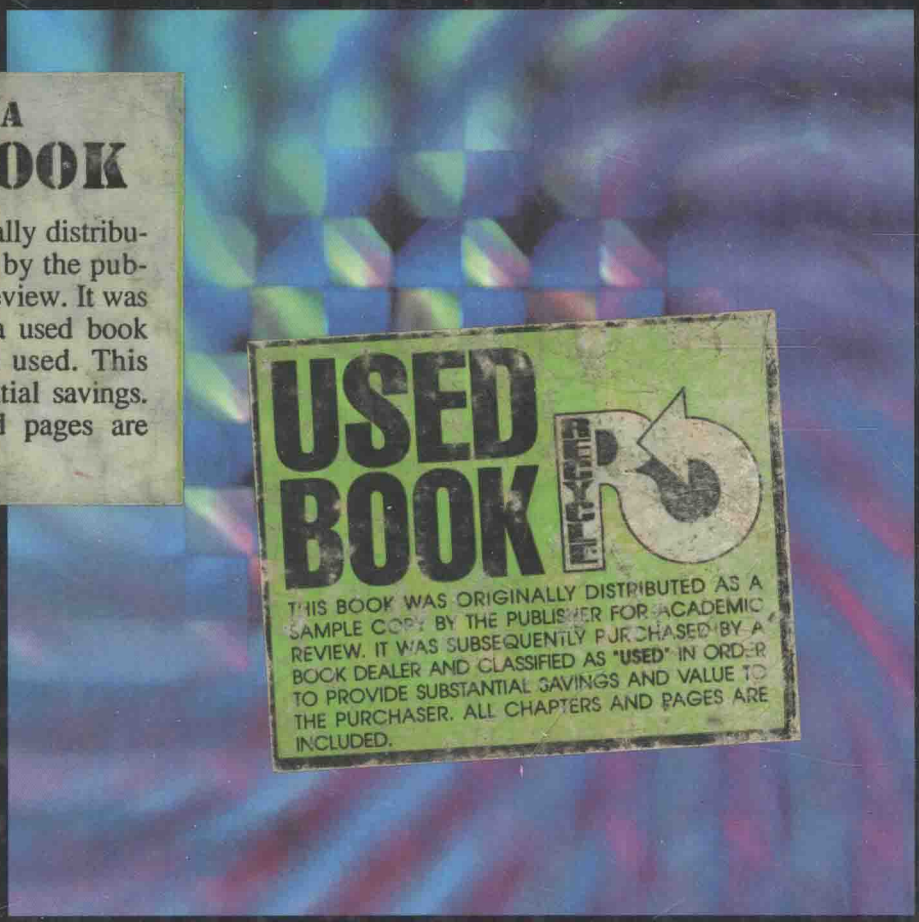
The Science and Design of Engineering Materials



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The Science and Design of Engineering Materials

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James P. Schaffer is an associate professor of Chemical Engineering at Lafayette College in Easton, Pennsylvania. After receiving his B.S. in mechanical engineering (1981), and M.S. (1982) and Ph.D. (1985) in materials science and engineering from Duke University, he taught at the Georgia Institute of Technology for five years before moving to Lafayette in 1990. He has taught an introductory materials engineering course to more than 900 undergraduate students using the integrated approach taken in this text.

Dr. Schaffer's field of research is the characterization of atomic scale defects in materials using positron annihilation spectroscopy along with associated techniques. Professor Schaffer holds two patents and has published more than 30 papers. He was a recipient of the 1989 Ralph R. Teetor Educational Award by the Society of Automotive Engineers and received Lafayette College's Jones Lecture Award for Distinguished Teaching and Scholarship in 1994. He is a member of ASEE, ASM International, TMS, Tau Beta Pi, and Sigma Xi.

ASHOK SAXENA

Ashok Saxena is currently professor and director of the School of Materials Science and Engineering at the Georgia Institute of Technology. Professor Saxena received his M.S. and Ph.D. degrees from the University of Cincinnati in materials science and metallurgical engineering in 1972 and 1974, respectively. After eleven years in industrial research laboratories, he joined Georgia Tech in 1985 as a professor of materials engineering. He assumed the directorship of the school in 1993. From 1991 to 1994, he also served as the director of the Campus-Wide Composites Education and Research Center.

Dr. Saxena's primary research area is mechanical behavior of materials in which he has published over 100 scientific papers and has edited several books. His research in the area of creep and creep-fatigue crack growth has won international acclaim, for which he was awarded the 1994 George Irwin Medal by ASTM. He is also the recipient of the 1994 ASTM Award of Merit. Professor Saxena is an ASTM Fellow and is a member of TMS, ASM International, ASEE, Sigma Xi and Alpha Sigma Mu Societies.

