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 articles 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 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
- The Shock and Vibration Digest

Cement and Concrete Composites, *effective 1990, not available*

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

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World of Composites

EDITOR'S NOTE:
This issue of the World of Composites will begin with a preview of activities scheduled for ASTM's Committee D-30 on High Modulus Fibers and Their Composites upcoming Spring meeting. This will be followed by a brief announcement regarding SACMA's Physical and Chemical Test Methods Task Force. Research activities at two universities, the University of Delaware and Virginia Polytechnic Institute, will then be summarized. The Adhesion Society's Award of Excellence for 1993 will be announced. Finally, a recently released composites publication will be outlined.

ASTM COMPOSITES ACTIVITIES

D-30 to Hold Symposium and Committee Meetings in Atlanta

Fifth ASTM Symposium on Composite Materials: Fatigue and Fracture

ASTM Committee D-30 will hold its Fifth Symposium on Composite Materials: Fatigue and Fracture on 4–6 May 1993 at The Hyatt Regency Atlanta in Atlanta, Georgia. Dr. Roderick H. Martin of Analytical Services and Materials, Inc., Hampton, Virginia will serve as the symposium chairman. The symposium, which will be conducted over three days, will feature 35 papers in its 8 sessions. Four additional manuscripts which will not be presented at the meeting will be included in the Standard Technical Publication that will be based on the symposium proceedings. A preliminary list of papers and authors is included below.

Tuesday, 4 May 1993

Session 1—Delamination Characterization I

Session Chairman—Anoush Poursartip
University of British Columbia,
Vancouver, British Columbia, Canada

Experimental Development of a Mixed Fatigue Delamination Criterion—P. Sriram, Y. Khourchid, and S. J. Hooper, Wichita State University, Wichita, Kansas, and R. H. Martin, Symposium Chairman

Mode I and II Delamination Growth of Interlayer-Toughened Carbon/Epoxy (T8000H/3900-2) Composite System—K. Kageyama, I. Kimpara, and I. Ohsawa, University of Tokyo, Tokyo, Japan, M. Hojo, IPRI, Tsukuba, Japan, and S. Kabashima, Mitsubishi Electric Corp., Japan

Interlaminar Fracture Toughness of Glass Fibre Laminates Additionally Reinforced With Carbon Bead—J. J. Lee, S. L. Ogin, and P. A. Smith, University of Surrey, Guildford, Surrey, United Kingdom

Delamination of Carbon/Epoxy Under Cyclic Mode II Loading—K. Kussmaul, M. V. Alberti, and U. Eisele, University of Stuttgart, Stuttgart, Germany, and T. Schneider, Dornier Luftfahrt, Friedrichshafen, Germany

Session 2—Damage Modelling

Session Chairman—John Fish
Lockheed Advanced Development Co.
Sunland, California

Prediction of Energy Release Rate for Edge Delamination Using a Crack Tip Element—B. D. Davidson, Syracuse University, Syracuse, New York

Characterization of Fiber-Matrix Interface Strength—R. A. Naik, Analytical Services & Materials Inc., Hampton, Virginia and J. H. Crews, Jr., NASA Langley Research Center, Hampton, Virginia

A Criterion for Fiber Matrix Splitting—N. Suresh and A. S. D. Wang, Drexel University, Philadelphia, Pennsylvania

A Simple Model for Crack Arrest in Cracked Lap Shear Specimens—B. H. Fortson, Phillips Laboratory, Kirtland AFB, New Mexico and E. A. Armanios, Georgia Institute of Technology, Atlanta, Georgia

Session 3—Damage Growth

Session Chairman—Wayne Stinchcomb
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Evaluation of the Long-Term Behavior of a Notched Thermoplastic Laminate—W. S. Kohl and W. W. Stinchcomb, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Delamination Growth Under Cyclic Compression in Composite Plates—G. Kardomateas and B. Malik, Georgia Institute of Technology, Atlanta, Georgia

Stacking Sequence Effects and Delamination Growth in Graphite/Epoxy Laminates Under Compression-Dominated Fatigue

Loading—J. P. Komorowski, National Research Council, Ottawa, Canada, D. Lefebvre and C. Roy, University of Sherbrooke, Quebec, Canada

Experimental Evaluation of Damage Growth in Stitched Epoxy Composites—D. G. Moon and J. M. Kennedy, Clemson University, Clemson, South Carolina

The Effect of Graphite Fibers on Microcracking Due to Thermal Cycling of Resin Matrix Composites—B. J. Knouff, University of Cincinnati, S. Tompkins, NASA Langley Research Center, Hampton, Virginia, and N. Jayaraman, University of Cincinnati, Cincinnati, Ohio

Wednesday, 5 May 1993

Session 4—Factors Effecting Fatigue Response

Session Chairman—Steven Hooper
Wichita State University
Wichita, Kansas

Interaction Between Composite Void Level and Fatigue Tension-Compression Loading in Filament Wound Composite Case—Y. T. Toombs and D. Cohen, Hercules Aerospace Co. Magna, Utah, and M. G. Abdallah and C. S. Muller, Hercules Advanced Materials & Systems Co., Magna, Utah

Damage Tolerance and Arrest Characteristics of Pressurized Graphite/Epoxy Tape Cylinders—C. U. Ranniger, P. A. Lagace, and M. J. Graves, Massachusetts Institute of Technology, Cambridge, Massachusetts

The Effect of Moisture and Elevated Temperature on the Fatigue Performance and Failure Modes of a Glass Reinforced SMC Material—G. N. Skaper and K. Hofer, L. J. Broutman & Assoc. Ltd., Chicago, Illinois

Marine Environmental Effects on Polymer Matrix Composites—F. Pomies and L. A. Carlsson, Florida Atlantic University, Boca Raton, Florida, and J. W. Gillespie, University of Delaware, Newark, Delaware

Session 5—Damage Prediction

Session Chairman—Erian Armanios
Georgia Institute of Technology
Atlanta, Georgia

Modeling Fatigue Crack Growth in Cross Ply Titanium Matrix Composites—J. G. Bakuckas, Jr., National Research Council, Hampton, Virginia and W. S. Johnson, NASA Langley Research Center, Hampton, Virginia

A Sub-Structuring Approach to the Fatigue Life Prediction of Polymeric Matrix Composite Materials—M. P. Connolly, South West Research Institute, San Antonio, Texas

Modeling of Progressive Failure and Response of Laminated Composites Subjected to Multiple In-Plane Loads—I. Shaid, Z. Kutlu, and F. K. Chang, Stanford University, Stanford, California

Experimental Characterization and Analysis of the Fatigue Delamination Process in a Carbon-Epoxy Composite—M. Beghini, L. Bertini, and E. Vitale, Dipartimento di Costruzioni Meccaniche e Nucleari, Pisa, Italy

Session 6—Impact

Session Chairman—John Masters
Lockheed Engineering and Sciences Co.
Hampton, Virginia

Delamination and Fibre Breakage of CFRP due to Low Mass and High Mass Impacts—D. Delfosse and A. Poursartip, University of British Columbia, Vancouver, British Columbia, Canada, and B. Coxon, Integrated Technologies Inc., Bothell, Washington

Impact and Fatigue Resistance of 3-D Braided Composites—M. A. Portanova, Lockheed Engineering & Sciences Co., Hampton, Virginia and J. W. Deaton, NASA Langley Research Center, Hampton, Virginia

Numerical Modeling of Impact Damage in Composite Laminates—R. Banerjee, University of Dayton Research Institute, Dayton, Ohio

Effect of Plate Size on Impact Damage—W. C. Jackson, NASA Langley Research Center, Hampton, Virginia, M. A. Portanova, Lockheed Engineering & Sciences Co., Hampton, Virginia, and C. C. Poe, Jr., NASA Langley Research Center, Hampton, Virginia

