国外优秀材料科学与工程教学用书

工程材料科学与设计

第二版 影印版

THE SCIENCE AND DESIGN OF ENGINEERING MATERIALS

Second Edition

■ SCHAFFER
SAXENA
ANTOLOVICH
SANDERS
WARNER

高等教育出版社
Higher Education Press

McGraw-Hill Companies

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PHYSICAL DATA FOR THE ELEMENTS

Element	Symbol	Atomic number	Atomic weight (amu)	Melting point (°C)	Density of solid, 20°C (gm/cm³)	Crystal structure, 20°C
Aluminum	Al	13	26.98	660.452	2.7	FCC
Antimony	Sb	51	121.75	630.755	6.69	Rhomb.
Argon	Ar	18	39.95	−189.352	—	—
Arsenic	As	33	74.92	603	5.78	Rhomb.
Barium	Ba	56	137.33	729	3.59	BCC
Beryllium	Be	4	9.012	1289	1.85	HCP
Boron	B	5	10.81	2092	2.47	—
Bromine	Br	35	79.9	−7.25	—	—
Cadmium	Cd	48	112.4	321.108	8.65	HCP
Calcium	Ca	20	40.08	842	1.53	FCC
Carbon	C	6	12.01	3826	2.27	Hex.
Cesium	Cs	55	132.91	28.39	1.91	BCC
Chlorine	Cl	17	35.45	−100.97	—	—
Chromium	Cr	24	52	1863	7.19	BCC
Cobalt	Co	27	58.93	1495	8.8	HCP
Copper	Cu	29	63.55	1084.87	8.93	FCC
Fluorine	F	9	19	−219.67	—	—
Gallium	Ga	31	69.72	29.7741	5.91	Ortho.
Germanium	Ge	32	72.59	938.3	5.32	Dia. cub.
Gold	Au	79	196.97	1064.43	19.28	FCC
Helium	He	2	4.003	−271.69	—	—
Hydrogen	H	1	1.008	−259.34	—	—
Iodine	I	53	126.9	113.6	4.95	Ortho.
Iridium	Ir	77	192.22	2447	22.55	FCC
Iron	Fe	26	55.85	1538	7.87	BCC

郑重声明

THE AUTHORS

James P. Schaffer

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 his 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 1200 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 has received a number of teaching awards including the Ralph R. Teetor Educational Award (SAE, 1989), Jones Lecture Award (Lafayette College, 1994), Distinguished Teaching Award (Middle Atlantic Section of ASEE, 1996), Superior Teaching Award (Lafayette Student Government, 1996), Marquis Distinguished Teaching Award (Lafayette College, 1996), and the George Westinghouse Award (ASEE, 1998). He is a member of ASEE, ASM International, TMS, Tau Beta Pi, and Sigma Xi.

Ashok Saxena

Ashok Saxena is currently professor and chair 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 chairmanship 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 125 scientific papers and has edited several books. His research in the area of creep and creep-fatigue crack growth has won international acclaim; he was awarded the 1992 George Irwin Medal for it by ASTM. He is also the recipient of the 1994 ASTM Award of Merit. Professor Saxena is an ASTM Fellow, a Fellow of ASM International, and a member of ASEE, TMS, Sigma Xi, and Alpha Sigma Mu.

Stephen D. Antolovich

Stephen D. Antolovich is currently a professor of Mechanical and Materials Engineering at Washington State University, where he also serves as director of the School of Mechanical and Materials Engineering. He received his B.S. and M.S. in metallurgical engineering from the University of Wisconsin in 1962 and 1963, respectively, and a Ph.D. in materials science from the University of California–Berkeley in 1966. He joined the Georgia Institute of Technology in 1983, where he served as professor of materials engineering, director of the Mechanical Properties Research Laboratory (MPRL), and director of the School of Materials Science and Engineering.

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, and AIME, and a Fellow Member of ASM International.

Thomas H. Sanders, Jr.

