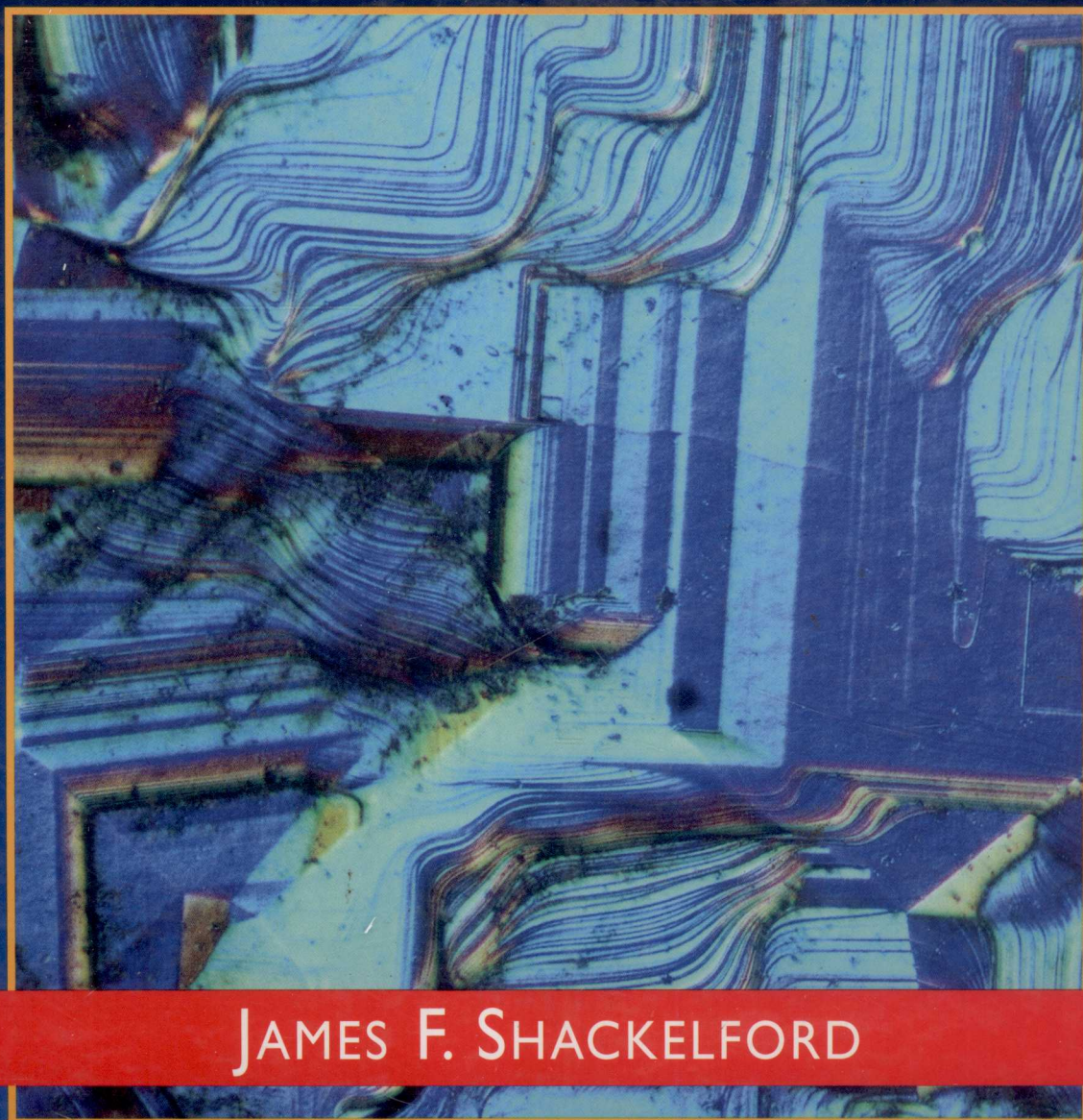


I N T R O D U C T I O N T O

MATERIALS SCIENCE FOR ENGINEERS

FIFTH EDITION



JAMES F. SHACKELFORD

0036179

INTRODUCTION
to MATERIALS
SCIENCE
— *for* —
ENGINEERS

FIFTH EDITION

JAMES F. SHACKELFORD

University of California, Davis



Prentice Hall
Upper Saddle River, New Jersey 07458

Shackelford, James F.