Influence of Impact Parameters on the Response of Laminated Composite Plates—D. R. Ambur, NASA Langley Research Center, Hampton, Virginia and C. B. Prasad, Analytical Services and Materials, Inc., Hampton, Virginia

Thursday, 6 May 1993

Session 7—Damage in Structural Configurations

Session Chairman—Kevin O'Brien
US Army Aerostructures Directorate
Hampton, Virginia

Fatigue and Fracture of the 767 Graphite Torsion Spring—R. W. Bliss and D. L. Wheeler, Hercules, Magna, Utah and R. Maguire, Boeing Aircraft Co., Seattle, Washington

Fracture of Glass/Epoxy Laminates Under Torsional and Combined Tension-Torsional Loading—J. C. Fish, Lockheed Advanced Development Company, Sunland, California and J. K. Sen, McDonnell Douglas Helicopter Company, Mesa, Arizona

Delamination Strength of Realistic Tapered Geometries—A. J. Vizzini, University of Maryland, College Park, Maryland

Delamination in Unidirectional Composites with Terminating Internal Plies Under Tension Fatigue Loading—M. R. Wisnom, M. I. Jones, and W. Cui, University of Bristol, Bristol, United Kingdom

Analysis of Thin-Walled Closed Section Composite Beams with Internal Damage—E. A. Armanios and A. Badir, Georgia Institute of Technology, Atlanta, Georgia

Session 8—Delamination Characterization II

Session Chairman—Kazuro Kageyama
University of Tokyo
Tokyo, Japan

Pure Mode III Delamination Using a Modified Split Cantilever Beam—Farhad Sharif and M. T. Kortschot, University of Toronto, Toronto, Ontario, Canada, and R. H. Martin, Symposium Chairman

Mixed Mode Interlaminar Fracture Toughness of Unidirectional Glass/Epoxy Composites—X.-J. Gong, Institute Superieur de L'Automobile et des Transports, Nevers, France and M. Benzeggagh, Universite de Technologie de Compigne, Compigne, France

Improvement of Delamination Resistance with Carbon Nonwoven Mat Interleafs—E. Armstrong-Carroll and R. Cochran, Naval Air Warfare Center, Warminster, Pennsylvania

Mode I and Mode II Fracture Toughness on Differently Oriented Interlaminae of Graphite/Epoxy Composites—I. Chou, Ishikawajima-Harima Heavy Industries Co., Ltd., Yokohama, Japan, and I. Kimpara, K. Kageyama, and I. Ohsawa, University of Tokyo, Tokyo, Japan

Papers Also To Be Published in The STP

A Random-Damage Finite Element for Modeling Failure in Advanced Composite Materials—K. T. Slattery, Washington University, St. Louis, Missouri

On Interface Strength in Fiber Pull-Out and Push-In with Frictional Interface, P. V. Kishore, A. C. W. Lau, and A. S. D. Wang, Drexel University, Philadelphia, Pennsylvania

Notch-Tip Damage Growth During Static and Fatigue Loading in Center Notched Aluminum and Titanium Matrix Composites—J. G. Bakuckas, Jr., National Research Council, Hampton, Virginia and J. Awerbuch, Drexel University, Philadelphia, Pennsylvania

Free Edge Stress Concentration of the Interface of Two Power Law Hardening Materials—A. Rahman, A. C. W. Lau, and T.-M. Tan, Drexel University, Philadelphia, Pennsylvania

D-30 Committee Activities

In addition to the symposium listed above, Committee D-30 will conduct a full schedule of subcommittee meetings. The symposium will adjourn at midday to facilitate committee attendance. A roster of subcommittees, their chairmen, and task groups are listed below.

D30.01 EDITORIAL—Elizabeth C. Goeke, Army Materials Technology Laboratory

D30.02 RESEARCH AND MECHANICS—Glenn C. Grimes, Lockheed Advance Development

Task Group on International Standards Harmonization
Task Group on Long Term Durability
Task Group on Textile Composites
Task Group on Symposium Planning
Task Group on Round Robin Testing
Task Group on Impact

D30.03 CONSTITUENT PROPERTIES—Christopher J. Spragg, Amoco Performance Products

Task Group on NDE

D30.04 LAMINA/LAMINATE PROPERTIES—Richard E. Fields, Martin Marietta

D30.04.01 Tension Test Methods
D30.04.02 Compression Test Methods
D30.04.03 Shear Test Methods
D30.04.04 Fatigue
D30.04.05 Ring/Filament Wound Composites Test Methods
D30.04.06 Guides
D30.04.07 Data Reporting
D30.04.08 Specimen Preparation

D30.05 STRUCTURAL PROPERTIES—Edward Gonterman, Integrated Technologies Inc.

D30.06 INTERLAMINAR PROPERTIES—T. Kevin O'Brien, U.S. Army Aerostructures Dir.

D30.06.01 Mode I Testing
D30.06.02 Mode II Testing
D30.06.03 Mixed Mode Testing
D30.06.04 Fatigue
D30.06.05 Interlaminar Shear Strength
D30.06.06 Interlaminar Tension Strength

D30.07 METAL MATRIX COMPOSITES—W. Steven Johnson, NASA Langley Research Center

D30.07.01 Tension Testing
D30.07.02 Fatigue Testing

D30.08 THERMO-PHYSICAL PROPERTIES—Douglas D. Ward, General Electric Aircraft Engines

For further information on the symposium or Committee activities, please contact Kathie Schaaf, ASTM 1916 Race St., Philadelphia, PA 19103; Tel. 215-299-5529, FAX 215-299-2630.

SUPPLIERS OF ADVANCED COMPOSITES MATERIALS ASSOCIATION

Physical and Chemical Test Methods Task Force Activities Highlighted

Task Force

The SACMA Physical and Chemical Test Methods Task Force was initiated in January 1991 to define common methods for determining physical properties and chemical characterizations of filament-reinforced plastic (FRP) composite materials. The task force concentrated on methods that would be useful in product manufacturing, acceptance testing, and end use. In May 1992, SACMA balloted methods for glass transition, ply thickness, flow, resin content, dynamic viscosity, high performance liquid chromatography (HPLC), and fluid resistance. The HPLC method is more of a guide (as defined by ASTM) than a test method. Emphasis was limited to epoxy matrix materials, but some of the developed methods are applicable to both thermoplastics and bismaleimides. A DSC method has been written but has not been balloted. As a result of SACMA's balloting process, several useful comments were received and are being incorporated into method rewrites which were due in October 1992.

SACMA is interested that these methods be pursued by ASTM. Some of this work has already begun in the Subcommittees D30.03 and D30.08. Methods outside of ASTM Committee D-30 jurisdiction (viscosity, fluid resistance, and DSC) need ASTM interface to enhance industry adoption.

The current task force activity is to pursue joint testing of the proposed methods between SACMA member companies (due to start in October 1992). The scope of the joint testing is for SACMA to be satisfied that technical issues have been adequately resolved before release of the methods. The joint testing is not designed to provide a precision and bias statement. However, lessons learned and rules for material/data sharing may later be found useful to ASTM as round robin testing is performed.

CENTER FOR COMPOSITE MATERIALS UNIVERSITY OF DELAWARE

Interdisciplinary Research Processing, Mechanics, and Design Activities Noted

Research on Engineered Materials and Processes

For more than a decade, the Center for Composite Materials (CCM) has based its research programs on the integration of several fundamental areas—processing science, materials science, engineering mechanics, durability, and design—with the research in all of these areas feeding into the Center's manufacturing science program. The work of Vistasp M. Karbhari, Associate Scientist at the Center and Research Assistant Professor of Civil Engineering, epitomizes this integration: his research collaborations touch on all of these areas, culminating in an interest in applying concurrent engineering approaches to intelligent manufacturing systems for composites. His work focuses on manufacturing and materials design issues, combining expertise in theoretical and applied mechanics, experimental techniques, materials science, and design.

