

# Journal of COMPOSITES Technology & Research

## EDITOR IN CHIEF

Dr. W. Steven Johnson  
NASA Langley Research Center  
MS 188E  
Hampton, VA 23681

## COEDITORS

Dr. John E. Masters  
Lockheed Engineering and Science  
144 Research Dr.  
Hampton, VA 23666

Dr. T. Kevin O'Brien  
US Army Vehicle Structures Directorate  
MS 188E  
Hampton, VA 23681

## EDITORIAL BOARD

Dr. Donald F. Adams  
Composites Materials Research Center  
University of Wyoming  
Laramie, WY 82071

Dr. Erian A. Armanios  
School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, GA 30332-0150

Dr. Christos C. Chamis  
NASA Lewis Research Center  
MS 49-8  
Cleveland, OH 44135

Dr. Fu-Kuo Chang  
Dept. of Aeronautics and Astronautics  
Stanford University  
Stanford, CA 94305-4035

Dr. Norman A. Fleck  
Engineering Department  
Cambridge University  
Cambridge, CB2 1PZ England

Mr. Samuel P. Garbo  
Sikorsky Aircraft Div.  
6900 Main St., (S314A2)  
Stratford, CT 06601-1381

Dr. Ronald F. Gibson  
Mechanical Engineering Dept.  
Wayne State University  
Detroit, MI 48202

Dr. Michael W. Hyer  
Engineering Science and Mechanics Dept.  
Virginia Polytechnic Inst. and State U.  
Blacksburg, VA 24061-0219

Dr. Larry B. Ilcewicz  
The Boeing Company  
P.O. Box 3707, M/S 6K-19  
Seattle, WA 98124

Dr. Ori Ishai  
Dept. of Mechanical Engineering  
Technion-Israel Institute of Technology  
Technion City 32000 Haifa, Israel

Dr. Frank K. Ko  
Dept. of Materials Engineering  
Drexel University  
Philadelphia, PA 19104

Dr. L. Neal McCartney  
National Physics Laboratory  
Teddington, Middlesex TW11 0LW  
United Kingdom

Dr. Michael R. Piggott  
Dept. of Chemical Engineering  
University of Toronto  
Toronto, Canada M5S 1A4

Dr. J. N. Reddy  
Dept. of Mechanical Engineering  
Texas A&M University  
College Station, TX 77843

Dr. Kenneth L. Reifsnider, *Founding Editor*  
Engineering Science and Mechanics Dept.  
Virginia Polytechnic Inst. & State U.  
Blacksburg, VA 24061-0219

Mr. Charles R. Saff  
McDonnell Douglas Aircraft  
P.O. Box 516, Dept. 337  
St. Louis, MO 63166

Dr. George Sendeckyj, *Past Coeditor*  
U.S. Air Force Wright Laboratories  
WL/FIBEC  
WPAFB, OH 45433-6523

Dr. Wayne W. Stinchcomb  
Engineering Science and Mechanics Dept.  
Virginia Polytechnic Inst. and State U.  
Blacksburg, VA 24061-0219

Dr. Ramesh Talreja  
School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, GA 30332-0150

Dr. Dick J. Wilkins  
Dept. of Mechanical Engineering  
University of Delaware  
Newark, DE 19716

Mr. Dale W. Wilson  
XXSYS Technologies, Inc.  
4619 Ridgeview Ave.  
San Diego, CA 92123

## Purpose and Scope

The objectives of *Journal of Composites Technology & Research* are (1) to provide a forum for the presentation, discussion, and dissemination of information on composite materials and their response to the environments in which they are used, especially the engineering and technology of their application to components and structures, and (2) to provide a means of communication for researchers, developers, producers, users, suppliers, and professional organizations concerned with composite materials.

The editorial scope includes full-length technical articles, technical notes (Composites Review), preliminary technical communications (Research Briefs), news articles and announcements (World of Composites), book reviews, letters, and discussions of previously published work.

*Journal of Composites, Technology & Research* is published quarterly by ASTM as part of the Testing and Evaluation Series, which includes the *Geotechnical Testing Journal* (published quarterly), *Cement, Concrete, and Aggregates* (published semi-annually), and the *Journal of Testing and Evaluation* (published bimonthly).

ISSN 0885-6804

Copyright © 1992 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia, PA. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

**Subscriptions:** United States and Canada for 1 year \$89.00 (members \$80.00), for 2 years \$151.00 (members \$136.00), and for 3 years \$200.00 (members \$180.00). Foreign for 1 year \$98.00 (members \$88.00), for 2 years \$151.00 (members \$136.00), and for 3 years \$220.00 (members \$198.00). Single copies are \$35.00. To subscribe, please send prepaid order to ASTM, Customer Service, 1916 Race St., Philadelphia, PA 19103. *Journal of Composites, Technology & Research* is indexed regularly by Engineering Information, Inc., and is available on microfilm from University Microfilms, a Xerox company, Ann Arbor, MI.

