Fibrous Materials

This new updated edition provides an unrivalled overview of fibrous materials, their processing, microstructure, properties, and applications.

The entire range of fibrous materials is discussed in depth, from natural polymeric fibers such as silk and vegetable fibers, and synthetic polymeric fibers such as aramid and polyethylene, to metallic fibers including steel, tungsten, NbTi, and Nb_3Sn, ceramic fibers such as alumina and silicon carbide, and carbon and glass fibers. Fundamental concepts are explained clearly and concisely along with detail on applications in areas including medicine, aerospace, optical communications, and recycling. Significant recent advances are also covered, with new information on the electrospinning of fibers, carbon nanotubes, and photonic bandgap fibers, and detail on advances made in the production and control of microstructure in high-stiffness and high-strength fibers.

Accessibly written and unrivalled in scope, this is an ideal resource for students and researchers in materials science, physics, chemistry, and engineering.

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एकं सद्विप्रा बहुधा वदन्ति

Ekam sadvipraa bahudhaa vadanti

The truth is only one;
Wise men call it by different names.

– Rigveda, 1.164.46

In loving memory of my dear parents, Manohar L. and Sumitra Chawla; and my brother from North Carolina, J. M. Rigsbee.

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Preface to the Second Edition

Fibrous materials are ubiquitous. Nature makes extensive use of the fibrous form of matter because fibers are extremely flexible, allowing for complex shapes to be formed. Fibers can be natural (cotton, jute, etc.) or synthetic (polyamide, polyethylene, etc.). Synthetic fibers, however, form a large part of our economy. Among synthetic fibers, the so-called high performance fibers (HPF) represent a very small segment by volume. Small though this segment is, it is a very vital one. It is driven by special functions that require specific properties unique to these fibers. Usually HPFs have very high levels of at least one of the following properties: stiffness, strength, ability to resist high temperatures, optical signal transmission, and high resistance to chemicals. Since the publication of the first edition of this book, there has been tremendous progress in the field of fibrous materials. As an example, carbon fibers (one of the HPFs) have entered the era of large scale commercial use in civilian aircraft. Impressive developments in our understanding of spidersilk fiber, processing of synthetic polymeric fibers, metallic fibers and ceramic fibers are recorded in this second edition. Impressive gains have been made in making high strength, lightweight organic fibers such as aramid, polyethylene, etc. as well as very high temperature ceramic fibers such as alumina, silicon carbide, etc. Metallic fibers are used for reinforcement (think of tires), cords and ropes for elevators, bridge cables, etc. Less well known are the superconducting metallic filaments. Other applications of materials in a fibrous form include:

- clothing, garments, carpets, cables, ropes and cords;
- reinforcement of polymers, metals, ceramics, and cement for structural purposes;
- geotextiles for soil-stabilization;
- optical fibers for communication purposes, etc. All the data (audio, video, and data) transmission that we take for granted today, indeed the whole field of fiber optics, would not be possible without the availability of specialty glass fiber. As an aside, we should mention that Charles Kao was awarded the Nobel Prize in physics in 2009 for his work on fiber optics.

The basic theme of the second edition of this book continues to be the triad of *processing–structure–properties* of various materials in fibrous form. It is the only book that covers the whole range of fibrous materials available. The range of fibrous materials covered spans natural polymeric fibers such as silk, vegetable fibers such as cotton, jute, and sisal; synthetic polymeric fibers such as nylon, aramid, and polyethylene; metallic fibers such as steel, tungsten, and Nb-based superconducting filaments;

and glass and ceramic fibers such as glass (for polymer composites and for optical communication including photonic bandgap fibers), carbon, electrospun nanofibers, alumina, and silicon carbide. New information and findings are included on silk fibers (silkworm fibers, spidersilk fiber, and efforts at producing silk fibers via genetic engineering), synthetic polymeric fibers, metallic fibers, ceramic fibers, glass fibers (conventional and for optical communications), and superconducting fibers. An important feature of this book is that it emphasizes *processing* of all kinds of fibers.

Fundamentals and important concepts are explained in a clear and concise manner. Important advances made in the production and control of microstructure to obtain high stiffness and high strength fibers are brought out for the non-specialist to understand. The book is written in a style that is easy to understand without oversimplifying. Mathematics has been kept to the bare minimum necessary. More emphasis is placed on the physical and chemical aspects. The author makes use of a wealth of diagrams and micrographs to bring home important principles and concepts to the reader.

