Fiber and Whisker Reinforced Ceramics for Structural Applications

David Belitskus

TB321
B431

9461544

E9461544

Fiber and Whisker Reinforced Ceramics for Structural Applications

David Belitskus
Alcoa Technical Center
Alcoa Center, Pennsylvania

Marcel Dekker, Inc. **New York • Basel • Hong Kong**

Library of Congress Cataloging-in-Publication Data

Belitskus, David
Fiber and whisker reinforced ceramics for structural applications / David Belitskus.
p. cm. -- (Materials engineering; 4)
Includes bibliographical references and index.
ISBN 0-8247-9111-8 (alk. paper)
1. Fiber-reinforced ceramics. 2. Crystal whiskers. I. Title. II. Series: Materials engineering (Marcel Dekker, Inc.); 4.
TA455.C43B45 1993
620.1'4--dc20 93-13644
CIP

The publisher offers discounts on this book when ordered in bulk quantities. For more information, write to Special Sales/Professional Marketing at the address below.

This book is printed on acid-free paper.

Copyright © 1993 by Marcel Dekker, Inc. All Rights Reserved.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage and retrieval system, without permission in writing from the publisher.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Current printing (last digit):
10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

Fiber and Whisker Reinforced Ceramics for Structural Applications

MATERIALS ENGINEERING

1. Modern Ceramic Engineering: Properties, Processing, and Use in Design. Second Edition, Revised and Expanded, *David W. Richerson*
2. Introduction to Engineering Materials: Behavior, Properties, and Selection, *G. T. Murray*
3. Rapidly Solidified Alloys: Processes · Structures · Applications, *edited by Howard H. Liebermann*
4. Fiber and Whisker Reinforced Ceramics for Structural Applications, *David Belitskus*

Additional Volumes in Preparation

Thermal Analysis of Materials, *Robert F. Speyer*

Friction and Wear of Ceramics, *edited by Said Jahanmir*

Mechanical Properties of Metallic Composites, *edited by Shojiro Ochiai*

此为试读，需要完整PDF请访问：www.ertongbook.com

Preface

Ceramics reinforced with fibers or whiskers are an important new class of structural materials. A properly designed and fabricated composite material of this type can retain attractive ceramic characteristics such as high strength and stiffness at very high temperatures, but without the brittleness and lack of reliability inherent with unreinforced ceramics. Ceramic composites can result in dramatically improved performance for existing applications, such as cutting tools. In advanced aerospace applications, ceramic matrix composites might be the only materials capable of enabling performance targets to be attained.

Although research on ceramic reinforcement has been carried out for many years, the greatest strides have been made in the last 10 to 15 years. The literature in this area is becoming relatively extensive, but single sources of information that cover all aspects of fiber and whisker reinforced ceramics in detail have been lacking. Although edited multiauthor books are becoming available, such books tend to emphasize areas of individual authors' interest, resulting in a somewhat biased picture of the importance of various aspects of composite technology as well as gaps in the coverage. Hence, this book is intended to fill the need for a single-author work that covers all important aspects of fiber and whisker reinforced ceramics in a logical progression and with balanced coverage of various aspects.

The book provides an introduction to fiber and whisker reinforced ceramics for those not directly involved in this field and having minimal technical background in ceramics, but is also adequately detailed to provide useful information to those entering this field or those whose technology areas will be impacted by these materials. It could also serve as a supplementary textbook for college-level courses in ceramic matrix composites.

Rather than providing an exhaustive reference list on ceramic matrix composites, the book gives key references that permit the reader requiring more information on a particular topic to acquire the necessary information without undue effort. Also, extensive mathematical developments that are associated with some of the topic areas are not covered, but references cited can provide details for those requiring the mathematical treatments.