**Photocopy Rights:** Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by the AMERICAN SOCIETY FOR TESTING AND MATERIALS for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of \$2.50 per copy, plus \$0.50 per page is paid directly to CCC, 27 Congress St., Salem, MA 01970; Tel. (508) 744-3350. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Service is 0885-6804/92 \$2.50 + .50.

**Change of Address:** Please return entire addressing label on wrapper to ASTM, Journal Subscriptions Dept.—JCTR, 1916 Race St., Philadelphia, PA 19103.

### General Information

This publication is one of many issued by ASTM in connection with its work in promoting knowledge of the properties and performance of materials, products, systems, and services and in developing standard specifications and test measurement techniques. Much of the information results from voluntary contributions of many of the leading technical authorities from industry, scientific agencies, and government. A list of ASTM publications and additional information will be furnished on request.

### Information for Authors

All contributions to *Journal of Composites Technology & Research* are subject to editing to bring them into accordance with ASTM style. Technical articles are also subject to peer review. Emphasis is placed on composites technology that bridges the gap between industry and the research and development community. Papers must contribute to the permanent literature, be of immediate interest to ASTM members, or be of general interest to a substantial part of the technical community. Articles that have been published or submitted for publication elsewhere or papers of an advertising or promotional nature cannot be printed in the *Journal of Composites Technology & Research*. The paper must not be seriously defective as to literary form and structure, continuity of thought, and clarity of expression. Authors should observe the conventions of style explained in the ASTM Style Manual. Since the journal does not request page charges, the author is expected to conform to these standard conventions. The original manuscript and five clear copies, including original illustrations, should be sent to Kathy Dernoga, Manager, Acquisitions and Review, ASTM, 1916 Race St., Philadelphia, PA 19103 (215-299-5581).

### In Appreciation

The high quality of the technical papers in this publication is a tribute not only to the obvious efforts of the authors represented but also to the unheralded, though essential, efforts of their reviewers. It is to the reviewers' dedication to upholding the high standards of their profession that this note pays tribute. On behalf of ASTM and the authors as well, we acknowledge with appreciation their important contribution to the success of this journal.



### EDITORIAL STAFF

Kathleen A. Peters, *Editor, Books and Periodical Publications*  
Barbara Stafford, *Administrative Assistant, Acquisition & Review*  
Kathy Dernoga, *Manager, Acquisition & Review*  
Susan L. Gebremedhin, *Manager, Books and Journals*  
Roberta Storer, *Director, Editorial Services*  
M. Bruce Vieth, *Director, Production and Graphic Arts*

### ASTM OFFICERS

Emery Farkas, *Chairman*  
Nancy M. Trahey, *Vice-Chairman*  
C. Ross Thomson, *Vice-Chairman*  
Arthur Cohen, *Treasurer*  
James A. Thomas, *President*

### Directors

Donald S. Abelson  
James E. Bihl  
Norma L. Bottone  
Frederic B. Clarke, III  
Sheldon W. Dean, Jr.  
Betty I. Dunbar  
Jon A. Epps  
Rololfo I. Godinez  
Allen W. Grobin, Jr.  
Cyrus P. Henry, Jr.  
Ben M. Hillberry  
John E. Kean  
James J. Lichtenberg  
Harry E. Lunt  
George C. Moran  
Michael M. O'Mara  
John M. Scanlon, Jr.  
Garland W. Steele

### Past Chairmen

John A. Millane  
Albert J. Bartosic

### Committee on Publications

James S. Perrin, *Chairman*  
Leonard Mordfin, *Vice-Chairman*  
Emery Farkas, *Ex-Officio*  
George Beestman  
Victor Chaker  
Gerald Davis  
Robert J. Goode  
R. D. Hooton  
Larry P. Jackson  
W. Steven Johnson  
Paul H. Langer  
Howard J. Pincus  
Sherilyn K. Rutenbeck  
Kenneth R. St. John  
Kurt H. Strauss  
James L. Teal

# MOVING?

To insure uninterrupted service on your CTR subscription, please notify us at least six weeks before you move.

1. Attach your address label from a recent issue in the space provided opposite. (If label is not available, be sure to give your old address, including Zip Code)

A large, empty rectangular box with a thin black border, intended for the user to paste an address label from a recent issue of the journal.

2. Print your name membership no., and address below. (Be sure to include Zip Code)

3. Mail entire notice to: **ASTM-CTR**  
**1916 Race St.**  
**Philadelphia, PA 19103**

Name \_\_\_\_\_ Membership No. \_\_\_\_\_

New Address \_\_\_\_\_

City \_\_\_\_\_ State \_\_\_\_\_ Zip Code \_\_\_\_\_  
(please print or type the above information)