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Stephen D. Antolovich is chairman of the Mechanical and Materials Engineering Department at Washington State University. He received his B.S. and M.S. in metallurgical engineering from the University of Wisconsin in 1962 and 1963, respectively and a

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In 1988 Dr. Antolovich was presented with the Reaumur Medal from the French Metallurgical Society. In 1989 he was named Professeur Invite by CNAM University in Paris. In 1990 he was presented with the Nadai Award by the ASME. Dr. Antolovich regularly makes presentations to learned societies in the United States, Europe, Canada, and Korea and has carried out funded research/consultation for numerous government agencies. Dr. Antolovich has published over 100 archival articles in leading technical journals. His major research interests are in the areas of deformation, fatigue, and fracture, especially at high temperatures. He is a member of ASME, ASTM, AIME, and Fellow Member of ASM International.

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Thomas H. Sanders, Jr., is currently Regents Professor in the School of Materials Science and Engineering at the Georgia Institute of Technology. Professor Sanders received his B.S. and M.S. in ceramic engineering from Georgia Tech in 1966 and 1969, respectively. In 1974 he completed his research for his Ph.D in metallurgical engineering at Georgia Tech and joined the Physical Metallurgy Division of Alcoa Technical Center, Alcoa Center, Pennsylvania. While at Alcoa Center his major research efforts were directed toward developing and implementing processing microstructure–properties relationships for high-strength aluminum alloys used in aerospace applications. He was on the faculty in Materials Science and Engineering at Purdue University from 1980 to 1986 and joined the faculty at Georgia Tech in 1987. He was awarded the W. Roane Beard Outstanding Teacher Award for 1994.

Dr. Sanders's primary research area is physical metallurgy of materials with primary emphasis on aluminum alloys. He has published approximately 100 scientific papers and has edited several books. He was awarded a Fulbright grant in 1992 to conduct research at Centre National de la Recherche Scientifique (ONERA), Châtillon, France. Professor Sanders is a member of TMS and ASM.

STEVEN B. WARNER

Steven B. Warner is Professor and Chairperson of the Textile Sciences Department, University of Massachusetts, Dartmouth. Dr. Warner earned his combined S.B. and S.M. degrees in metallurgy and ceramics in 1973 from the Massachusetts Institute of Technology. In 1976 he was awarded an Sc.D. from the Department of Materials Science and Engineering at MIT. He was a research scientist from 1976–1982 at Celanese Research Co. and from 1982–1988 at Kimberly-Clark Corp. In 1987 he joined Georgia Institute of Technology as Adjunct Professor in Chemical Engineering; in 1988 he became Associate Professor in Materials Engineering; and from 1990–1994 he was a faculty member in Textile and Fiber Engineering.

Dr. Warner's research interests are the structure–property relationships of materials, especially polymers. He has published 30 scientific papers, holds six U.S. patents, and is the author of *Fiber Science.* In addition he is an established technical expert in diaper infringement lawsuits.

Preface

A society's ability to develop and use materials is a measure of both its technical sophistication and its technological future. This book is devoted to helping all engineers better understand and use materials to ensure the future of technology.

THE INTENDED MARKET

The book is intended for undergraduate students from all engineering disciplines. It assumes a minimal background in calculus, chemistry, and physics at the first-year college level. Drafts of the text have been used successfully in a variety of situations including:

- A traditional 40–42 lecture single-semester/quarter course;
- A yearlong course sequence;
- A foundation course for materials engineering majors;
- A service course with students from multiple engineering disciplines;
- A service course targeted at a specific audience (for mechanical or electrical engineers only);
- A section composed of only first- and second-year students;
- As a refresher course for materials engineering graduate students with a B.S. degree in another engineering discipline.

Though only some of the chapters might be used in a single-semester/quarter course, experience suggests that the students benefit from reading the entire text. The authors have intentionally made no effort to mark optional sections or chapters, since topic selection is a function of many factors, including instructor preferences, the background and needs of the students, and the course sequence at a specific institution.

THE AUTHOR TEAM

The field of materials engineering is so vast that no single individual can master it all. Therefore, a team was assembled with expertise in ceramics, composites, metals, polymers, and semiconductors. The author team has the collective expertise to explain clearly all the important aspects of the field in a single coherent package. The authors teach or have taught in chemical, materials, mechanical, and textile engineering departments. We teach at small colleges, where the engineering program is within a liberal arts setting, as well as major technological universities. Just as a composite combines the best features of its constituent materials, this book combines the varied strengths of its authors.