Introduction to materials science for engineers / James F. Shackelford. -- 5th ed.

p. cm.

Includes bibliographical references and index.

ISBN 0-13-011287-9

1. Materials I. Title.

TA403.S515 1999

99-41181

620.1-dc20

CIP

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The cover: Weldment between Ti-6Al-4V and Ni-Cr alloys following an argon anneal. Nomarski interference contrast, with incident illumination. (Courtesy of Dr. Michael Meier, University of California, Davis)



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Printed in the United States of America

10 9 8 7 6 5 4 3

ISBN 0-13-011287-9

Prentice-Hall International (UK) Limited, *London*

Prentice-Hall of Australia Pty. Limited, *Sydney*

Prentice-Hall Canada Inc., *Toronto*

Prentice-Hall Hispanoamericana, S.A., *Mexico*

Prentice-Hall of India Private Limited, *New Delhi*

Prentice-Hall of Japan, Inc., *Tokyo*

Prentice-Hall (Singapore) Pte. Ltd., *Singapore*

Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

Dedicated to Penelope and Scott

PREFACE

This book is designed for a first course in engineering materials. The field that covers this area of the engineering profession has come to be known as “materials science and engineering.” To me, this label serves two important functions. First, it is an accurate description of the balance between scientific principles and practical engineering that is required in selecting the proper materials for modern technology. Second, it gives us a guide to organizing this book. Each word defines a distinct part. After a short introductory chapter, “science” serves as a label for Part I on “The Fundamentals.” Chapters 2 through 10 cover various topics in applied physics and chemistry. These are the foundation for understanding the principles of “materials science.” I assume that some students take this course at the freshman or sophomore level and may not yet have taken their required coursework in chemistry and physics. As a result, Part I is intended to be self-contained. A previous course in chemistry or physics is certainly helpful, but should not be necessary. If an entire class has finished freshman chemistry, Chapter 2 (atomic bonding) could be left as optional reading, but it is important not to overlook the role of bonding in defining the fundamental types of engineering materials. The remaining chapters in Part I are less optional, as they describe the key topics of materials science. Chapter 3 outlines the ideal, crystalline structures of important materials. Chapter 4 introduces the structural imperfections found in real, engineering materials. These structural defects are the bases of solid-state diffusion (Chapter 5) and plastic deformation in metals (Chapter 6). Chapter 6 also includes a broad range of mechanical behavior for various engineering materials. Similarly, Chapter 7 covers the thermal behavior of these materials. Subjecting materials to various mechanical and thermal processes can lead to their failure, the subject of Chapter 8. In addition, the systematic analysis of material failures can lead to the prevention of future catastrophes. Chapters 9 and 10 are especially important in providing a bridge between “materials science” and “materials engineering.” Phase diagrams (Chapter 9) are an effective tool for describing the equilibrium microstructures of practical engineering materials. Instructors will note that this topic is introduced in a descriptive and empirical way. Since some students in this course may not have taken a course in thermodynamics, I avoid the use of the free-energy property. (A companion volume, described below, is available for those instructors wishing to discuss phase diagrams with a complementary introduction to thermodynamics.) Kinetics (Chapter 10) is the foundation of the heat treatment of engineering materials.