The ultimate goal of this effort is to understand the close interactions among constituent materials, processes, and performance and thereby to control and develop both the processes and the resultant microstructures to enable a true "materials-by-design" approach to the study and development of advanced composites. That is the rationale for conducting research in several different areas—processing (resin transfer molding, rheology, and flow-related issues); materials science (interphase tailoring, surface treatment, and bonding); mechanics and durability (microcracking and damage mechanisms, textile structural composites); design (methodology, rehabilitation of structures, and concurrent engineering); and even recycling and reuse of composites. These various projects fit into a master plan—fundamental research aimed at understanding and developing engineered materials and structures.

Manufacturing Science—Resin Transfer Molding/Textile Preforming

Resin transfer molding (RTM) is a versatile method by which a composite can be truly tailored through a materials-by-design methodology. While computer simulations yield useful insights into this manufacturing method, there still exists a need to focus on the actual processing of RTM ed composites and delve into the interactions among materials, processing, and performance. The potential of local tailoring through architectural modification, interphase design, and novel resin formulations makes this an exciting area for both fundamental science and technology.

RTM may appear to be a straightforward and sequential process. You prepare the preform, load it into the tool, inject the resin, cure the part, and then demold it. This simple process is a good example of where concurrent engineering can best be used.

The preform must be designed based on not only structural aspects but those of resin infusion and flow as well, and it must be sized keeping in mind the intricacy of chemistry and resin kinetics. The tool has to be designed based on the particular features of the finished product as well as on injection rates and location, cure rates, cooling, and demolding. The injection of the resin must reflect the delicate balance between a quick fill and the integrity of the architecture, as well as tooling and preform-related aspects such as local exotherms through thick sections, differential flow rates through the preform, and resin reactivity. If all of these factors are considered before the product is designed, the RTM process itself can be designed to ensure that the product is of high quality, yet economical.

Karbhari is currently advising several students on RTM projects. They are investigating the problems associated with the design and manufacture of RTM parts with co-cured attachments and connections. The research to date has focused on the placement of metal inserts within the preform, using braiding as a mechanism of enhancing pullout resistance. Surface treatment of the insert is necessary in most cases, but has to be applied in such a way that it will not be abraded by the braiding process. This research will build on the Center's work in joining and design.

In another associated study, preforming issues, specifically preform compressibility and preform joints, and their effect on resin flow, part quality, and structural response, are investigated. Although the preform in many cases is built up by the stacking of layers of fabric akin to the laminae in a laminate, the impregnated structure does not show distinct interlaminar resin-rich regions but acts as a monolithic structure at the macroscopic level. The compressibility of the fabric leads to a very different microstructure, which has significant and diverging effects on performance metrics such as tensile strength and modulus.

The design of fabric architectures for enhanced impact performance of RTM structures is being addressed in a third study. This work encompasses materials science, processing, and durability issues. The goal here is not only to understand and quantify the impact phenomenon in composites, but also to design the material at the constituent level, including the use of interface tailoring of textile structures to contain damage.

The objectives are to tailor the material to withstand impact while retaining residual structural integrity and to evaluate and predict the actual response of the structure in use. Advances made in nondestructive evaluation (NDE) and image enhancement, as well as those in fiber-optics and sensor technology, are being used in this work. The investigation to date has focused on studying and quantifying the impact response of textile structural composites using concepts similar to those of response surfaces and rebound energies to identify material and architecture-specific mechanisms.

Although it is well known that flow has a significant effect on the behavior of RTM composites, there is a surprising lack of data on its effect using actual resin systems. Simulations need to be coupled with experiments that look at both architectural effects and the influence of sizings and binders to determine the influence of wet-out and the significance of microflow and capillarity. These effects, as well as processing/microstructure interactions, are being investigated in an attempt to develop toughening mechanisms for impact and increased fracture toughness. A recently completed preliminary study on the performance of composites under Arctic-type environments indicated that there can actually be performance enhancement of thermoset RTM structures under these environments. In addition to economics, this makes RTM structures attractive for offshore structures and other such applications in extreme environments.

In addition to this ongoing work, Karbhari recently completed a project which investigated the potential for combining RTM and braiding technologies. The work resulted in the manufacture of a structure that forms part of a tree-harvester bed. In a simultaneous investigation, Karbhari investigated the crush resistance of stiffened plate structures fabricated using multi-element preforms. The use of specific architectures enables the development of not only higher performance levels but also "designed-in" modes of failure. The work on "designed-in" failure modes and related work in crush behavior of composites is now being extended to automotive-type crush structures. Damage models as guides for materials design at the constituent level are being developed. The potential of composite materials for automotive applications are being investigated with two goals—to characterize the crush properties of composites under static and dynamic conditions and to define cost-effective manufacturing processes.

Materials Science—Interfacial Studies and Construction Materials

An important element of RTM and other composites processing methods is wet-out—the degree to which the resin infuses the fibers, resulting in fiber/matrix adhesion. Wet-out is further complicated in RTM by the speed of resin infusion and the compatibility of the surface energies of the fibers and the flowing matrix. Research on the effect of various surface coatings on fiber wet-out is also being conducted. The research encompasses interfacial effects in composites in general but with a focus on RTM.

The effect of actual resin systems flowing at different rates and the effects of various sizings are being studied with the goal of tailoring the interface to have "good" and "bad" bonds at will. When the resin infuses the preform, it wets out the surface of a bundle and moves on. Very often, individual rovings within the bundle are not impregnated until much later.

The selection and tailoring of interfaces is also connected to the research on textile structural composites for impact, enhanced toughness, and designed-in benign failure modes. Interface studies as related to pullout, microdebonding, and fragmentation techniques are planned. In addition, the work may include investigations of plasma treatment of surfaces.

Researchers at CCM are also interested in the use of composites for structural applications. The construction industry represents a high-volume application area for composites, but issues of cost and reliability are critical. Research in this area is just developing, with key areas being the investigation of bond strength development through (1) the use of composite bars instead of steel reinforcement, (2) the use of composite waste as high-performance aggregate, and (3) surface modification.

Research to investigate pullout and flexural strength through composites reinforcement, surface modification, and polymer-modified concrete has been initiated. The experimental results will be used to provide design guidelines for composite-reinforced concrete. Full-profile reinforcement will prove to be more beneficial than traditional fiber reinforcement, both for construction of high-performance, light-weight structures and for the rehabilitation of infrastructure.

This area also offers high potential for the reuse/recycling of composites as aggregate or reinforcement or both. The key to its success is low-cost modification of the composite surface, thus creating good bonding with the cement slurry. Investigations to date have focused on composite aggregate in the form of glass-reinforced polycarbonate, polypropylene, and other pellets. Compression tests show gains in strength as well as reduced weight, which makes this attractive from the viewpoint of not only reuse but also performance enhancement.

In addition to reuse/recycling, composites also have high potential in the construction industry for rehabilitation of the nation's infrastructure. In other ongoing related work in the infrastructure rehabilitation area, researchers are investigating concepts such as overwrapping columns with prepreg and bonding panels to the tension-cracked surfaces of concrete beams and plates. The appropriate use of composites can provide the much-needed addition of strength at minimal weight to our weakened structures. Ultimate displacement and energy dissipation of such rehabilitated columns is significantly improved.

Karbhari will be collaborating with other civil engineering faculty to develop new advanced materials and corresponding design methods for structural and construction applications, both for repair/rehabilitation and for building for the future reliably, cost effectively, and designed against both long-term and dynamically induced damage and degradation. Starting in the Fall of 1992, Karbhari will be working with two other civil engineering faculty on a project funded by the Delaware Department of Transportation to investigate the use of composites in rehabilitating bridge box girders.

