HANDBOOK OF ADVANCED MATERIALS

ENABLING NEW DESIGNS

Editor-in-chief

James K. Wessel

Wessel & Associates
Oak Ridge, Tennessee

WILEY-INTERSCIENCE

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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

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Library of Congress Cataloging-in-Publication Data

Wessel, James K.
Handbook of advanced materials: enabling new designs / James K. Wessel.
p. cm.
"Wiley-Interscience publication."
ISBN 0-471-45475-3 (cloth)
1. Materials—Handbooks, manuals, etc. I. Title.
TA403.4.W48 2004
620.1′1—dc22

2004004219

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

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PREFACE

The use of improved materials enables engineers to design new and better products and processes. Benefits include increased sales of improved products and, where new materials are used in manufacturing, reduced plant cost. Society benefits through the use of improved products that use these new materials.

Sophisticated new materials save lives (artificial hearts, shatterproof glass, bulletproof vests), conserve energy (lightweight cars) and expand human horizons (aircraft, spacecraft, computers through the World Wide Web). In the twenty-first century a new generation of materials promises to again reshape our world and solve some of the planet's most pressing problems. Although there is a tremendous array of materials, this book focuses on so-called advanced materials, especially those offering the latest advancements in properties. They are materials of construction with exceptional properties enabling improvement in the engineering components or final products in which they are used. They are also the latest in revolutionary materials and the latest improvement in more traditional advanced materials.

As a designer of "hardware," you may be tempted to assume that the best material for your use is the one you have been using. If so, you will find that this book includes many common materials of construction that have seen recent improvements. For the more adventuresome, we include revolutionary materials whose use may result in great benefit, enabling unique and cost-effective product design.

This handbook presents the most recently introduced advanced materials in an effort to inform you as soon as possible of materials that may improve your product or process. Each chapter describes material characteristics from which materials can be tentatively selected for further exploration. Additional information is available from the references, engineering societies, and trade associations. Examples include The Composite Fabricators Association, The United States Advanced Ceramic Association, ASM International, The American Society of Mechanical Engineers, The Aluminum Association, The American Iron & Steel Institute, The Steel Manufacturers Association, International Titanium Association, and others. All are available through their websites.

This book's purpose is not to provide all the data you need to select materials. Each chapter describes an individual class of materials. Most include corrosion-resistant data plus a separate chapter on this important property. The book's purpose is to narrow your material selection. For your final decision, work with the material supplier as a partner, sharing your problem's parameters. Material suppliers have broad experience that will benefit your material selection. Treat them as a joint problem solver rather than a vendor. Be open to a design change that will realize the benefits of using a new material. Always test materials before use.

Some of the materials presented have revolutionary performance compared to the existing materials that you are using. Others are improvements over existing materials, but, unlike revolutionary materials, they are more familiar, with abundant engineering data, and some similarity to your existing material. Revolutionary materials, like continuous fiber ceramic composites (CFCCs), offer a breakthrough in performance in extreme environments like superior resistance to high temperature, corrosion, and wear. Others, including CFCCs, are also stronger and lighter weight.

Some of the materials presented are high priced, reflecting their high performance. They are used where the result economically benefits the provider and the user. Life-cycle costing will reveal if this is true for your application.

Designing a product involves selecting a material, shape, and manufacturing process. Finding an optimal combination of these to maximize performance and minimize cost is essential for innovation in engineering design and education.

Psychologists tell us that 5% of designers are willing to try something new and 80% will follow if the 5% are successful. Be one of the 5%. The use of new materials can save money, reduce downtime, reduce maintenance, increase operating temperature, increase efficiency, lower emissions, and reduce life-cycle costs.

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CHAPTER 1

Polymer Composites

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*Sections 1.1–1.7
†Sections 1.8–1.13

Handbook of Advanced Materials Edited by James K. Wessel
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1.A POLYMER COMPOSITES

1.1 DESCRIPTION

1.1.1 Scope

Polymer composites can cover a broad range of material combinations. For this chapter, we will consider those combinations that are between the stages of those still being invented and those in wide use. We will also restrict our consideration to those combinations that are intended for structural application. Many, if not most, of the basic concepts and principles of use will be applicable across the total range of materials developed. The specific characteristics of the materials discussed or used as examples will be of those that are advanced in the sense that their full use potential has not yet been realized. For that reason, a great deal of attention will be given to those material combinations that incorporate continuous carbon or graphite fibers as a reinforcing material in a high-performance polymer matrix. Unlike many metals, polymer composite formulas are often proprietary to their suppliers. Contact the supplier to determine the best polymer composite for your application. Suppliers can be identified by contacting the Composite Fabricators Association at `www.cfa-hq.org`. They are located at 1010 North Glebe Road, Suite 450, Arlington, VA 22201, telephone 703-525-0511.

1.1.2 History and Future Developments

Modern polymer composites can trace their origins back to the 1950s when researchers at Wright-Patterson Air Force Base in Ohio began to investigate the properties of plastics that had within them embedded glass fibers. The motivation for these investigations was the search for materials that would meet the ever-increasing demands for higher performance aircraft. Lighter, stronger, and stiffer were the guiding principles. In conjunction with companies such as Owens-Corning Fiberglas and Union Carbide, a high-performance composite of continuous S-Glass and epoxy was developed. This composite found applications in such places as the Poseidon missile casing and ballistic armor. It is still an important material today.

In the 1960s, fibers composed of oriented carbon or graphite began to be developed. The fibers were of low density and higher stiffness than glass fiber. As the demands of agencies such as the Air Force and National Aeronautics and Space Administration (NASA) grew for higher stiffness materials than metal or glass fiber composites, these carbon/graphite fibers and their composites became the materials of choice. Today, many consider *advanced composites* to be those reinforced with carbon or graphite fiber. In actuality, glass-fiber-reinforced composites continue to find new, advanced uses. The design, manufacturing, testing, and performance measuring methods for polymer composites containing any fiber were developed during the time when glass-reinforced composites were finding expanded usage.

The history of glass and carbon-fiber-reinforced composite development is documented by several authors. It is not the intent here to review that history beyond the simple introduction given above. It needs to be pointed out, however, that the composites developed as a result of the search for stiffer, lighter, stronger has had some fortunate side effects in other areas. The new materials also gave the designers more choices of materials for their electrical, thermal, and corrosion needs. These nonstructural properties will be further explored later in the chapter.

The future of polymer composite development is mixed. The decade of the 1990s has seen a slowdown in the drive for improvements led by aerospace. Companies that competed with each other in the need to produce ever more advanced products have seen the market drastically change. Performance used to be the differentiating factor. In today’s world, performance with affordability or value is the key. The industry is looking for new customers in application areas that were not even imagined when advanced polymer composites were developed. Golf clubs, tennis rackets, hockey sticks, softball bats, pole vault poles, canoes, fishing poles, and the like are but the tip of the iceberg for new applications. Automobile, truck cab and trailer, railroad car, and ship applications are under active development. The success of these applications will depend upon designers embracing these materials in their work.

As inventors and applications engineers begin to be comfortable with the type and nature of these advanced materials, application areas will expand and costs will come down. It is hoped that this chapter will give to the designer the basic knowledge and understanding of how these material work, how they are made, and, most importantly, how they can open design imagination.