

**Life Prediction
Methodology for**

Titanium Matrix Composites



W. S. JOHNSON

J. M. LARSEN

B. N. COX

EDITORS



STP 1253

STP 1253

Life Prediction Methodology for Titanium Matrix Composites

W. S. Johnson, J. M. Larsen, and B. N. Cox, editors

ASTM Publication Code Number (PCN)
04-012530-33



ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
Printed in the U.S.A.

Library of Congress Cataloging-in-Publication Data

Life prediction methodology for titanium matrix composites / W.S.

Johnson, J.M. Larsen, and B.N. Cox. editors.

(STP ; 1253)

“ASTM publication code number (PCN) 04-012530-33.”

Papers presented at the symposium held 22–24 March 1994 in Hilton Head, S.C.

Includes bibliographical references and indexes.

ISBN 0-8031-2039-7

1. Metallic composites—Testing—Congresses. 2. Titanium—Congresses. 3. Service life (Engineering)—Congresses. I. Johnson, W. S. (W. Steven) II. Larsen, James M. III. Cox, B. N. IV. Series: ASTM special technical publication; 1253.

TA481.L55 1996

620.1'89322—dc20

96-10845

CIP

Copyright © 1996 AMERICAN SOCIETY FOR TESTING AND MATERIALS, West Conshohocken, 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.

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, 222 Rosewood Dr., Danvers, MA 01923; Phone: (508) 750-8400; Fax: (508) 750-4744. 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 0-8031-2039-7/96 \$2.50 + .50.

Peer Review Policy

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

Printed in Chelsea, MI

April 1996

Foreword

The papers in the publication, *Life Prediction Methodology for Titanium Matrix Composites*, were presented at a symposium held 22–24 March 1994 in Hilton Head Island, South Carolina. The symposium was sponsored by ASTM Committee D30 on High Modulus Fibers and Their Composites, E8 on Fatigue and Fracture Mechanics, and NASA Langley Research Center. W. S. Johnson, Georgia Institute of Technology, J. M. Larsen, USAF Wright Laboratories, and B. N. Cox, Rockwell International Science Center, presided as symposium cochairmen and are coeditors of this publication.

Contents

Overview	1
-----------------	---

INTERFACE PROPERTIES AND MICROSTRUCTURE

Interfacial Mechanics and Macroscopic Failure in Titanium-Based Composites —T. W. CLYNE, P. FEILLARD, AND A. F. KALTON	5
Effects of Reaction Layer on Interfacial Shear Properties and Strength of Fiber in Silicon-Carbide (SiC) Fiber-Reinforced Titanium Alloy Composite —Y. KAGAWA, C. MASUDA, C. FUJIWARA, AND A. FUKUSHIMA	26
Fiber-Matrix Micromechanics and Microstructural Observations Under Tensile and Cyclic Loading —D. L. DAVIDSON	43
The Role of Frictional Sliding in Transverse Failure of a Titanium Aluminide Composite —D. B. MARSHALL, W. L. MORRIS, B. N. COX, AND D. A. KOURIS	58
Issues Related to Prediction of Residual Stresses in Titanium Alloy Matrix Composites —P. RANGASWAMY AND N. JAYARAMAN	66

FIBER BRIDGING BEHAVIOR

Stress Transfer Mechanics: Models that Should be the Basis for Life Prediction Methodology —L. N. McCARTNEY	85
Crack-Bridging Effects in Notch Fatigue of SCS-6/TIMETAL 21S Composite Laminates —J. M. LARSEN, J. R. JIRA, R. JOHN, AND N. E. ASHBAUGH	114
High Temperature/High Frequency Fatigue Crack Growth in Titanium Metal Matrix Composites —D. ZHENG AND H. GHONEM	137
Modeling and Prediction of Crack Arrest in Fiber-Reinforced Composites —D. C. CARDONA, C. BARNEY, AND P. BOWEN	164

INELASTIC MATERIAL BEHAVIOR AND MODELING

- Sustained Load Behavior of SCS-6/TIMETAL 21s Composites**—M. KHOBAIB,
R. JOHN, AND N. E. ASHBAUGH 185
- Inelastic Deformation Mechanisms in SCS-6/Ti 15-3 Metal Matrix Composite
(MMC) Lamina Under Compression**—G. M. NEWAZ, B. S. MAJUMDAR, AND
F. W. BRUST 208
- A Fully Associative, Nonlinear Kinematic, Unified Viscoplastic Model for
Titanium-Based Matrices**—S. M. ARNOLD, A. F. SALEEB, AND M. G. CASTELLI 231
- Inelastic Deformation of Titanium Matrix Composites Under Multiaxial
Loading**—C. J. LISSENDEN, C. T. HERAKOVICH, AND M. J. PINDERA 257
- Time-Dependent Deformation of Titanium Metal Matrix Composites**—
C. A. BIGELOW, Y. A. BAHEI-EL-DIN, AND M. MIRDAMADI 278
- A Comparison of Analysis Tools for Predicting the Inelastic Cyclic Response
of Cross-Ply Titanium Matrix Composites**—J. L. KROUPA, R. W. NEU,
T. NICHOLAS, D. COKER, D. D. ROBERTSON, AND S. MALL 297
- Modeling of Thermomechanical Fatigue in $[0/\pm 45/90]_s$ Sigma/TIMETAL 21S
Laminates**—Y. A. BAHEI-EL-DIN, G. J. DVORAK, H. NIGAM, AND A. M. WAFA 328

FATIGUE

- Prediction of Matrix Fatigue Crack Initiation from Notches in Titanium
Matrix Composites**—D. J. HERRMANN, G. T. WARD, E. J. LAWSON, AND
B. M. HILLBERRY 359
- Fatigue Damage Evolution and Degradation of Mechanical Properties in
Silicon-Carbide (SiC) Fiber-Reinforced Titanium Matrix
Composites**—S. M. JENG, P. C. WANG, AND J.-M. YANG 377
- Matrix Fatigue Cracking in α_2 Titanium Matrix Composites for Hypersonic
Applications**—T. P. GABB AND J. GAYDA 395
- Characterization of Damage Progression in SCS-6/TIMETAL 21S $[0]_4$ Under
Thermomechanical Fatigue Loading**—M. G. CASTELLI 412

ISBN 0-8031-2039-7