THE INTEGRATED APPROACH

The book is organized into four parts. Part I, Fundamentals, focuses on the structure of engineering materials. Important topics include atomic bonding, thermodynamics and kinetics, crystalline and amorphous structures, defects in crystals, and strength of crystals. The concepts developed in these six chapters provide the foundation for the remainder of the course. In Part II, Microstructural Development, the important processing variables of temperature, composition, and time are introduced, along with methods for controlling the structure of a material on the microscopic level. Part III focuses on the engineering properties of the various classes of materials. It builds upon the understanding of structure developed in Part I and the methods used to control structure set forth in Part II. It is in the properties section of the text that our approach, termed the integrated approach, differs from that of most of the competing texts.

Traditionally, all the macroscopic properties of one type of material (usually metals) are discussed before moving on to describe the properties of a second class of materials. The process is then repeated for ceramics, polymers, composites, and semiconductors. This traditional progression offers several advantages, including the ability to stress the unique strengths and weaknesses of each material class.

As authors, we believe most engineers will be searching for a material that can fulfill a specific list of properties as well as economic, processing, and environmental requirements and will want to consider all classes of materials. That is, most engineers are more likely to ''think'' in terms of a property class rather than a material class. Thus, we describe the mechanical properties of all classes of materials, then the electrical properties of all classes of materials, and so on. We call this the *integrated approach* because it stresses fundamental concepts applicable to all materials first, and then points out the unique characteristics of each material class. During the development of the book the authors found that there were times when ''forcing integration'' would have degraded the quality of the presentation. Therefore, there are sections of the text where the integrated approach is temporarily suspended to improve clarity and emphasize the unique characteristics of specific materials.

The fourth and final part of the book deals with processing methods and with the overall materials design and selection process. These two chapters tie together all the topics introduced in the first three parts of the book. The goal is for the student to understand the methods used to select the appropriate material and processing methods required to satisfy a strict set of design specifications.

EMPHASIS ON DESIGN AND APPLICATIONS

Students are better able to understand the theoretical aspects of materials science and engineering when they are continually reinforced with applications and examples from their personal experiences. Thus, we have made a substantial effort to include both familiar and technologically important applications of every concept introduced in the text. In many cases we begin a discussion of a topic by describing a familiar situation and asking why certain results occur. This approach motivates the students to learn the details of the quantitative models so that they can solve problems, or understand phenomena, in which they have a personal interest.

The authors believe that most engineering problems have multiple correct solutions and must include environmental, ethical, and economic considerations. Therefore, our homework problems include both numerical problems with a single correct

answer and design problems with multiple valid solution techniques and "correct" answers. The sample exercises within the text are divided into two classes. The **Example Problems** are straightforward applications of concepts and equations in the text and generally have a single correct numerical solution. In contrast, **Design Problems** are open-ended and often involve selecting a material for a specific application.

We have used a **Case Study** involving the design of a camcorder as a continuous thread throughout the manuscript. Each of the four parts of the text—Fundamentals, Microstructural Development, Properties, and Design—begins with the identification of several materials issues associated with the camcorder that can only be understood using concepts developed in that portion of the text. This technique allows students to get a view of the forest before they begin to focus on individual trees. The ongoing case also permits us to form bridges between the important aspects of the course within a context that is familiar to most students.

The authors' belief in the importance of materials design and selection is underscored by the inclusion of an entire chapter on this subject at the end of the book. We recommend strongly that the instructor have the students read this chapter even if the schedule does not permit its inclusion in lecture. We find that it "closes the loop" for many of our students by helping them to understand the relationship among the many and varied topics introduced in the text. The design chapter contains 10 case studies and addresses issues such as life-cycle cost analysis, material and process selection, nuclear waste disposal, inspection criteria, failure analysis, and risk assessment and product liability.

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This book has undergone extensive revision under the direction of a distinguished panel of colleagues who have served as reviewers. The book has been greatly improved by this process and we owe each reviewer a sincere debt of gratitude. They are:

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SUPPLEMENTS

We have devoted considerable effort to the preparation of a high-quality solutions manual. Our approach is to employ a common solution technique for every homework problem. The procedure includes the following steps:

1. Find: (What are you looking for?)
2. Given: (What information is supplied in the problem statement?)
3. Data: (What additional information is available, from tables, figures, or equations in the text, and is required to solve this problem?)
4. Assumptions: (What are the limits on this analysis?)
5. Sketch: (What geometrical information is required?)
6. Solution: (A detailed step-by-step procedure.)
7. Comments: (How can this solution be applied to other similar situations and what alternative solution techniques might be appropriate?)

A set of transparencies of the figures and tables in the text are available from the publishers.

ACCURACY

All equations, example problems, homework problems and solutions, illustrations, and tables have been checked by at least two of the authors and then independently verified by Professor David B. Knorr at Rensselaer Polytechnic Institute. The book has been class-tested by the authors at Lafayette College and The Georgia Institute of Technology.

James P. Schaffer
Ashok Saxena
Stephen D. Antolovich
Thomas H. Sanders, Jr.
Steven B. Warner

Contents in Brief

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