The word *materials* gives us a label for Part II of the book. We identify the four categories of *structural materials*. Metals (Chapter 11), ceramics (Chapter 12), and polymers (Chapter 13) are traditionally identified as the three types of engineering materials. I have entitled Chapter 12 “Ceramics and Glasses” to emphasize the distinctive character of the noncrystalline glasses, which are chemically similar to the crystalline ceramics. Chapter 14

adds “composites” as a fourth category that involves some combination of the three fundamental types. Fiberglass, wood, and concrete are some common examples. Advanced composites, such as the graphite/epoxy system, represent some of the most dramatic developments in structural materials. In Part II, each chapter catalogues examples of each type of structural material and describes their processing, the techniques used to produce the materials.


The word *materials* also labels Part III. Materials used primarily for *electronic*, *optical*, and *magnetic* applications can generally be classified in one of the categories of structural materials. But a careful inspection of electrical conduction (Chapter 15) shows that a separate category, semiconductors, can be defined. Metals are generally good electrical conductors, while ceramics and polymers are generally good insulators, and semiconductors are intermediate. The exceptional discovery of superconductivity in certain ceramic materials at relatively high temperatures augments the long-standing use of superconductivity in certain metals at very low temperatures.

Chapter 16 covers optical behavior which determines the application of many materials, from traditional glass windows to some of the latest advances in telecommunications. Chapter 17 is devoted to the important category of semiconductor materials that is the basis of the solid-state electronics industry. A wide variety of magnetic materials is discussed in Chapter 18. Traditional metallic and ceramic magnets are being supplemented by superconducting metals and ceramics, which can provide some intriguing design applications based on their magnetic behavior.

The “engineering” in “materials science and engineering” labels Part IV, “Materials in Engineering Design,” which focuses on the role of materials in engineering applications. Chapter 19 (Environmental Degradation) discusses limitations imposed by the environment. Chemical degradation, radiation damage, and wear must be considered in making a final judgment on a material’s application. Finally, in Chapter 20 (Materials Selection), we see that our previous discussions of properties have left us with “design parameters.” Herein lies a final bridge between the principles of materials science and the use of those materials in modern engineering designs.

I hope that students and instructors alike will find what I have attempted to produce: a clear and readable textbook organized around the title of this important branch of engineering. It is also worth noting that materials play a central role across the broad spectrum of contemporary science and technology. In the National Research Council’s report *Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials*, it is estimated that approximately one-third of all employed physicists and chemists work in materials. In the report *Science: The End of the Frontier?* from the American Association for the Advancement of Science, 10 of the 26 technologies identified at the forefront of economic growth are various types of advanced materials.

In the presentation of this book I have attempted to be generous with sample problems and practice problems within each chapter, and I have tried to be even more generous with the end-of-chapter homework problems (with

the level of difficulty for the homework problems clearly noted). Problems dealing with the role of materials in the engineering design process are noted with the use of a design icon . One of the most enjoyable parts of writing the book was the preparation of biographical footnotes for those cases in which a person's name has become intimately associated with a basic concept in materials science and engineering. I suspect that most readers will share my fascination with these great contributors to science and engineering from the distant and not-so-distant past. In addition to a substantial set of useful data, the Appendixes provide convenient location of materials' properties, characterization tools, and key term definitions.

The various editions of this book have been produced during a period of fundamental change in the field of materials science and engineering. This change was exemplified by the change of name in the Fall of 1986 for the "American Society for Metals" to "ASM International"—a society for *materials*, as opposed to metals only. An adequate introduction to materials science can no longer be a traditional treatment of physical metallurgy with supplementary introductions to nonmetallic materials. The first edition was based on a balanced treatment of the full spectrum of engineering materials. The second edition reinforced that approach with the timely addition of new materials poised to play key roles in the economy of the twenty-first century: lightweight metal alloys, "high-tech" ceramics for power generation, engineering polymers for metal substitution, advanced composites for aerospace applications, semiconductors for increasingly sophisticated electronic devices, and nonmetallic superconducting magnets with increasingly high operating temperatures. The third edition was updated to include recent, fundamental research on grain boundary structure and quasicrystals, which have significantly broadened our understanding of the structure of materials. Similarly, advances in high-temperature superconductors, semiconductor devices, and biomaterials were included. The fourth edition was updated to include several new developments. Numerous crystal structure illustrations were created with computer simulation software, reflecting the significant advances in the computer modeling of materials. The discussions of microscopy and processing were expanded to include developments such as the scanning tunneling microscope (STM) and self-propagating high temperature synthesis (SHS), respectively. Developments in advanced composites, biomaterials, and "smart materials" were also included.