CENTER FOR COMPOSITE MATERIALS AND STRUCTURES VIRGINIA POLYTECHNIC INSTITUTE

NASA-Virginia Tech Program Outlined; Recent Research Results Highlighted

The NASA-Virginia Tech Composites Program

Introduction

The NASA-Virginia Tech Composites Program was initiated in 1974 and is a cooperative effort between Virginia Tech and the NASA-Langley Research Center. The primary purposes for establishing the Program were to encourage research in the then-new field of composite materials and educate graduate students in this field for eventual employment in academic institutions and government and industrial laboratories.

The research topics funded in the Program began with a study of the tensile and compressive behavior of borsic/aluminum laminates. Since then, funding has been directed at:

- thermal expansion and thermally induced microcracking of graphite-epoxy laminates;
- the effects of radiation on mechanical properties;
- topics relating to the joining of composites;
- geometrically nonlinear effects in composite plates, curved panels, and cylinders, including buckling and postbuckling;
- skin-stiffener interaction in stiffened composite plates, optimal design;
- fabrication, including resin transfer molding and powder processing;
- damage development and progression, including compressive behavior;
- crashworthiness;
- ply dropoffs;
- micromechanics of carbon-carbon; and
- three-dimensional reinforcement.

Funding levels for the Program began with a modest $27 000 per year (approximately the salary of a full professor) and now exceed $650 000 per year. The Program began by supporting one student and now supports up to twenty. A unique feature of the Program is the fact that the students spend a period of time in residence at the NASA-Langley Research Center making use of the experimental and computer facilities and interacting with researchers. Graduates of the Program are highly recruited by universities, government agencies, and private companies. In addition, the results of the research appear in highly respected peer review journals and are presented at national and international technical meetings. The current Director of the Program is Michael W. Hyer. He may be reached at 703-231-5372 for further information.

The next section includes brief descriptions of the current research problems. Each description lists the title of the problem, the Principal Investigator (PI), the Graduate Research Assistant (GRA), and a description of the research. Short biographies of the faculty, staff, and students in the Program follow those descriptions.

Research Topics

Mechanics of Textile Composites (O. H. Griffin, Jr.—PI and E. Glaessgen—GRA): This study is developing models of textile composites, including elastic properties, strength, and failure loads and modes, for use in general purpose finite element programs.

Mechanics of Crashworthy Composite Structures (O. H. Griffin, Jr.—PI and D. M. Thompson—GRA): This study is aimed at development of design methods for crashworthy composite airframe structural components.

Design of Advanced Composite Stiffened Panels (Z. Gürdal—PI and T. Perry—GRA): A cost-effective program, developed earlier, for the geometrically nonlinear analysis of stiffened plates is being incorporated into a design code. The code will be used to design minimum weight panels with various stiffener geometries that are capable of operating in a postbuckled state. Effects of geometric imperfections and lamination variables on structural weight are being investigated.

Integrated Design of Advanced Composite Wing-Skin/Rib-Plate (Z. Gürdal—PI and S. Ragon—GRA): Design optimization of wing-rib and wing-skin panels are commonly performed by using models that ignore the connectivity between the two and use idealized boundary conditions for each panel. The objective of this research is to include effects resulting from interaction of two panels (for example, pressure pillowing, rib crushing loads, and so forth) during the minimum-weight design of a wing box.

Advanced Design Concepts for Composite Aircraft Fuselage (Z. Gürdal and E. R. Johnson—co-PIs and R. Ley—GRA): The objective of this research is to design anisotropic ring and longitudinally stiffened shell structures loaded under combined axial compression, torsion, and internal pressure. The emphasis is on including local stress concentrations at the skin-stiffener interaction region and using a buckling analysis based on nonlinear axisymmetric prebuckling equilibrium configuration during design optimization.

Bending Response of Cylinders (M. W. Hyer—PI and H. Fuchs—GRA): The response of thin-walled composite cylinders to pure rotations of the ends is being studied experimentally and numerically. An extensive experimental fixture is near completion. An analysis that accounts for geometric nonlinearities and is designed to predict structural and material failure has been developed.

Thermally-Induced Buckling of Composite Structures (M. W. Hyer—PI and N. Breivik—GRA): The buckling, postbuckling, and general geometrically nonlinear response of plates has been thoroughly studied with approximate solutions, and the work is being expanded to include the heat transfer characteristics of the problem, other structural shapes, and experiments.

Micromechanical Modelling of Fiber-Matrix Interactions in Carbon-Carbon Composites (M. W. Hyer and O. H. Griffin, Jr.—co-PIs and E. Carapella—GRA): The stresses at the fiber/matrix interface around a crenulated fiber in a composite subjected to transverse tension, transverse shear, fiber-direction tension, and a temperature change are being computed.

Buckling Response of Composite Plates Having Trapezoidal Planform (M. W. Hyer—PI and H. Radloff—GRA): The buckling response of symmetrically laminated composite plates having trapezoidal planform is determined using a nondimensional, semi-analytical, closed-form solution. The calculated buckling loads are compared with both finite element results and experimental results.

Time-Dependent Behavior of Materials for Space (M. W. Hyer—PI and T. Brown—GRA): The need for long-term dimensional stability in various spacecraft and space structures has motivated this investigation. Small levels of creep of the polymer in polymer-matrix composites can cause small changes in shape and surface smoothness that can be disruptive to the role of the space mission if such small changes are not controlled or, perhaps, eliminated completely.

Analysis for Optimal Design of Laminates with Dropped Plies (E. R. Johnson—PI and P. Harrison—GRA): The purpose of this research is to develop a method of analysis that yields improved accuracy and efficiency for predicting interlaminar stresses in a dropped ply laminated as compared to displacement-based finite element methods. We are using mixed variational models of laminates that include the interlaminar stresses as explicit dependent variables.

Improved Crashworthy Composite Fuselage Frames (E. R. Johnson and R. T. Haftka—co-PIs and M. Woodson—GRA): The purpose of this project is to improve the crash behavior of a composite material fuselage frame that is subjected to vertical loading as encountered in drop tower testing. The frames are thin-walled open section rings laminated from graphite-epoxy unidirectional tape. We wish to design these frames optimally for energy absorption so including some progressive failure modeling to account for the limiting loads involved in the crushing process is necessary. A finite element has been developed based on Vlasov's curved bar theory extended to laminated composites to model the intact frame's response.

Resin Transfer Molding (A. C. Loos—PI and V. Hammond and J. D. MacRae—GRAs): The overall objective of this investigation is to develop and verify an analytical resin transfer molding (RTM) model for infiltration and cure of advanced fiber architecture materials with advanced thermosetting resins. Different fiber preforms and thermoset resins will be characterized and incorporated into the RTM model. In addition to RTM model development, processes for fabrication of void free RTM preforms will be developed.

Thermal Cycling Effects on Stitched RTM Composites (A. C. Loos—PI and K. Furrow—GRA): The objective of this investigation is to determine the combined effects of thermal cycling and absorbed moisture on the mechanical performance of stitched textile composites. Preliminary studies have shown the existence of cracks in the microstructure of textile composites with through-the-thickness stitching. This study will attempt to identify the mechanisms that cause microcracking and determine if the presence of microcracks degrades the static and fatigue performance of the material.

Experimental Characterization of Damage Initiation and Growth in Braided Composites (D. H. Morris—PI and S. Burr—GRA): This study focuses on the determination of damage development and progression in braided composite specimens with and without cutouts subjected to combinations of tensile and compressive fatigue loadings.

Recent Research Highlights

Effects of Layer Waviness on Compression-Loaded Thermoplastic Composite Laminates

The effects of layer waviness on the compressive response of T300/P1700 carbon/polysulfone composite laminates were investigated both experimentally and analytically. A three-step procedure was used to fabricate isolated layer waves into the central 0° layer of $[90_2/0_2/90_2/0_2/90_2/0_{2w}]_s$ laminates. The influence of various layer wave geometries on the static compressive strength and compressive fatigue life were determined experimentally. Moire interferometry was used to investigate the disturbance in the displacement fields, and the modes of deformation associated with layer waviness under compressive loading. The state of stress in the vicinity of the layer waves and the influence of the layer waves on static compressive strength were predicted using a plane-strain finite element analysis which included material nonlinearity.

