (ASD) located at Wright-Patterson AFB is very optimistic about the role of composites in future weapon systems procurements. ASD is responsible for the transition of new technology to full-scale development of new aircraft for use by the USAF operational commands. One of the functions of the Structures Division of ASD is to ensure that new materials will meet the stringent requirements for structural integrity when they are placed in service. One of the ways this is accomplished is through the writing of specifications that give the contractors guidance on analysis and testing that is needed to meet the USAF requirements for strength, durability, and damage tolerance of new aircraft.

For composite structures, the development of this guidance has gone through a long evolutionary process. Early setbacks, such as the discovery of the impact of moisture and temperature on the compressive strength of composites, made ASD initially wary of the application of this material to new aircraft.

Another issue that concerned ASD was the effect of age on structural integrity. This, of course, presented a dilemma since the effects of aging could not be evaluated without placing composite structures in a service environment. The Flight Dynamics Laboratory and the Materials Laboratory at Wright-Patterson AFB addressed these early inhibitors by an aggressive set of programs referred to as "the composites roadmap." These programs included the design and construction of small secondary structures that the using commands were willing to place on service aircraft.

Also included in this roadmap was a program on the fatigue sensitivity of composites that was performed by Northrop and a program on the environmental sensitivity of composites that was performed by Grumman. Both of these programs were sponsored by the Flight Dynamics Laboratory. These early programs provided that basis for initial efforts by ASD to develop a specification basis for the procurement of a composite aircraft. However, it was not until Northrop had completed the Wing/Fuselage program (a program on the durability of composites), and Boeing and Northrop had completed the Damage Tolerance of Composites program, that there was a sound basis for writing a specification that eliminated the unnecessary conservatisms that existed in earlier specifications. This new guidance is in AFGS-87221A and was released on 8 June 1990.

When one reads this new guide specification, it is found that the analysis and testing requirements for composites are completely compatible with the USAF Aircraft Structure Integrity Program (ASIP). ASIP, which is described in MIL-STD-1530A, was initially developed for metal aircraft. However, there is only a change in emphasis for composite applications. It is believed that this new specification will promote the use of composites in future USAF aircraft.

The aircraft performance benefits derived from composites have eliminated the question on whether to use them in new

About the Author

John W. Lincoln is the Technical Expert for the Structures Division of the Aeronautical Systems Division at Wright-Patterson Air Force Base. He has responsibility for the USAF Aircraft Structural Integrity Program at ASD. He has a background of experience in the aerospace industry as well as the government. His Ph.D. is in Engineering Mechanics from the University of Texas.

designs. The debate is on which composites best meet the goals of the intended application. The USAF does not direct the contractors to use or not use a specific material. The approach is to have the contractors test each new material against technology transition criteria that are designed to eliminate materials that are not suitable for the weapon system being designed.

These technology transition criteria assess five basic issues. The first is whether the manufacturers of the material have stabilized the process. The emphasis here is on the uniformity of the material produced under appropriate process specifications. The second issue is producibility. That is, whether the material can be manufactured into the desired shapes and sizes and is compatible with the shop environment. The third is characterized material properties. Testing to satisfy this issue is directed towards an adequate examination of aspects such as environmental effects on strength, durability, and damage tolerance. It is the purpose of this testing to identify fatal defects. It is not intended to develop the final allowables to be used in full-scale design. The fourth issue is predictability of structural performance. This is a significant issue with composites since some of the analytical procedures are still evolving. This difficulty has emphasized the need for a good design development test program that will provide an empirical database to make the needed predictions. This issue was skillfully handled in the Northrop Wing/Fuselage program by use of the "building block process." Last and certainly not least is supportability. The Aeronautical Systems Division must provide aircraft that the user can rely on to perform their mission. Each new material that is brought into the inventory must pass the test of support by the Logistics Command. The Logistics Command must be able to inspect and make adequate repairs on all of their aircraft.

The outlook for composites appears to be bright. Based on studies performed by the laboratories, composite structures can be designed to withstand the peacetime and wartime operational environment in which the USAF operates. However, each composite part will have to compete for its place on aircraft of the future. The metals suppliers have responded to the challenge of composites and are providing the aircraft designer with some attractive alternatives to composites. This kind of competition is certainly healthy for the USAF since it should give them the best possible aircraft to perform their mission.