CHANGES IN THE FIFTH EDITION

The Fifth Edition represents the most extensive revision to date. After consultation with a wide spectrum of users, I have made a number of structural changes which I believe will provide an even more effective introduction to the field of materials science and engineering. There are now separate chapters on mechanical, thermal, and optical behavior, as well as diffusion and failure analysis and prevention. Discussions on the various materials types have been expanded and updated, and materials processing has been integrated into those discussions. I also provide new or expanded treatments of several topics including heat capacity, polarization curves, luminescence,

photoconductors, lasers, optical fibers, liquid crystal displays, light-emitting diodes, amorphous metals for electric power distribution, honeycomb structures, and environmental issues including recycling.

Consistent with previous editions, over 150 new and revised homework problems are provided. Symbolic of the substantial nature of this revision, there are nearly 80 new Key Terms identified throughout the text and added to the glossary in Appendix 7. Finally, several one-page inserts labelled “The Material World” have been added to provide focus on some fascinating topics in the world of both engineered and natural materials.

SUPPLEMENTARY MATERIAL

An *Instructor's Manual* with fully worked-out solutions to the practice problems and homework problems is available from the publisher. This volume includes a set of *Laboratory Experiments* of general interest for an introductory course on engineering materials and a discussion of *Thermodynamics* which can be introduced just prior to Chapter 9 as a foundation for the discussions of phase diagrams and kinetics in Chapters 9 and 10.

All illustrations and tables are available for classroom use at a website devoted to this text. This site is readily accessed at

www.prenhall.com/shackelford.

The “Shackelford site” also contains a variety of other material of interest to instructors and students alike, especially a comprehensive collection of materials science software from ESM Software.

ACKNOWLEDGMENTS

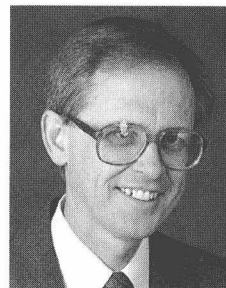
Finally, I want to acknowledge a number of people who have been immensely helpful in making this book possible. My family has been more than the usual “patient and understanding.” They are a constant reminder of the rich life beyond the material plane. Peter Gordon (first edition), David Johnstone (second and third editions), and Bill Stenquist (fourth and fifth editions) are much appreciated in their roles as editors. I am especially indebted to Prentice-Hall for providing Deena Cloud as Development Editor. Her expert guidance was exceptionally helpful and effective. Lilian Davila skillfully produced the computer-generated crystal structure images. A special appreciation is due to my colleagues at the University of California—Davis and to the many reviewers of all editions, especially D. J. Montgomery, John M. Roberts, D. R. Rossington, R. D. Daniels, R. A. Johnson, D. H. Morris, J. P. Mathers, Richard Fleming, Ralph Graff, Ian W. Hall, John J. Kramer, Enayat Mahajerin, Carolyn W. Meyers, Ernest F. Nippes, Richard L. Porter, Eric C. Skaar, E. G. Schwartz, William N. Weins, M. Robert Baren, John Botsis, D. L. Douglass, Robert W. Hendricks, J. J. Hren, Sam Hruska, I. W. Hull, David B. Knoop, Harold Koelling, John McLaughlin, Alvin H. Meyer, M. Natarajan, Jay Samuel, John R. Schlup, Theodore D. Taylor, Ronald Kander, Alan Lawley, and Joanna McKittrick.

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