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 a Fellow of 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 more than 30 scientific papers, holds six U.S. patents, and is the author of *Fiber Science*. In addition he has been a technical expert in a number of patent cases.

FOREWARD

If one's technical library were to contain only a single book on materials, this is the book to have. The authors have succeeded in covering the field of materials science and engineering in even its broadest aspects. They have captured both the science of the discipline as well as the engineering and design of materials. All classes of materials are treated; metals, semiconductors, ceramics, and polymers, as well as composites made of combinations of these. As urged in the National Research Council's recent study of materials science and engineering, processing and synthesis also are included, as are the subjects of machinability and joining. (No material, however outstanding its properties, is likely to be very useful if it can't be produced, shaped, or attached to other components.)

The breadth of *The Science and Design of Engineering Materials*, which reflects the varied fields of expertise of the authors, makes it an ideal text for a survey course for students from all fields of engineering. Because of the depth as well as the breadth with which the topics are treated, the text also is an excellent choice for introductory courses for materials science and engineering majors. Graduates of these introductory and survey classes will value *The Science and Design of Engineering Materials* as a resource book for years to come. The clear explanations and frequent examples allow the practicing engineer, on his or her own, to become acquainted with the materials field or update his/her knowledge of it. Care and skill have been exercised in the choice of illustrations. Numerous drawings and graphs augment explanations in the text, and clearly reproduced micrographs provide real-life examples of the phenomena being described. The examples and questions are especially noteworthy. While a portion of the questions are of the "one right answer" kind, and are intended to reinforce and clarify the material in the text, others are of the open-ended, design type that require creative thought and more closely resemble real-life situations. They can form the bases for useful and provocative class discussions.

This new edition of *The Science and Design of Engineering Materials* is a valuable addition to the materials literature. It will contribute to the materials education of engineers and scientists for years to come.

Julia Weertman
Walter P. Murphy Professor of Materials Science and Engineering
Northwestern University

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. The text has been used successfully in a variety of situations including:

- A traditional 40- to 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 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 **Examples** are straightforward applications of concepts and equations in the text and generally have a single correct numerical solution. In contrast, **Design Examples** 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 relationships 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.

CHANGES TO THE SECOND EDITION

Five new features have been added to the second edition of the text:

1. Each chapter begins with a motivational insert called Materials in Action. This feature is designed to introduce the reader to the important ideas in the chapter through an interesting real-world situation. Examples include a description of how adding 0.4 weight percent carbon to iron increases the strength of the material by two orders of magnitude, a discussion of why directionally solidified nickel-based turbine blades are worth their weight in gold in some aerospace applications, and an illustration of the false economy of using less expensive machining operations if they have a negative influence on fatigue crack initiation. This new feature extends our emphasis on design and applications, which was one of the most popular attractions of the first edition.

2. We have developed a new Materials in Focus CD-ROM to enhance the textbook presentation. The CD-ROM contains a phase diagram tool and over 30 animations designed to help the reader gain an understanding of some of the visual concepts in the book. Examples include "three-dimensional" views of unit cells and polymer molecules, the movement of dislocations through crystals, changes in the population of electron energy levels in semiconductors with temperature, illustrations of polarization mechanisms, and examples of processing operations. In addition, the CD-ROM contains all of the photomicrographs in the text, and a series of interactive example problems. For example, in the portions of Chapter 7 on phase diagrams students can select a state point on a phase diagram and have the software help them determine the phases present, the compositions of the phases, and their relative amounts. Every illustration on the CD-ROM is directly linked to an illustration, concept, or problem in the text. In fact, every location in the text that has a link to a CD-ROM animation or example is clearly indicated by the presence of a "CD-ROM" icon in the margin of the text.

3. Over 225 new homework problems have been added throughout the text. The majority of the chapters contain several design problems (i.e., problems with multiple correct solutions). These homework problems are marked with a "Design Problem" icon in the margin of the text.

4. We have added an eight-page full color insert near the center of the book. This feature allows us to illustrate several important applications of materials science and engineering that simply are not easily described with either words or two-color illustrations.