Layer wave geometries up to 1.5-layer thicknesses in amplitude and 22-layer thicknesses in length were tested. These levels of layer waviness are shown to produce reductions in static strength as high as 36%, although the wavy 0° accounts for only 20% of the load-carrying capacity of the laminate. Moderate layer wave geometries produce a one and a half decade loss of compressive fatigue life as compared to specimens without layer waviness. Specimen failures in both static compressive and compressive fatigue tests were sudden and catastrophic. Brooming failure, characterized by through-the-thickness splaying of the layers and numerous delaminations, was the common failure mode. Finite element predictions are shown to correlate with moire interferometry results in regions of accurate in-plane 0° fiber alignment. Interlaminar tensile failure is predicted for a more moderate layer wave geometry, whereas fiber compressive failure is predicted for a more severe layer wave.

For the laminates considered, layer waviness was shown to be detrimental to both static strength and fatigue life. Static strength reductions up to 36% and fatigue life reductions up to 1.5 decades were recorded.

Postbuckling Failure of Composite Plates with Central Holes

The postbuckling failure of square composite plates with central holes is analyzed numerically and experimentally. The particular plates studied have stacking sequences of $[\pm 45/0/90]_{2S}$, $[\pm 45/0_2]_{2S}$, $[\pm 45/0_6]_S$, and $[\pm 45]_{4S}$. A simple plate geometry, one with a hole-diameter-to-plate-width ratio of 0.3, is considered. Failure load, failure mode, and failure locations are predicted numerically by using the finite-element method. The predictions are compared with experimental results. In the experiments, to be accommodated by the test fixture it is necessary for the plates to be slightly larger than the analysis region, extending somewhat beyond the supports. The region outside the supports is included in the numerical study. It is shown that not considering these regions can lead to erroneous numerical predictions. In numerical failure analysis, the interlaminar shear stresses, as well as the inplane stresses, are taken into account. By comparing the interlaminar shear stress calculations from the finite-element method with analytical results for simple cases, a solid foundation for interlaminar shear stress calculation is established. As a failure criterion, the maximum stress criterion is used. A special test fixture was designed for loading the plates. In the experiments, strain gages, linear variable displacement transducers (LVDTs), and the shadow moire and acoustic emission tests are used to monitor plate response.

An issue addressed in the study is the possible mode shape change of the plate during loading. To account for the fact that plates can experience mode shape change, two deformation configurations are considered. One configuration assumes the plate responds with one half-wave in the loading direction, and the other configuration assumes the plate responds with two half-waves in the loading direction. Failure predictions are made for each configuration. No attempt is made to predict the configuration change. However, it is predicted that the first three laminates fail as a result of excessive stresses in the fiber direction and, more importantly, that the load level is independent of whether the laminate is deformed in the one half-wave configuration or the two half-wave configuration. The location of failure does depend on the deformed configuration. It is predicted that the fourth laminate fails because of excessive in-plane shear stress. Interlaminar shear failure is not predicted for any laminate. For the first two laminates, the experimental observations correlated well with the predictions. In the experiments, the third laminate failed along the side support as a result of interlaminar shear. The twelve clustered 0° layers resulted in very low interlaminar shear strength S_{23}. The fourth laminate failed because of in-plane shear in the location predicted. However, material softening resulted in an actual failure load quite different from the predicted value.

Despite multiple half-waves on the loading direction, failure of plates with holes loaded in the postbuckling range fail as a result of excessive inplane stresses.

An Infiltration/Cure Model for Manufacture of Fabric Composites by the Resin Infusion Process

A one-dimensional infiltration/cure model was developed to simulate fabrication of advanced textile composites by the resin film infusion process. The simulation model relates the applied temperature and pressure processing cycles, along with the experimentally measured compaction and permeability characteristics of the fabric preforms, to the temperature distribution, the resin degree of cure and viscosity, and the infiltration flow front position as a function of time. The model also predicts the final panel thickness, fiber volume fraction, and resin mass for full saturation as a function of compaction pressure. The infiltration model is based on D'arcy's law for flow through porous media.

Composite panels were fabricated using the RTM film infusion technique from knitted, knitted/stitched, and two-dimensional (2-D) woven carbon preforms and Hercules 3501-6 resin. Before fabrication, the deflection and permeability of the preforms were measured as a function of compaction pressure. Measurements of the temperature distribution, the resin viscosity and degree of cure, and the infiltration flow front position were compared with the RTM simulation model results. The model predictions were within 12% of the experimental results.

Fabric composites were fabricated at different compaction pressures and temperature cycles to determine the effects of the processing on the properties. The composites were C-scanned and micrographed to determine the quality of each panel. Composite panels fabricated using different temperature cycles to the same state of cure and similar compaction pressures were found to have similar compressive and shear properties.

Advanced cure cycles, developed from the RTM simulation model, were used to reduce the total cure cycle times by a factor of three and the total infiltration times by a factor of two.

The RTM film infusion technique was successfully developed and used to fabricate advanced textile composites from knitted, knitted/stitched, and 2-D woven preforms with a standard epoxy resin system.

The RTM film infusion model was used to predict the final thickness and fiber volume fraction of textile composites to within 7% of measured values and the resin mass within 11% of the measured values. The model prediction of the position of the infiltration front as a function of time correlated well with the experimental results. The total infiltration times obtained from the model were within 12% of the experimentally measured values. The measured and calculated temperature distributions in the RTM layup agreed well for the four different cure cycles. Finally, the model predictions of the resin viscosity and degree of cure correlated with the experimentally measured results obtained from frequency dependent electromagnetic sensors (FDEMS).

Short block compression (SBC) and Iosipescu shear specimens were used to evaluate the compressive and shear mechanical properties of the composite panels. SBC and Iosipescu shear specimens processed at similar pressures with different cure cycles to the same state of cure had nearly identical compressive and shear mechanical properties.

Postbuckling of Laminated Circular Cylindrical Shells According to the Layer-Wise Shell Theory

The layer-wise shell theory of Reddy is used to develop the postbuckling equations of circular cylindrical shells. The Rayleigh-Ritz method is used to solve the equations by assuming a double Fourier expansion of the displacements with trigonometric coordinate functions. Numerical results for postbuckling response of axially compressed multilayer cylinders with simply supported edge conditions are presented for different values of shell imperfections.

The postbuckling response of circular cylindrical shells made of cross-ply lamination schemes is studied using the layer-wise shell theory. The effect of imperfection on the postbuckling response is investigated for isotropic and cross-ply and thin and thick cylindrical shells with simply supported boundary conditions. Thin isotropic cylinders exhibit many eigenvalues close to the minimum eigenvalue. For thick cylinders, the number of eigenvalues close to the minimum eigenvalue is relatively small. On the other hand, cross-ply composite cylindrical shells, thin or thick, show less number of eigenvalues closer to the minimum eigenvalues. When the cylinder is thick, the number is further reduced.

In the postbuckling analysis, it is observed that the magnitude of imperfection has an effect on the load-carrying capacity of the shells. The maximum load-carrying capacity of a shell can be achieved only for small imperfection (say 10^{-5} to approximately 10^{-4} times the thickness of the shell). For large imperfections, the shell does not exhibit any obvious elastic limit load; the nonlinear load-deflection curves indicate softening structural response. In the postbuckling regime, thick cylinders show higher stiffness when compared to thin cylinders. This is due to the large bending rigidity of thick shells.

