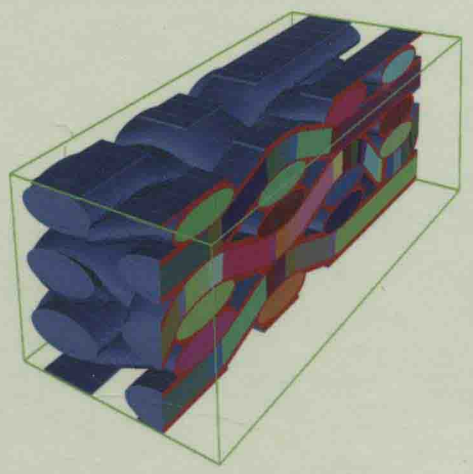
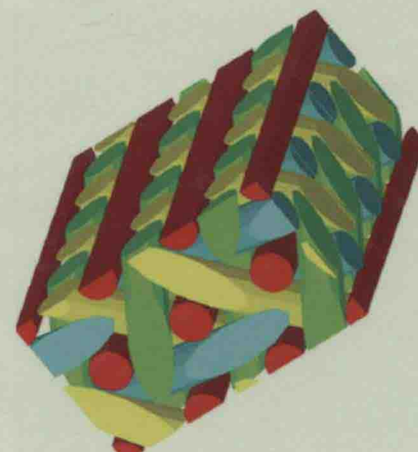
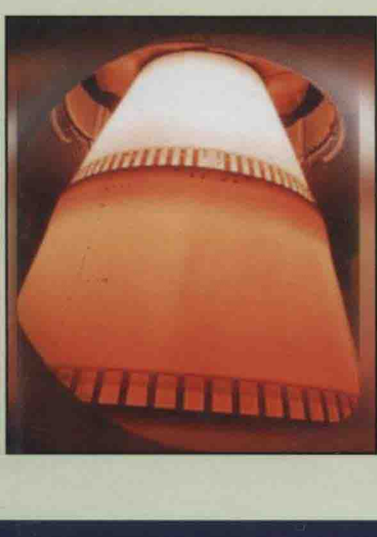
CERAMIC MATRIX COMPOSITES

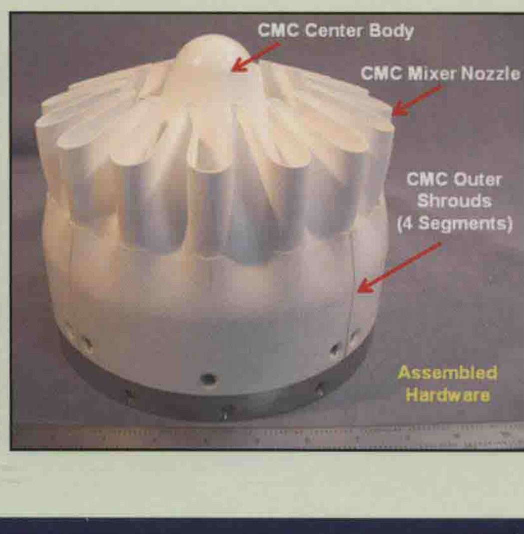
MATERIALS, MODELING AND TECHNOLOGY

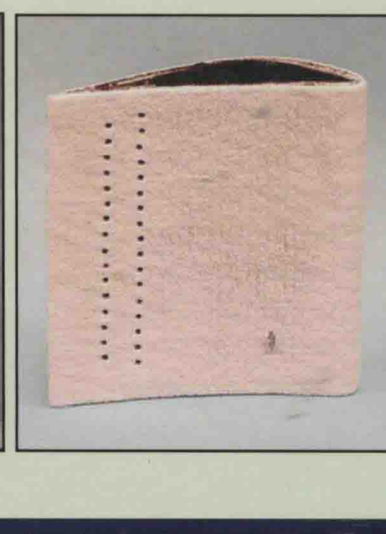
Edited by **NAROTTAM P. BANSAL AND JACQUES LAMON**











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Preface

The concept of composites covers a wide variety of materials of which one can tailor the properties with respect to end-use applications, through a clever combination of constituents. A large variety of composite properties are theoretically foreseeable. A sound combination of continuous brittle fibers and brittle matrix ends up in damage-tolerant ceramic matrix composites (CMCs) with good mechanical properties in a broad range of temperatures. CMCs are lightweight and exhibit much greater resistance to high temperatures and aggressive environments than metals or other conventional engineering materials. They consist of ceramic or carbon matrix reinforced with continuous ceramic or carbon fibers. Their mechanical behavior displays several typical features that differentiate them from the other composites (such as polymer matrix composites and metal matrix composites) and from the homogeneous (monolithic) materials. These features depend on fiber and matrix properties, composite microstructure, interfaces/interphases, and so on.

CMCs are of great interest as thermostructural materials and were developed initially for military and aerospace applications. Now they are being introduced into many other new fields and their range of applications will grow when production cost is drastically reduced. Potential applications include heat exchangers, heat engines, gas turbines, structural components for the aerospace industry, nuclear reactors, chemical industries, automotive industry, biological implants, and so on.