5. The entire book has been redesigned for enhanced readability. In particular, the use of the icons illustrated below permits the reader to quickly identify several important features of the second edition:

→ Design Problems

→ Design Examples

→ Animated CD-ROM Concept

We have made a determined effort to improve the quality of the photomicrographs and to eliminate errors that were present in the first edition. We would like to express our sincere thanks to those of you who spotted problems and pointed them out to us. The book is better for your efforts, and if you have additional suggestions for how to improve the text we would be happy to hear them.

6. A Web site for the book can be found at http://www.mhhe.com. It contains information about the book and its supplements, Web links, and teaching resources.

ACKNOWLEDGMENTS

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. The reviewers for the first edition were:

John R. Ambrose,	*University of Florida*
Robert Baron,	*Temple University*
Ronald R. Bierderman,	*Worcester Polytechnic Institute*
Samuel A. Bradford,	*University of Alberta*
George L. Cahen, Jr.,	*University of Virginia*
Stephen J. Clarson,	*University of Cincinnati*
Diana Farkas,	*Virginia Polytechnic Institute*
David R. Gaskell,	*Purdue University*
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Charles M. Gilmore,	*The George Washington University*
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Ian W. Hall,	*University of Delaware*
Craig S. Hartley,	*University of Alabama at Birmingham*

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Peter A. Thrower,	*Pennsylvania State University*
Jack L. Tomlinson,	*California State Polytechnic University*
Alan Wolfenden,	*Texas A&M University*
Ernest G. Wolff,	*Oregon State University*

The reviewers for the second edition are:

Bezad Bavarian,	*California State University–Northridge*
David Cahill,	*University of Illionois*
Stephen Krause,	*Arizona State University*
Hillary Lackritz,	*Purdue University*
Thomas J. Mackin,	*University of Illinois–Urbana*
Arumugam Manthiram,	*The University of Texas at Austin*
Walter W. Milligan,	*Michigan Technological University*
Monte J. Pool,	*University of Cincinnati*
Suzanne Rohde,	*University of Nebraska–Lincoln*
Jay Samuel,	*University of Wisconsin–Madison*
Shome N. Sinha,	*University of Illinois–Chicago*

The authors would also like to thank the members of the editorial team: Tom Casson, publisher; Scott Isenberg; Kelley Butcher, developmental editor; and Gladys True, project manager. We would also like to thank James Mohler of the Department of Technical Graphics, Purdue University, the developer of the Materials in Focus CD-ROM.

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?)

The solutions manual is available to adopters of the text. Also, the authors have gained considerable experience using the "integrated" approach in the classroom and are available to discuss implementation strategies with interested colleagues at other institutions.

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

UNIT CONVERSION FACTORS

Temperature	K = °C + 273 °C = 1.8(°F − 32) °R = °F + 460
Length	1 m = 10^{10} Å = 3.28 ft = 39.4 in
Mass	1 kg = 2.2 lbm
Force	1 N = 1 kg-m/s^2 = 0.225 lbf
Pressure (stress)	1 Pa = 1 N/m^2 = 1.45×10^{-4} psi
Energy	1 J = 1 W-s = 1 N-m = 1 V-C 1 J = 0.239 cal = 6.24×10^{18} eV
Current	1 A = 1 C/s = 1 V/Ω

CONSTANTS

Avogadro's number	6.02×10^{23} mol^{-1}
Gas constant, R	8.314 J/(mol-K)
Boltzmann's constant, k	8.62×10^{-5} eV/K
Planck's constant, h	6.63×10^{34} J-s
Speed of light in a vacuum, c	3×10^8 m/s
Electron charge, q	1.6×10^{-19}C

SI PREFIXES

giga, G	10^9
mega, M	10^6
kilo, k	10^3
centi, c	10^{-2}
milli, m	10^{-3}
micro, μ	10^{-6}
nano, n	10^{-9}

BRIEF CONTENTS

CONTENTS