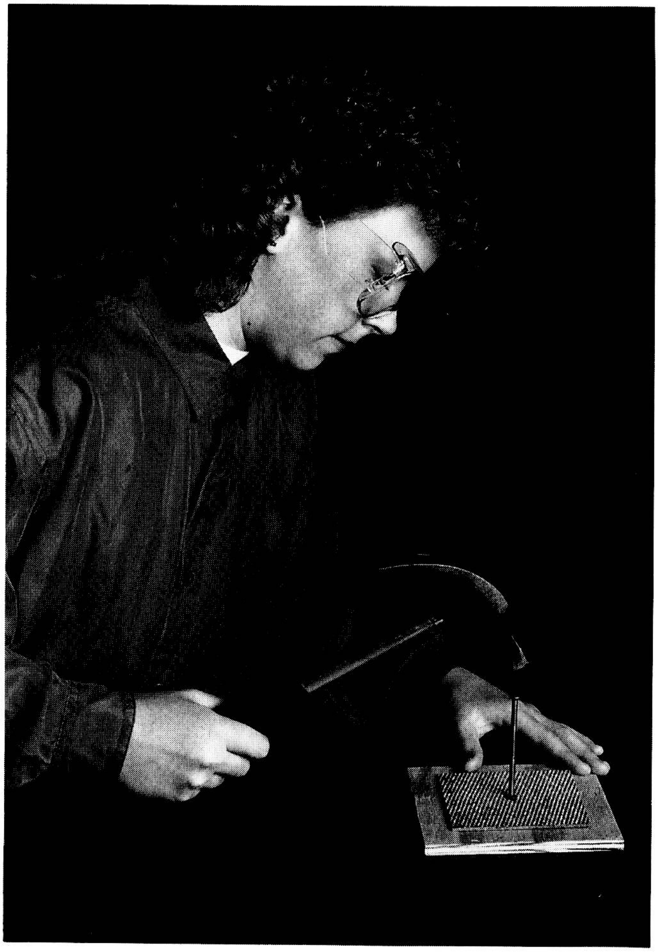
An unavoidable limitation in the reference sources cited warrants mention. The properties of ceramic matrix composites, particularly with regard to continuous fiber reinforcement, have important implications for the military establishment, largely with regard to aerospace applications. For this reason, a great deal of information generated in the United States is restricted in its dissemination by International Traffic in Arms Regulations (ITAR) of the Office of Defense Trade Controls, U.S. Department of State. Similar restrictions are applicable in a number of other countries as well. Thus, while I am aware of developments beyond those reported in this book, they were not mentioned if not documented in publications, reports, or patents that were approved for unlimited distribution. It is my experience that for all but the most sensitive information, general dissemination of new developments lags restricted disclosure by approximately two years.

Some background on my qualifications for writing this book and on events leading to its publication may be of interest. In the mid-1980s, I became involved in formulating programs and conducting R&D on continuous fiber reinforced ceramics at the Aluminum Company of America (Alcoa). For this purpose, a variety of background information on all aspects of ceramic matrix composite technology was collected, organized, studied, and assessed.

Over a period of several years, I had the opportunity to organize and conduct lectures on the technology of ceramic matrix composites. Included were lectures at two offerings, in 1987 and 1989, of a ceramic matrix composite short course organized by Professor Pradeep Rohatgi at the University of Wisconsin–Milwaukee. Professor Rohatgi, as well as several of the course attendees, first suggested that my lecture material could form the basis for a book. The information was expanded and refined for a lecture at the Materials Technology Center of the University of Southern Illinois at Carbondale, a short course conducted at a conference, Advanced Ceramics '90, sponsored by the Society of Manufacturing Engineers, and at a workshop, sponsored by Professor Shaik Jeelani, at Tuskegee University.

The detailed writing of the text was done outside of my normal work hours, but Alcoa Laboratories management graciously provided ancillary support. This included supplying photographic reproductions and the redrafting of a number of figures. Special thanks are due to Margo Xidis of Alcoa Laboratories Information Department for obtaining the permissions required to use the many copyrighted figures and tables utilized in the book.