Several approaches are available for processing of CMCs, using liquid, gaseous, or solid precursors. The chemical vapor infiltration (CVI) technique fostered the development of CMCs. The continuous fiber-reinforced CMCs followed the development of C/C composites and the CVI manufacturing technique. Development of CVI SiC/SiC composites began in the 1980s when SEP (now SNECMA), Amercorm, Refractory Composites, and others began to develop equipment and processes for producing CMC components for aerospace, defense, and other applications. SNECMA was at the forefront of this technology and demonstrated satisfactory performance of various CVI SiC/SiC components in turbine engine and flight tests. A number of CVI SiC/SiC components have performed successfully in turbine engines or full-scale tests.

The CVI technique has been studied since the 1960s, as an extension of chemical vapor deposition (CVD) technology. CVD involves the deposition of a solid on a heated substrate, from gaseous precursors. It has been used for many years to produce wear resistant coatings, coatings for nuclear fuels, thin films for electronic circuits, ceramic fibers, and so on. When the CVD technique is used to impregnate rather large amounts of matrix materials in fibrous preforms, it is called chemical vapor impregnation or infiltration. CVI was first used for the fabrication of carbon–carbon composites via pyrolysis of CH_4 at 1000–2000°C. Carbon–carbon (C/C) composites display several advantageous properties (such as low density and good mechanical properties at high temperatures). However, it was realized ca. 1973 that applications of C/C composites would be limited because of their poor oxidation resistance at temperatures higher than 450°C. SiC matrix composites were considered to be a solution to overcome the above shortcoming of C/C composites for long service life at elevated temperatures in oxidative environments. The feasibility of CVI SiC matrix composites was established in 1977 and confirmed independently in 1978. CVI SiC matrix composites reinforced by SiC fibers were manufactured in 1980. The current CVI SiC/SiC composites exhibit excellent performance in extreme environments at elevated temperatures. In the meantime, alternative manufacturing methods have been devised such as melt infiltration (MI), polymer infiltration and pyrolysis (PIP), and hybrid approaches which are a combination of CVI and other methods.

During the past 30 years, tremendous progress has been made in CMC developments. A large amount of knowledge has been acquired, and numerous processing/microstructure/property data have been produced. Results and state-of-the-art at a certain point in time were discussed in published conference proceedings, journal articles, and a few books. However, since we have entered the new millennium, the CMCs have reached maturity for use in systems working at high temperatures. They have now reached a high level of technological development. The issues have moved from processing methods and basic characteristics to stability at high temperatures in aggressive environments, life of material and components, predictive models, and simulation.

Among the features of long fiber-reinforced composites that have to be capitalized, versatility is quite important. For this purpose, characteristics and behavior of constituents have to be considered. The performance of primary constituents requires further and full consideration. From this point of view, the fibers, the interfaces/interphases, the reinforcing preforms, and the matrices are key elements. Some efforts have been devoted to multiscale approaches to thermostructural behavior, including (i) bottom-up approaches to establish microstructure/property relations with a view to a complete approach integrating processing/microstructure/property relations and (ii) top-down approaches for component simulations.

In this book, opportunity was given to international specialists to produce a comprehensive review of recent developments in their field of expertise. They were encouraged to discuss state-of-the-art knowledge on the following topics related to CMCs:

- Behavior and properties of constituents: fibers (including single filaments and tows), fiber/matrix interfaces and interphases, and preforms. (***Chapters 1–4***)
- Carbon/carbon, C/SiC, C/C-SiC, SiC/SiC, oxide/oxide, and ultrahigh temperature ceramic-based composites: manufacturing methods, properties, technology development, and recent advances for major continuous fiber-reinforced composite systems. (***Chapters 5–9***)
- Environmental effects, including effects of steam on high temperature performances of oxide/oxide composites, stress-oxidation degradation in SiC-based composites, thermomechanical ablation, radiation effects on SiC-based and carbon fiber composites, and foreign object damage. (***Chapters 10–14***)
- Protective coatings against surface recession in SiC/SiC and oxidation of ultrahigh temperature composites. (***Chapters 15 and 16***)
- Multiscale modeling of material behavior and computational simulation of life of engineering structures. (***Chapters 17 and 18***)
- Integration and joining of CMCs and mechanical testing of joined structures. (***Chapter 19***)
- Acoustic emission–based detection and quantification of damage with a view to life prediction. (***Chapter 20***)
- Applications of CMCs in key sectors including aeronautics, space, and nuclear plants. (***Chapters 21–23; also Chapters 5, 6, 7, and 8***)

The editors hope that this book will spark interest in the ceramic composite design and development communities and within other organizations that relate to these activities. Universities that educate future engineers who will be working with these complex materials will find much that is valuable and intellectually challenging.

The authors are fully responsible for the material presented in their chapters and they deserve the credit also. The editors are greatly indebted to them for their hard work and dedication in presenting their material in a timely fashion. Thanks are due to Ms. Anita Lekhwani, Senior Acquisitions Editor for Chemistry, Biotechnology, and Materials Science, John Wiley & Sons, Inc., for her cooperation and understanding during the publication of this book.

