

# Journal of COMPOSITES Technology & Research

## EDITORS

K. L. Reifsnider, *Coeditor*  
Virginia Polytechnic Institute and State  
University, Blacksburg, VA 24061

G. P. Sendekyj, *Coeditor*  
Air Force Wright  
Aeronautical Laboratories  
Dayton, OH 45433

S. S. Wang, *Coeditor*  
University of Illinois  
Urbana, IL 61801

W. Steven Johnson, *Associate Editor*  
NASA Langley  
Hampton, VA 24061

W. W. Stinchcomb, *Associate Editor*  
Virginia Polytechnic Institute and State  
University, Blacksburg, VA 24061

N. J. Pagano, *Associate Editor*  
AFWAL/MLBM  
Wright Patterson AFB, OH 45433

H. T. Hahn  
Pennsylvania State University  
Engineering Science and Mechanics Dept.  
State College, PA 16802

T. Johansson  
Linköping University  
Institute of Technology  
Department of Mechanical Engineering  
S-581-83 Linköping, Sweden

N. J. Johnston  
NASA Langley Research Center  
Mail Stop 226  
Hampton, VA 23665

P. K. Mallick  
University of Michigan-Dearborn  
Department of Mechanical Engineering  
Dearborn, MI 48128

J. F. Mandell  
Massachusetts Institute of Technology  
Department of Materials Science and  
Engineering  
Cambridge, MA 02139

R. J. Morgan  
Michigan Molecular Institute  
1910 W. St. Andrews Rd.  
Midland, MI 48640-2696

E. Morris, *President*  
Structural Composites Industries, Inc.  
Pomona, CA 91768

T. K. O'Brien  
NASA Langley Research Center  
Hampton, VA 23665

L. Penn  
Chemical Engineering Dept.  
Polytechnic University  
Brooklyn, NY 11201

Michael R. Piggott  
University of Toronto  
Department of Chemical Engineering and  
Applied Chemistry  
Toronto, Ontario M5S 1A4, Canada

R. L. Sierakowski  
Ohio State University  
Columbus, OH 43210

C. T. Sun  
Purdue University  
West Lafayette, IN 47907

R. Talreja, *International Coordinator*  
The Technical University of Denmark  
Department of Solid Mechanics  
Lyngby, Denmark

S. W. Tsai  
AFWAL/MLBM  
Wright Patterson AFB, OH 45433

J. M. Whitney  
4371 Round Tree Dr.  
Dayton, OH 45432

Dick Wilkins  
College of Engineering  
University of Delaware  
Newark, DE 19716

C. Zweben  
General Electric Co.  
Space Division  
Valley Forge Space Center  
Philadelphia, PA 19101

## EDITORIAL BOARD

R. J. Arsenault  
Dept. of Chemical and Nuclear Engineer-  
ing  
University of Maryland  
College Park, MD 20742

R. Badaliance  
Naval Research Laboratory  
Washington, DC 20375

H. W. Bergmann  
Director, Institut für Strukturmechanik  
DFVLR  
3300 Braunschweig, West Germany

C. C. Chamis  
NASA Lewis Research Center  
Cleveland, OH 44135

L. J. Cohen, *Industry Coordinator*  
McDonnell Douglas Astronautics  
Company  
Advanced Programs Design and  
Technology  
Engineering Division  
Huntington Beach, CA 92647

I. M. Daniel  
Department of Civil Engineering  
Northwestern University  
Evanston, IL 60201

W. W. Feng  
Lawrence Livermore National Laboratory  
Livermore, CA 94550

R. F. Gibson  
University of Idaho  
Mechanical Engineering Department  
Moscow, ID 83843

## 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.

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

*Journal of Composites Technology & Research* (ISSN 0885-6804; previous title, *Composites Technology Review*) is published quarterly by the American Society for Testing and Materials. Editorial office at the Headquarters of the Society, 1916 Race St., Philadelphia, PA 19103.

**Subscriptions:** *United States and Canada* for 1 year \$38.00 (members \$28.00), for 2 years \$66.00 (members \$48.00), for 3 years \$87.00 (members \$60.00). *Foreign* for 1 year \$43.00 (members \$32.00), for 2 years \$76.00 (members \$56.00), for 3 years \$102.00 (members \$72.00). Single copies are \$14.00. To subscribe, please send prepaid order to ASTM, Subscription Dept.—CTR, 1916 Race St., Philadelphia, PA 19103. *Journal of Composites Technology & Research* is indexed regularly by Engineering Index, Inc., and is available on microfilm from University Microfilms, a Xerox company, Ann Arbor, MI. Copyright 1988 by the American Society for Testing and Materials.

Change of address: Please return entire addressing label on wrapper to *Journal of Composites Technology & Research*, ASTM, Subscription Dept.—CTR, 1916 Race St., Philadelphia, PA 19103 along with new address.

## 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 Greene, 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.

# 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)

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)



## EDITORIAL STAFF

Susan L. Gebremedhin, *Senior Assistant Editor*  
Bette Grugan, *Secretary, Acquisition & Review*  
Kathy Greene, *Manager, Acquisition & Review*  
Bill Benzing, *Manager, Editorial*  
Janet R. Schroeder, *Managing Editor*  
M. Bruce Vieth, *Manager of Production*  
Robert L. Meltzer, *Vice-President, Publications and Marketing*

## ASTM OFFICERS

W. DeWayne France, Jr., *Chairman*  
Albert J. Bartosic, *Vice-Chairman*  
David M. Greason, *Vice-Chairman*  
Nancy M. Trahey, *Treasurer*  
Joseph G. O'Grady, *President*

## Directors

Jack A. Bono  
Richard H. Brown  
Arthur Cohen  
Rebecca A. Cohen  
Emery Farkas  
John E. Foster  
Connie Glover  
John A. Heslip  
Thomas M. Hopkins  
Mary W. Jenkins  
Raymond G. Kammer  
John M. Millane  
Donald M. Preiss  
Kenneth L. Reifsnider  
Henry J. Roux  
Eberhard L. Schuerer  
Richard A. Stimson  
Paul L. Strigner

## Past Chairmen

Robert Baboian  
Gladys B. Berchtold

## Committee on Publications

Sheldon W. Dean, *Chairman*  
James S. Perrin, *Vice-Chairman*  
W. DeWayne France, Jr., *Ex-officio*  
John M. Barsom  
Edward P. Bartkus, *Ex-officio*  
Thomas W. Crooker  
Gerald Davis  
William G. Dukek  
Larry P. Jackson  
Petter M. Jarrett  
W. Steve Johnson  
Edwin L. Lewis  
Leonard Mordfin  
Kenneth R. St. John  
Clifford G. Scott  
William Selconis  
Kenneth St. John  
Frank T. Wagner