Given the advances made in new types of fibers and processing techniques, substantial new material has been added to this edition. Among these are the electrospinning of fibers (a whole new chapter is devoted to that) and new types of fibers (photonic band gap fibers, carbon nanotubes, etc.). Of course, there are always incremental advances in other conventional fibers. New insights into silk fibers, polymeric, metallic, and ceramic fibers are included. While the book can be used as a text for a semester long course for senior undergraduates, the author has always had the broader aim of providing a text that is suitable as a source of reference for the practicing researcher, scientist, or engineer.

Finally, there is the pleasant task of acknowledgments. In writing a book of this type, there are many sources on which the author depends: research funding sources which help keep the author an active player in the field and collaborators of all sorts, direct and indirect. I am grateful to National Science Foundation, Office of Naval Research, Federal Transit Administration, Los Alamos National Laboratory, Sandia National Laboratory, and Oak Ridge National Laboratory for supporting my research work over the years, parts of which are included in this text. It is my immense pleasure to acknowledge help in various forms from (in alphabetical order): C. H. Barham, A. R. Boccaccini, A. Chawla, K. Chawla, N. Chawla, M. E. Fine, S. G. Fishman, G. M. Gladysz, the late B. Ilschner, M. Koopman, A. Mortensen, P. D. Portella, the late J. M. Rigsbee, P. Rohatgi, N. Shah, U. Vaidya, A. K. Vasudevan, and the late C. A. Wert. Thanks are due to Kanika Chawla, Bryan Whitmore, and Alex Woodman for help with the figures in this edition. I owe a special debt of gratitude to my wife, Nivi, for her patience and understanding.

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Preface to the First Edition

This book is about materials in fibrous form, precisely what the title says. Perhaps the only thing that needs to be emphasized is that the materials aspects of fibers are highlighted. The main focus is on the triad of processing, microstructure, and properties of materials in a fibrous form. I have kept the mathematics to the bare minimum necessary. More emphasis is placed on physical and chemical insights. Although all kinds of fibers are touched upon, there is a distinct tilt toward synthetic, nonapparel-type fibers. This is understandable inasmuch as the second half of the twentieth century has seen tremendous research and development activity in this area of high performance fibers, mainly for use as reinforcement in a variety of matrix materials.

The field of fibrous materials is indeed very vast. To compress all the information available in a reasonable amount of space is a daunting task. My aim in writing this text has been to provide a broad coverage of the field that would make the text suitable for anyone generally interested in fibrous materials. I have provided ample references to the original literature and review articles to direct the reader with a special interest in any particular area.

The plan of the book is as follows. After an introductory chapter, some general terms and attributes regarding fibers and products thereof are described in Chapter 2. This chapter also serves to provide a mutually comprehensible language to textile and nontextile users of fibers. There is no gainsaying the fact that many definitions, units, and terms about fibers owe their origin to the textile industry. Thus, it behooves a materials scientist or engineer to take cognizance of those and be at home with them. At the same time, it is not unreasonable to expect that a textile engineer should know the stress–strain curves of fibers in engineering units. This general chapter is followed by Chapters 3 and 4 on natural and synthetic polymeric fibers, respectively. Chapter 5 covers metallic fibers, which are quite widely used in a variety of engineering applications, although generally not so recognized. Chapter 6 describes ceramic fibers where much innovative processing work has been done during the last quarter of the twentieth century. This is followed by two chapters (7 and 8) on glass and carbon fibers; two fibers that have been commercially most successful and find widespread use as engineered materials, for example both are used as reinforcements in a variety of composites, and optical glass fiber has an enormous market in telecommunications. Chapter 9 describes some of the testing and characterization techniques used with fibers. Finally, Chapter 10 provides a statistical treatment of strength of fibrous materials. One of the major sources of confusions about fiber characteristics is due to the different units that are used, especially the textile and engineering units. An appendix giving different units and their conversion factors is provided. A book on the materials aspects of fibers, or for that matter any other entity, must have photomicrographs to illustrate the microstructural aspects pertinent to that particular material form and the processing that resulted in that material form. Never was the adage, ‘A picture is worth a thousand words’, truer than in the present case. I have tried to include as many micrographs as possible. The sources of these are acknowledged in the figure captions.

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