David Belitskus



The author's daughter illustrates the remarkable toughness of a continuous fiber reinforced ceramic material. A nail driven through the material produced only a localized effect; an ordinary ceramic material would shatter under the same conditions! (Photo by Hugh Fox.)

Contents

此为试读,需要完整PDF请访问: www.ertongbook.com

1

Introduction

I. BACKGROUND

Ceramics are inorganic, nonmetallic materials that have been subjected to high temperatures (above red heat, ~500°C) during manufacture and, often, during use. Although typical ceramics are metal oxides, borides, carbides, nitrides, or combinations of these, most ceramic products developed throughout history have been oxide materials, largely based on clay (which consists mostly of aluminum oxide and silicon dioxide). There is evidence that clay-derived pottery was used as long ago as 10,000 B.C., and that use in bricks and tile was practiced by 2000 B.C.[1]

The term "traditional ceramics" refers to ceramics made solely from unrefined clay or from clay in combination with other powdered or nonplastic materials. Traditional ceramic materials have found wide application in kitchenware such as plates, mugs, and cookware, in decorative articles such as vases, in so-called sanitary ware such as lavatories and toilet bowls, in decorative tile, and in "technical ceramics" such as electrical insulators for power lines and spark plugs. Properties such as high hardness, low thermal conductivity, low thermal expansion, and ability to be brightly colored by coating with other ceramics (in the form of "glazes") have led to development of uses of these types. However, an undesirable characteristic of any of these materials is "brittleness," or susceptiblity to catastrophic cracking. Another undesirable feature is the considerable variablity in properties among apparently identical items.

Few, if any, of us have not learned about the brittleness of a ceramic in dramatic fashion relatively early in life when we accidentally dropped, and shattered, a dinner plate, drinking mug, or mother's favorite vase. We might also have acquired some insight into the variability of ceramic products if we on other occasions accidentally dropped outwardly identical ceramic items onto the same floor from the same height with the good fortune of no breakage! In contrast, probably all of us learned that dropping an item of silverware or a polymeric ("plastic") plate or mug under the same conditions invariably caused no apparent damage. Implicitly, at least, we learned that despite many useful attributes, traditional ceramics have major shortcomings relative to other materials.

Most of the applications mentioned above do not require particularly strong materials. Strengths of traditional ceramics are quite satisfactory for such structural products such as bricks, drain tile, and sewer pipe. Another widely used ceramic structural material, concrete, has a relatively low strength also. However, in more recent years, much time and money has been expended on developing stronger ceramic materials and to otherwise improve properties to compete with metal alloys for more demanding structural applications. These materials include more highly refined oxide materials as well as non-oxides such as those mentioned above. These new materials are commonly termed "advanced ceramics" or, usually in Japan, "fine ceramics." Uses and envisioned uses for advanced ceramic materials include cutting tools, wear-resistant parts, and high-temperature engine parts.

Research and development work on advanced ceramics has resulted in dramatic increases in strengths relative to traditional ceramics; other properties important for specific applications have been improved also. More quantitatively, strengths ranging from 10 to 100 times those of traditional ceramics have been attained. In many cases, strengths exceed those of the best structural metal alloys. On average, the ceramic materials are lower in density than the metal alloys, an important feature for structural applications, particularly those involving moving parts. Typically, the ceramic materials have higher melting or decomposition points than metal alloys, further increasing their attractiveness for many uses.

Nonetheless, even though some improvements have been attained, the major shortcomings of traditional ceramic materials, catastrophic fracture and considerable variability in properties among similar items, have largely remained. Thus, despite considerable effort on development of improved ceramic materials, uses have been limited by these undesirable characteristics.

For some applications, such as a cutting tool bit made from a strong, high temperature resistant advanced ceramic material, occasional catastrophic failure might be merely a tolerable nuisance with only a modest economic penalty. In other applications, such as an automobile engine part, such failure might produce serious economic consequences, if pieces of the failed part are propelled against and damage other engine parts. In a still more demanding application such as an airplane engine part or exterior structural part, catastrophic failure might well lead to loss of flying ability of the plane, with a subsequent crash and loss of life. Thus, the potential application determines just how serious catastrophic, poorly predictable failure of a ceramic material would be.