A Layer-Wise Shell Theory with Applications to Buckling and Vibration of Cross-Ply Laminated Stiffened Circular Cylindrical Shells

Analytical solutions for buckling loads and natural vibrations of circular cylindrical composite shells with axial and circumferential stiffeners are presented. A layer-wise shell theory is used to represent the kinematics of the shell, and the effect of stiffeners is averaged over the domain of the shell. The effect of stiffener eccentricity is taken into account. The Navier solution procedure is used for buckling and vibration analyses. Numerical results for buckling loads are presented to illustrate the accuracy of the layer-wise shell theory compared to conventional shell theories. Finally, the nonlinear (that is, the von Kármán) version of the layer-wise shell theory is formulated and its Rayleigh-Ritz solution is developed.

Exact solutions for buckling and natural vibration of cross-ply laminated circular cylindrical shells with axial and circumferential stiffeners according to the layer-wise theory are developed. The averaged stiffener approach is used to account for the stiffeners. The Navier solution procedure is used to develop the exact solutions for cross-ply lamination schemes and simply supported edge boundary conditions. The computer program based on these solutions contains options to investigate parametric effects of various geometric and material parameters on the buckling loads and natural frequencies. The Rayleigh-Ritz equations associated with the von Kármán (nonlinear) equations of the layer-wise theory are developed for use in the postbuckling analysis. The layer-wise theory predicts more accurate solutions when compared to the conventional shell theories.

Effect of Interfacial Thermal Conductance and Fiber Orientation on the Thermal Diffusivity/Conductivity of Unidirectional Fiber-Reinforced Ceramic Matrix Composites

The role of an interfacial barrier at the fiber-matrix interface in the heat conduction behavior of an uniaxial silicon carbide fiber-reinforced reaction-bonded silicon nitride and the effect of fiber orientation on the heat conduction characteristics of carbon fiber-reinforced borosilicate glass were investigated.

In the study of the effect of an interfacial thermal barrier, a composite with fibers having a carbon-rich coating of about 3 μm was chosen as the reference material. The fiber-matrix interface was then modified by removal of the carbon coating by preferential oxidation, using fibers with no original carbon coating and hot-isostatic-pressing (HIP) after nitridation. The formation of an interfacial gap at the interface, as a result of thermal expansion mismatch between the fiber and the matrix in reference and HIPed composites and removal of carbon coating for oxidized composites, resulted in the dependence of thermal diffusivity/conductivity on the surrounding atmosphere. This effect was attributed to gaseous heat transfer at the interface. However, no atmospheric effects were observed for composites with fibers without the carbon coating as a result of very strong bonding between the fiber and the matrix. HIPing increased the thermal diffusivity/conductivity of the composites caused by densification of the matrix, crystallization of the fibers, and increased physical contact at the interface. Removal of the interfacial carbon layer by preferential oxidation lowered the interfacial conductance considerably, as a result of a decrease in the direct thermal contact between the fibers and the matrix. Interfacial contact conductance determined from measurements made in vacuum for reference and HIPed composites increased rapidly with increasing temperature in accordance with interfacial gap closure. These observations indicate that the heat conduction behavior transverse to the fiber direction of all the composites investigated was strongly affected by the existence of an interfacial thermal barrier.

An analysis was conducted to determine the expression for the effective thermal conductivity of a uniaxially reinforced finite composite strip with insulated edges as a function of the angle between the fiber direction and the temperature gradient. Carbon fiber-reinforced aluminoborosilicate glass composite specimens were used to carry out experimental verification of this analysis. Three types of specimens were used for this study; thin, angled, and thick rectangular. The thin specimens and the angled specimens, with geometry such that the net direction of heat flow was parallel to the fiber direction, represented the case of a composite infinite in extent. The thick rectangular specimens were expected to behave like a finite composite strip. For thin and angled specimens, the thermal conductivity dependence on fiber orientation showed excellent agreement with theoretical behavior predicted from the analysis of a semi-infinite plate. However, for thick specimens, the thermal conductivity turned out to be much lower than that for thin and angled specimens, especially for small fiber angles, below 45°. Thermal conductivity values calculated from the analytical model developed for a finite composite strip with insulated sides agreed very well with experimental values for the thick rectangular specimens for high fiber angles, greater than 45°.

The results of this study have established the important role an interfacial thermal barrier at the fiber-matrix interface can play in determining the transverse thermal diffusivity/conductivity of unidirectionally reinforced ceramic matrix composites. In view of the current trend in ceramic composites research of tailoring interfaces to achieve optimum interfacial mechanical properties, the corresponding thermal effects based on this study should be expected and accounted for. In addition, composites with interfacial gaps have exhibited atmospheric dependence of their thermal diffusivity/conductivity, thereby making it necessary to determine or predict these properties in different atmospheres for use in composite design.

THE ADHESION SOCIETY

1993 Award of Excellence Announced

The Adhesion Society Award for Excellence in Adhesion Science for 1993, sponsored by the 3M Company, will be awarded to Dr. Louis H. Sharpe at the annual meeting of the Society at Williamsburg, Virginia, 21–26 Feb. 1993. Dr. Louis Sharpe was associated with AT&T Bell Labs and worked in the area of adhesion science for over 30 years. Dr. Sharpe is cited in the award:

> For his recognition of the nature and significance of the interphase and for unparalleled leadership in the establishment of the archival literature in adhesion science.

The 1993 Adhesion Society meeting is an International Symposium with emphasis on "The Interphase," in recognition of his insight and the significant efforts in research to understand this region in materials systems.

Dr. Louis Sharpe obtained the B.S. degree in chemistry (honors curriculum) from Virginia Polytechnic Institute and State University and a Ph.D. in physical chemistry from Michigan State University. He was associated with AT&T Bell Laboratories for 30 years; 25 of those years were spent in adhesion research and in adhesives engineering and development.

He took early retirement from Bell Laboratories in 1985 and moved to Hilton Head Island, South Carolina, to pursue a new career as a Consultant in Adhesion and Adhesives as well as an Expert Witness.

Dr. Sharpe was a member of the Board of Advisors of The Center for Adhesion Science at VPI&SU and is presently an Adjunct Professor at that institution. He was a charter member of, and served a three-year term on, the Board of Directors of the Adhesive and Sealant Council Education Foundation.

He was one of the founders of The Adhesion Society and served as its President from 1986 to 1988. He is the Editor-in-Chief of *The Journal of Adhesion* which has been in publication since January 1969. This *Journal* is now starting its 39th volume and will celebrate its 25th year of publication in 1993.

Dr. Sharpe is a member of the American Chemical Society, The Adhesion Society, and the American Association for the Advancement of Science. He is a Fellow of ASTM and was given the ASTM Award of Merit in 1982. He was named the first William C. Wake Memorial Lecturer of the Plastics and Rubber Institute of Great Britain in 1990 and was named the first Robert L. Patrick Fellow of the Adhesion Society in 1991.

He is listed in American Men and Women of Science, Who's Who in the South and Southwest, and Who's Who in Technology.

RECENT COMPOSITES PUBLICATIONS

NDE Test Outlined

Nondestructive Characterization of Composite Media

REFERENCE: Kline, R. A., *Nondestructive Characterization of Composite Media*, Technomic Publishing Co., Inc., 851 New Holland Ave., Box 3535, Lancaster, PA 17604; Telephone: 717-291-5609, FAX: 717-295-4538, ISBN: 0-87762-925-0, 1992, 193 pp., 6 × 9, softcover, $65.

A typical nondestructive evaluation of a composite material usually tests to find large-scale defects and provides little information about the nature of the defect, its effect on mechanical properties of the material, and the expected performance of the part.

Now, a new book, *Nondestructive Characterization of Composite Media*, examines the features of ultrasonic wave propagation that can yield important quantitative information about composite materials, their microstructure, and their mechanical properties.