Total Process Control in the Third Age of Aerospace Materials

by John C. Halpin, Assistant for Product Assurance to the Commander of the Aeronautical Systems Division, Wright-Patterson Air Force Base

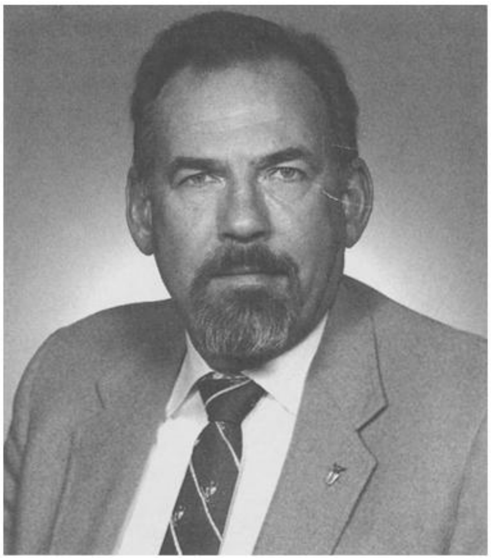
We are now in the third age of aerospace materials, the age of composite material. When our industry was young, we constructed our vehicles with wood and fabrics using simple tools. Limited availability of hard woods, the high cost of maintaining wood and cloth structures, combined with a need for improved specific strength, drove aircraft construction into metallics in the 1930s. We paid a price in terms of corrosion, fatigue, and fracture control. In turn, we developed methods to manufacture metallic structure in an efficient and effective manner. Continuing growth in demands on aeronautical structures pushed us to search for increased specific strength and less demanding corrosion, fatigue, and fracture control. Today's graphite fiber-based materials are the result.

Advanced composites have won and are winning major commitments for military aircraft. Some transport structural commitments are coming—but slowly. One significant cause is that composites must compete with metallics in terms of manufactured cost and consistency. Variations in materials, processes, and manufactured components is unnecessarily inhibiting expanded applications. Variations in part thickness, voids, and porosity continually plague production. Thickness variations typically range from −20 to +40% influencing assembly time and cost as a result of:

- poor "fit-up,"
- excessive shimming requirements, and
- necessitates the stocking of different fastener lengths to cover the entire thickness variation ranges.

Material vendor specifications tolerate a 17% variation in prepregs. Similar variability exists in the width of prepreg tapes. Our earlier manufacturing activities emphasized thin structure and inner moldline tooling. Thin structure allowed us to use controlled "bleeding" to accommodate variation in prepreg tolerances. Inner moldline tooling allows the outer surface to float minimizing the misfit between the inner moldline and the substructure. Today's programs involve thicker structure and a change to *external* moldline tooling driven by *external* dimensional requirements and reduced tooling costs. The changes are aggravating the manufacturing variability. With the evolution to thicker parts, the need to control voids and porosity has intensified. Voids and porosity are the principle causes of production inspection requirements which negatively influence manufacturing cost and cycle time.

Variability in materials and processes are the causes of variability in productivity—as noted earlier an economic impediment to expanded applications. There are at least two reasons for this. A convenient explanation is that we are continuing to grow in our understanding. To a degree this point is correct despite our



About the Author

Dr. Halpin is the Assistant for Product Assurance to the Commander of the Aeronautical Systems Division at Wright-Patterson Air Force Base in Dayton, Ohio. In this role, he is the Senior Civilian Advisor for the integration of design engineering, specialty engineering, manufacturing, quality assurance and product support in aircraft development and acquisition for the United States Air Force. Among his many accomplishments, Dr. Halpin was, and continues to be, a pioneering leader in advanced composite materials science and technology. Through his technical direction, the material focus, processing procedures and certification procedures were developed and first applied to the F-15 and F-16 aircraft and all subsequent USAF aircraft. He published the initial textbook on aircraft structural design with advanced composites. This textbook was the single most significant reference material used to train the first generation of aeronautical composite designers across the United States and the European aerospace industry. Dr. Halpin is a visiting Professor of Material Science at Washington University, St. Louis, Missouri; on the Advisory Board of the Composite Research Center at the University of Washington, Seattle, Washington; and for the Department of Materials and Production Engineering at the University of Naples, Naples, Italy. Dr. Halpin has produced three books and over 70 papers in his field of work.

efforts in the past two decades to understand the basic processes. Perhaps a more fundamental cause is a cultural bent to inspect and correct manufactured products as a method to achieve conformity. In effect, our actions in aerospace industries imply that it is economically more effective to inspect and correct fabricated products than to design and control manufacturing processes without the need for rework, repair, or scrap as the method to achieve conformity—a perspective in conflict with the international industrial competitive experiences of the 1980s. Therein lies a dilemma for the broader application of composites and for the health of our aerospace industry.

We expect our aeronautical industries to remain competitive in the world economy by being the leader in using technology. However, a potential technology advantage disappears quickly if it cannot be used because of excessive manufacturing cost. If a competitor can copy and fabricate with the new technology, in a more uniform manner, the technology advantage is more than lost. We have seen this happen in electronics, in automobiles! Will composite airframes be next? We have the tools! Through our processing science and manufacturing science programs, we have worked hard to characterize and understand the fundamental unit processes that form the basis of the manufacturing operations for composite materials. From this understanding process, simulation models are becoming available for the "off-line" design of the manufacturing processes. This understanding combined with the design of experiments provides a proven set of tools to optimize materials, processes, and product features. Will we use this capability to develop a preventive process control methodology?—from the raw material vendors to the finished product? The international competitors will!

Journal of Composites Technology & Research
Table of Contents, Vol. 12
1990

No. 1, Spring

No. 2, Summer

No. 3, Fall

No. 4, Winter