II. SOME GENERAL COMMENTS ON REINFORCED CERAMICS

Fortunately, there is available a means for retaining most of the attractive properties of advanced ceramic materials, while eliminating or at least greatly reducing the probability of catastrophic fracture, as well as increasing consistency among outwardly identical items. The method used for achieving these improvements is reinforcement with other materials. Reinforcement of ceramics, in general terms, is by no means a new concept. As an example, early bricks containing straw were composites. More familiarly, most structural concrete is reinforced with steel rods or wire to reduce the possibility of catastrophic failure.

However, the subject of this book deals with a relatively new and exciting form of a ceramic composite, consisting of a ceramic matrix reinforced with fine ceramic (or carbon) fibers or whiskers. Only this type of composite has been shown to retain many of the attractive properties of an unreinforced advanced ceramic while appreciably reducing the two major shortcomings described above.

Throughout the remainder of this book, unreinforced ceramics will generally be referred to as "monolithic ceramics." A number of terms will be used to refer to ceramics reinforced with fibers or whiskers. The terms "continuous fiber reinforced ceramics" or "continuous fiber reinforced ceramic composites" will denote ceramics in which the fibers continuously span the material in one or more directions. "Whisker reinforced ceramics" or "whisker reinforced ceramic composites" have the obvious meaning. Work on ceramics containing discontinuous fibers, as opposed to true whiskers, is limited. Although composites containing discontinuous fibers will at times be referred to as "discontinuous fiber reinforced ceramics" or "discontinuous fiber reinforced ceramic composites," more often these will be considered similar to whisker reinforced ceramics and will not be specifically mentioned.

Ceramic materials combined with other ceramic materials not in the form of fibers or whiskers ("particulate composites") are also an important class of materials that can have improved properties over monolithic ceramics. However, in general, the dramatic reduction in the brittleness and/or variability of a ceramic possible with fiber or whisker reinforcement is not attained by particulate reinforcement. One exception is a "transformation toughened ceramic," which provides appreciable improvement at ordinary temperatures but not at the elevated temperatures required for many new ceramic applications. Transformation toughened ceramics and other particulate ceramic composites will not be discussed in this book, except as useful for comparison with fiber or whisker reinforced ceramics.

In the following chapters of this book, key properties of monolithic ceramics relative to other structural materials will be quantified and described in more detail than above. Improvements in ceramic properties possible by fiber and whisker reinforcement will be indicated. Emphasis will be given to properties at high temperatures, since ceramics become more attractive relative to other materials with increasing application temperatures. The mechanisms responsible for improvement in important properties of ceramics by fiber or whisker reinforcement will then be described.

Subsequent chapters will deal with the compositions, structures, production, and properties of representative reinforcing fibers and whiskers, with emphasis on properties at high temperatures. Possibilities for arranging reinforcing fibers in a composite ("fiber architecture") will be discussed. Considerations in the selection of compatible fiber and matrix materials will be indicated, and the importance of the fiber/matrix interfaces and how these interfaces can be influenced to give good composite properties will be covered.

Other chapters will describe all of the significantly investigated ceramic matrix composite fabrication techniques and properties of composites fabricated using these techniques. Joining, machining, structural designing, and nondestructive evaluation will be covered. The book will conclude with a chapter on applications and potential applications.

REFERENCE

1. Girard, W. P., and Wachtman, J. B., Jr., Ceramics, general survey. In *Ullmann's Encyclopedia of Industrial Chemistry*, Fifth Edition, vol. A6, F. T. Campbell, R. Pfefferkorn, and J. F. Rounsaville (Ed.), VCH Publishers, NewYork, 1986, 1-42.

此为试读，需要完整PDF请访问：www.ertongbook.com