Written by Ronald A. Kline, School of Aerospace and Mechanical Engineering, University of Oklahoma, this guide to NDE through acoustic wave propagation details both theory and practical applications. The book includes: advanced ultrasound methods for detailed identification and measurement of defects and characterization of microstructure and mechanical properties.

Contents of the book include: Basic Governing Equations, Wave Surfaces, Energy Propagation, Bulk Wave Propagation Anisotropic Media, Guided Waves, Experimental Consideration for Ultrasonic Measurements, Methods for Elastic Modulus Reconstruction from Ultrasonic Data, Experimental Considerations for Dynamic Modulus Measurement in Anisotropic Media: Phase Velocity Versus Group Velocity, Ultrasonic Modulus Measurements in Composite Media, and Composite Microstructure Characterization.

Calendar on Composites

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

15–19 February 1993
International Conference on Advanced Composites
Wollongong, Australia
Contact: T. Chandra—Conference Chairman, Department of Materials Engineering, University of Wollongong, Wollongong NSW 2500 Australia; Telephone: 61-42-213008, FAX: 61-42-213112, E-MAIL: T. CHANDRA@UOW.EDU.AU

21–26 February 1993
International Symposium on The Interphase (Adhesion Society, Inc.)
Williamsburg, Virginia
Contact: Dr. Louis H. Sharpe, 28 Red Maple Rd., Hilton Head Island, SC 29928; Telephone: 803-671-4810, FAX: 803-671-4810

23–25 February 1993
Asia Pacific Conference on Materials Engineering
Nanyang Technological University, Singapore
Contact: Prof. F. W. Travis, School of Mechanical and Production Engineering, Nanyang Technological University, Nanyang Ave., Singapore; Telephone: 2641744, ext. 5500, FAX: 2641859

30 March–2 April 1993
The Second International Symposium on Mineral and Organic Functional Fillers in Polymers (MOFFIS 93)
Namur, Belgium
Contact: Dr. J. G. Fripiat, Facultes Universitaires Notre Dame de la Paix, Rue de Bruxelles, 61, B-5000, Namur, Belgium; Telephone: 32-81-72-45-51, FAX: 32-81-23-03-91

13–17 April 1993
9th International Conference on Wear of Materials
San Francisco, California
Contact: Dr. R. G. Bayer, IBM Corp., Technology Laboratory, P.O. Box 8003, Endicott, NY 13760; FAX: 607-757-1126

2–4 May 1993
Woodfiber-Plastic Composites: Virgin and Recycled Woodfiber and Polymers for High-Volume, Low-Cost Composites
Madison, Wisconsin
Contact: University-Industry Research Program, Rm. 1215 WARF Bldg., 610 Walnut St., UW-Madison, Madison, WI 53705; Telephone: 608-263-2840

4 May 1993
International Composite Repair Seminar
CROSSAIR Conference Center, EuroAirport Basel-Mulhouse-Freiburg
Contact: SACMA, 1600 Wilson Blvd., Suite 1008, Arlington, VA 22209; FAX: 703-841-1559

4–6 May 1993
Fifth Symposium on Composite Materials: Fatigue and Fracture (ASTM)
Atlanta, Georgia
Contact: Dr. Roderick H. Martin, Symposium Chairman, Analytical Services and Materials, Inc., MS 188E, NASA Langley Research Center, Hampton, VA 23665-5225; Telephone: 804-864-3482, FAX: 804-864-7729

6–9 June 1993
First Joint SES, ASME-AMD, ASCE-EMD Meeting
Charlottesville, Virginia
Contact: Carl T. Herakovich, Applied Mechanics Program & Civil Engineering Department, University of Virginia, Charlottesville, VA 22903-2442; Telephone: 804-924-3605, FAX: 804-982-2951, E-MAIL: HERAK@VIRGINIA.EDU

13–18 June 1993
21st Biennial Conference on Carbon
Buffalo, New York
Contact: Prof. D. Chung, Composite Materials Research Laboratory, Furnas Hall, State University of New York at Buffalo, Buffalo, NY 14260; Telephone: 716-636-2520, FAX: 716-636-3875

5–7 July 1993
The SEVENTH International Conference on Composite Structures (ICCS/7)
Paisley, Scotland
Contact: Professor I. H. Marshall, Dept. of Mechanical & Manufacturing Engineering, University of Paisley, High St., Paisley PA1 2BE, Scotland; Telephone: 041-848-3562, FAX: 041-848-3555, Telex: 778951 PCT LIBG

12–16 July 1993
The Ninth International Conference on Composite Materials (ICCM/IX)
Madrid, Spain
Contact: Prof. Antonio Miravete, Department of Mechanical Engineering, University of Zaragoza, Maria de Luna, 3, 50015 Zaragoza, Spain; Telephone: 34-76-517401, FAX: 34-76-512932

27–29 September 1993
Second Canadian International Conference on Composite Structures and Materials (CANCOM '93)
Ottawa, Ontario, Canada
Contact: Dr. W. Wallace, Co-Chairman, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada K1A 0R6; Telephone: 613-993-2469, FAX: 613-993-7136

19–21 October 1993
SAMPE 93
International Convention Center, Birmingham, United Kingdom
Contact: SAMPE 93 Secretariat, Glen House, 200 Tottenham Court Rd., London W1P 9LA, United Kingdom

2–4 November 1993
3rd Pacific Rim Forum on Composite Materials
Honolulu, Hawaii
Contact: Stephen W. Tsai, Department of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305-4035; Telephone: 415-725-3305, FAX: 415-725-3377

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

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

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

17–22 November 1996
ASME Winter Annual Meeting
Atlanta, Georgia
Contact: ASME, 345 E. 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
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Guest Commentary

New Horizons in Composite Structure

by Charles W. Rogers, Principal Engineer, Bell Helicopter Textron Inc.

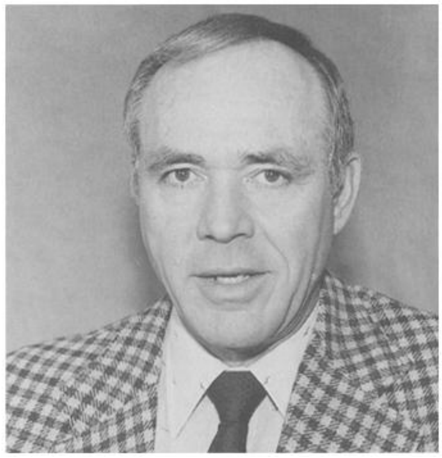
Extensive use of composite materials on the V-22 airframe revealed two facts that greatly influenced its development cost. A shortfall in analytical methods for fracture as a result of out-of-plane loads forced an expensive trial and error approach to the design of a critical component. The structural concepts selected were similar to those used in metal involving many small parts mechanically assembled to meet a desired function. These many small parts and their assembly proved to be more costly than were justified by their associated weight savings. Resolution of these problems will require new analytical methods, material forms, and design and manufacturing concepts.

New approaches to analysis include: (1) classical lamination theory that accounts for out-of-plane deformation, (2) fracture mechanics methods that recognize the importance of matrix cracking, and (3) finite element methods that allow both material and geometric nonlinearity. These are the tools of the future in composite design. New material forms are: (1) a rod of straight carbon fibers, (2) discontinuous fiber prepreg, and (3) dry preforms. These material forms will offer cost reductions and, in the case of the rod, improved compressive strength.

New design concepts use bias laminates $[\pm 45_n]_s$ for skins and attachment areas because of their damage tolerance and unidirectional rods for axial members because they eliminate any question of the quality of fiber alignment.