NAROTTAM BANSAL
JACQUES LAMON

Contributors

Yvan Aspa, Laboratoire des Composites Thermostructuraux, Université de Bordeaux, Pessac, France

Narottam P. Bansal, Materials & Structures Division, NASA Glenn Research Center, Cleveland, OH, USA

Emmanuel Baranger, Laboratoire de Mécanique et Technologie (LMT), CNRS (Centre National de la Recherche Scientifique), ENS Cachan (Ecole Normale Supérieure), UPMC (Univesité Pierre et Marie Curie), Cachan, France

Philippe Boisse, Laboratoire LaMCoS, INSA de Lyon, Université de Lyon, Villeurbanne Cedex, France

Valentina Casalegno, Dipartimento di Scienza dei Materiali e Ingegneria Chimica (DISAT), Politecnico di Torino, Torino, Italy

Sung R. Choi, Naval Air Systems Command, Patuxent River, MD, USA

Christophe Cluzel, Laboratoire de Mécanique et Technologie (LMT), CNRS (Centre National de la Recherche Scientifique), ENS Cachan (Ecole Normale Supérieure), UPMC (Univesité Pierre et Marie Curie), Cachan, France

Patrick David, CEA Le Ripault, Monts, France

James A. DiCarlo, Materials and Structures Division, NASA Glenn Research Center, Cleveland, OH, USA

Monica Ferraris, Dipartimento di Scienza dei Materiali e Ingegneria Chimica (DISAT), Politecnico di Torino, Torino, Italy

Qiangang Fu, National Key Laboratory for Thermostructure Composite Materials, Northwestern Polytechnical University, Xi'an, Shaanxi, China

Martin Genet, Laboratoire de Mécanique et Technologie (LMT), CNRS (Centre National de la Recherche Scientifique), ENS Cachan (Ecole Normale Supérieure), UPMC (Univesité Pierre et Marie Curie), Cachan, France

Nathalie Godin, Laboratoire MATEIS, CNRS, INSA de Lyon, Universit de Lyon, Villeurbanne, France

Shuqi Guo, Hybrid Materials Unit, National Institute for Materials Science, Tsukuba, Ibaraki, Japan

Hiroshi Hatta, Division of Space Propulsion, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa, Japan

Bernhard Heidenreich, German Aerospace Center (DLR), Institute of Structures and Design, Department of Ceramic Composites and Structures, Stuttgart, Germany

George Jefferson, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH, USA

Yutaka Kagawa, Research Center for Advanced Science and Technology, The University of Tokyo, Meguro-ku, Tokyo, Japan

Yutai Katoh, Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

Kristin A. Keller, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH, USA

Ronald J. Kerans, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH, USA

Walter Krenkel, Ceramic Materials Engineering, University of Bayreuth, Bayreuth, Germany

Jean Lachaud, Laboratoire des Composites Thermostructuraux, Université de Bordeaux, Pessac, France

Pierre Ladèveze, Laboratoire de Mécanique et Technologie (LMT), CNRS (Centre National de la Recherche Scientifique), ENS Cachan (Ecole Normale Supérieure), UPMC (Univesité Pierre et Marie Curie), Cachan, France

Jacques Lamon, Laboratoire de Mécanique et Technologie (LMT), CNRS (Centre National de la Recherche Scientifique), ENS Cachan (Ecole Normale Supérieure), UPMC (Univesité Pierre et Marie Curie), Cachan, France

Kang N. Lee, Rolls-Royce Corporation, Indianapolis, IN, USA

Stéphane Mazerat, Laboratoire des Composites Thermostructuraux, Université de Bordeaux, Pessac, France

Gregory N. Morscher, Department of Mechanical Engineering, The University of Akron, Akron, OH, USA

Herwig Peterlik, Faculty of Physics, University of Vienna, Vienna, Austria

Mohamed R'Mili, Laboratoire MATEIS, CNRS, INSA de Lyon, Université de Lyon, Villeurbanne, France

Marina B. Ruggles-Wrenn, Department of Aeronautics & Astronautics, Air Force Institute of Technology, Wright-Patterson Air Force Base, OH, USA

Cédric Sauder, CEA, DEN, DMN, SRMA, F-91191 Gif Sur Yvette, France

Patrick Spriet, Herakles, Safran Group (Retired), Aeronautics and Hi-Temp Composites B.U., Les Cinq Chemins, Le Haillan, France

Jacques Georges Thébault, Thermostructural composites expert, SAFRAN group (Retired), Bordeaux, France

Gerard L. Vignoles, Laboratoire des Composites Thermostructuraux, Université de Bordeaux, Pessac, France

Yiguang Wang, National Key Laboratory for Thermostructure Composite Materials, Northwestern Polytechnical University, Xi'an, Shaanxi, China

Roland Weiss, Schunk Kohlenstofftechnik GmbH, Abteilung Composites, Giessen, Germany

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