New manufacturing approaches encourage the designer to focus on integration of function and structure with emphasis on tooled surfaces for next assembly mating. A wing skin, for example, must mate with the rib flanges. If the skin is molded to the inside surface and the rib is tooled to this same interface, a close tolerance fit is assured. While the outside surface of a wing skin is smooth, the inside is complex, containing all the details such as stringers and pad-ups. This detail in the tool also serves to locate the parts of the lay-up. With so much lay-up information on the tool, standardization of the lay-up components frees the operator from constant reference to the lay-up instructions. Standardization also allows material to be dispensed at the work station rather than the labor intensive kiting now practiced.

In the future, certain ground rules will guide design: *(1) minimize composite part count, (2) design for mechanized processes,*



About the Author

Mr. Rogers has been active in research in advanced composite materials since its inception in 1965. His first responsibility was program manager of the F-111 boron/epoxy horizontal tail at General Dynamics. This program ran the full course from development through flight test and limited production. Other programs included the first use of carbon fiber composites on an F-5 aft fuselage section which led to the use of carbon fiber on the full empennage of the F-16 through its production of almost 4000 aircraft. He was consultant to North American Rockwell on the carbon/epoxy space shuttle payload bay doors. More recently, he was responsible for the development of the composite forward wings on the Beech Starship. He has served as associate editor of the *Journal of Composite Materials*, been a member on numerous National Research Council, Air Force, and NASA committees, and written many papers including a NASA Monograph. He is currently active on teams to design a low-cost V-22 wing and a new low-cost light helicopter using the rod concept in both applications.

and (3) design for standardized material forms. These may seem obvious, but let me add to Rule 1 to emphasize the authority that must be exercised with these rules. *(1A) Do not design parts that weigh less than two pounds for the conventional laminating processes*. This rule forces the designer to integrate parts as much as he is able to or make the part out of metal or composites by some other process.

The payoff for these new approaches to composite design and manufacturing will be higher usable strength and lower cost. Along with higher usable strength will be an increased awareness of compressive instability failure modes and aeroelasticity effects. The lower cost of composite structure will allow better value judgments to be made between alternate materials or processes. Greater reliance on analysis as opposed to the more expensive empirical approach will allow more aggressive application in the aerospace field and increased usage in the industrial sector.

The current overcapacity in carbon fiber and composite part manufacturing can change quickly as new applications currently in study come to fruition. For instance, one off-shore tethered oil platform in deep water could use a million pounds of fiber in the tethers alone.

These new composite designs will not look like "black aluminum," and they will not function like isotropic materials. The components will have a molded look, and deformation will be used to advantage. The light general aviation industry is making a comeback in the form of kits of molded composite parts that, when assembled by the buyer (to avoid liability costs), result in very high performance aircraft. Helicopter designers have used composite flexures to replace bearings for several years now, increasing reliability and lowering cost.

The factories will look different, too. Gone will be the large open areas of tables with rolls of tape supported on one end. A multiplicity of specialized machines will service individual work stations. The mold on which the material will be placed will be supported on an articulated mount that will hold the mold in the position best suited for each lay-up. Each bond form will have two parts. The second part will be a shell over the mold to support a custom-fitted curing bag while the bag is not in use. The shell will be held up and out of the way during the lay-up process by the same articulated mount.

All of this will take time and capital, and the United States no longer has any advantage over the rest of the world except our own creative nature.

Best Presentation Award

ASTM Committee D-30 Best Presentation Award

Albert J. DiNicola of United Technologies-Sikorsky Aircraft is a recipient of the D-30 Best Presentation Award for his presentation entitled "Bearing Strength Behavior of Clearance-Fit Fastener Holes in Toughened Graphite/Epoxy Laminates" at the Eleventh Symposium on Composite Materials: Testing and Design held in May 1992 in Pittsburgh with Dr. Eugene Camponeschi as the Symposium Chairman. The Symposium was sponsored by ASTM Committee D-30. The presented paper was coauthored by Steven C. Fantle. The recipient of this award is selected based upon evaluations of all the symposium speakers by five members of the audience.

Bearing Strength Behavior of Clearance-Fit Fastener Holes in Toughened Graphite/Epoxy Laminates

Albert J. DiNicola and Steven C. Fantle

Laminates made of standard modulus carbon fiber in a toughened thermosetting resin matrix were tested under pin-bearing conditions to determine the effects of fastener hole oversize on both 4% hole deformation strength (4% HDS) and maximum bearing stress (MBS) both per the ASTM Test for Bearing Strengths of Plastics (D 953). The types of laminates and the nominal and oversize diameters examined in the study were selected to bracket effectively typical industry practice with regard to aerospace primary structure. Results indicated 4% HDS was reduced by up to 30% as a result of hole oversize, whereas MBS, which results from a complicated progressive damage mechanism, was generally unaffected (Fig. 1). The local effects that characterized the 4% HDS reduction were investigated using nonlinear finite element contact analyses, assuming both the laminate and the bearing pin to be linear elastic materials. Maximum contact force was greatly influenced by hole oversize, ranging from 90 to 240% of the maximum calculated for a conventional cosine contact distribution. Significant differences in the variation of contact force as a function of angular position were noted also. An inverse relationship between contact angle and amount of oversize was noted for all nominal diameters, thereby indicating concentration of contact load near the initial contact point ($\Theta = 0°$) as oversize increased. For applied loads corresponding to the experimentally determined 4% HDS, finite element stress results, used in conjunction with a ply level Hoffman failure criterion, allowed the formulation of a model which could accurately predict 4% HDS for all nominal and oversize diameters tested. The proposed model, which is a variation of the point stress characteristic distance hypothesis, reflects both the local load concentration effects and the nonconstant features of the Hoffman failure contour at points removed from the boundary.

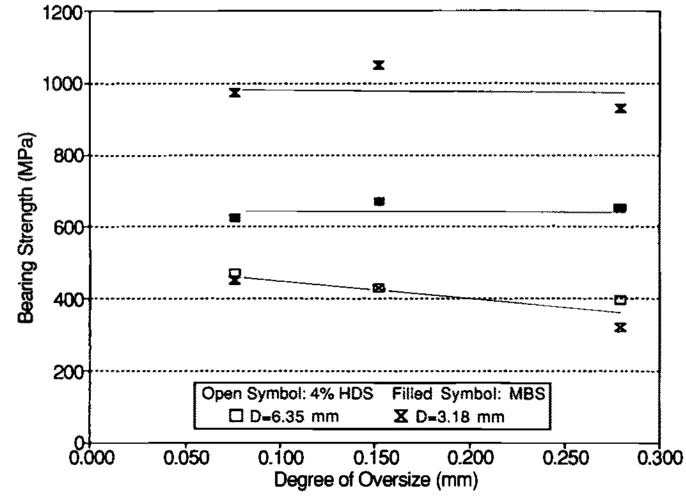
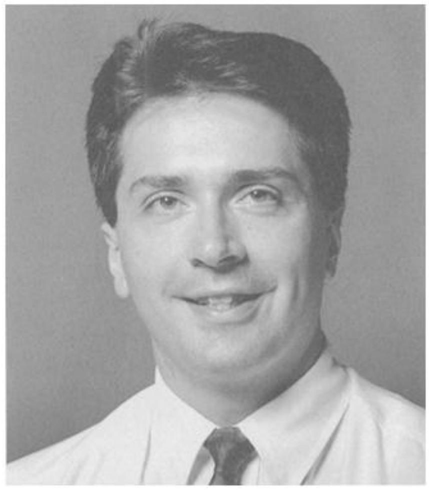


FIG. 1—*Bearing strengths versus oversize.*



About the Author

A native of central Pennsylvania, Mr. DiNicola attended the Pennsylvania State University majoring in Engineering Science and Mechanics. He received a Bachelor of Science Degree with Honors in Engineering Science (1985) and a Master of Science Degree in Engineering Mechanics (1986). He has worked at United Technologies-Sikorsky Aircraft in the areas of composite analysis and testing and analytical methods development. He is currently attending Columbia University, researching applications of three-dimensional anisotropic boundary element methods to fracture mechanics of layered media.

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