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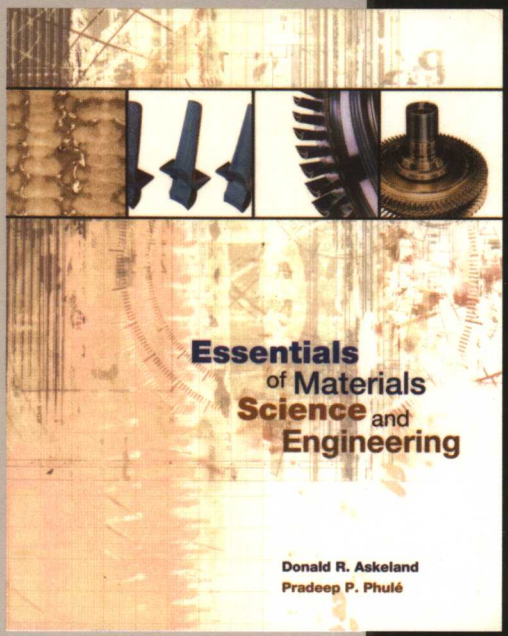
国外大学优秀教材——材料科学与工程系列（影印版）

Donald R. Askeland, Pradeep P. Phulé

材料科学与工程基础

Essentials of Materials Science and Engineering



清华大学出版社

Donald R. Askeland and Pradeep P. Phulé
Essentials of Materials Science and Engineering
EISBN: 0-534-25309-1

981-254-928-5

北京市版权局著作权合同登记号　图字：01-2004-6470

图书在版编目(CIP)数据

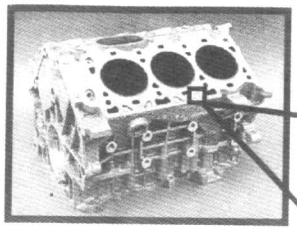
材料科学与工程基础 = Essentials of Materials Science and Engineering：英文/（美）阿斯克兰德（Askeland, D. R.）等著. —影印本. —北京：清华大学出版社，2005.1
（国外大学优秀教材. 材料科学与工程系列）
ISBN 7-302-09981-2

Ⅰ. 材… Ⅱ 阿… Ⅲ. 材料科学－高等学校－教材－英文 Ⅳ. TB3

中国版本图书馆 CIP 数据核字（2004）第 123137 号

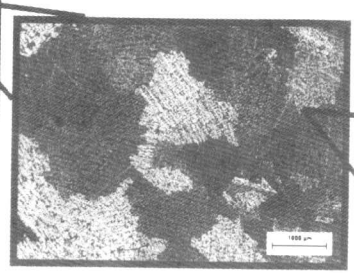
出 版 者：清华大学出版社　　**地　　址**：北京清华大学学研大厦
http://www.tup.com.cn　　**邮　　编**：100084
社总机：(010) 6277 0175　　**客户服务**：(010) 6277 6969
责任编辑：宋成斌
印 刷 者：北京市清华园胶印厂
装 订 者：三河市金元装订厂
发 行 者：新华书店总店北京发行所
开　　本：185×230　**印张**：38　**插页**：1
版　　次：2005 年 1 月第 1 版　2005 年 1 月第 1 次印刷
书　　号：ISBN 7-302-09981-2/TB・83
印　　数：1~3000
定　　价：49.80 元（含光盘）

What is Materials Science and Engineering?



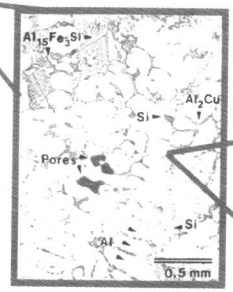
Macro-Scale Structure
Engine Block
≅ upto 1 meter

Performance Criteria
- **Power generated**
- **Efficiency**
- **Durability**
- **Cost**



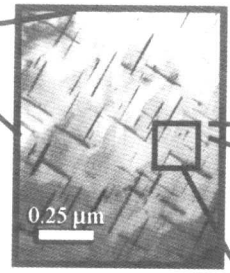
Microstructure
- Grains
≅ 1 – 10 millimeters

Properties affected
- High cycle fatigue
- Ductility



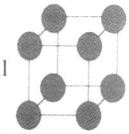
Microstructure
- Dendrites & Phases
≅ 50 – 500 micrometers

Properties affected
- Yield strength
- Ultimate tensile strength
- High cycle fatigue
- Low cycle fatigue
- Thermal Growth
- Ductility

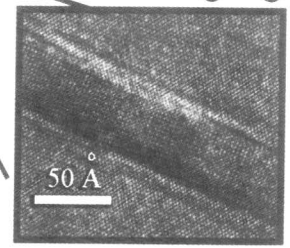


Nano-structure
- Precipitates
≅ 3-100 nanometers

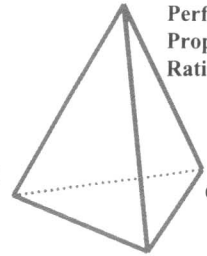
Properties affected
- Yield strength
- Ultimate tensile strength
- Low cycle fatigue
- Ductility



Unit Cell



Atomic-scale structure
≅ 1-100 Angstroms
Property affected
- Young's modulus
- Thermal Growth



A real-world example of important microstructural features at different length-scales, resulting from the sophisticated synthesis and processing used, and the properties they influence. The atomic, nano, micro,and macro-scale structures of cast aluminum alloys (for engine blocks) in relation to the properties affected and performance are shown. The materials science and engineering (MSE) tetrahedron that represents this approach is shown in the upper right corner.

(Illustrations Courtesy of John Allison and William Donlon, Ford Motor Company).

■ *Units and conversion factors*

1 pound (lb) = 4.448 Newtons (N)
1 psi = pounds per square inch
1 MPa = MegaPascal = MegaNewtons per square meter (MN/m^2)
= Newtons per square millimeter (N/mm^2) = 100,000,0 Pa
1 GPa = 1000 MPa = GigaPascal
1 ksi = 1000 psi = 6.895 MPa
1 psi = 0.006895 MPa
1 MPa = 0.145 ksi = 145 psi

■ *Some useful relationships, constants, and units*

Electron volt = 1 eV = 1.6×10^{-19} Joule = 1.6×10^{-12} erg
1 amp = 1 coulomb/second
1 volt = 1 amp · ohm
$k_B T$ at room temperature (300 K) = 0.0259 eV
c = speed of light 2.998×10^{-8} m/s
ε_0 = perimitivity of free space = 8.85×10^{-12} F/m
q = charge on electron = 1.6×10^{-19} C
Avogadro's number $N_A = 6.023 \times 10^{23}$
k_B = Boltzmann's constant = 8.63×10^{-5} eV/K = 1.38×10^{-23} J/K
h = Planck's constant 6.63×10^{-34} J-s = 4.14×10^{-15} eV-s

英文影印版序

我自1995年在美国大学为工学院本科生教授“材料科学与工程”至今已经快十年了，这门课程在全美国的工学院里既是作为材料专业的必修课，也是为其它专业（比如化工、机械、航空）的学生学习有关材料的知识而设置，但侧重点有所不同。比如对于冶金工程专业的学生，该课的教程会把重点放在金属材料的章节里。而对于非材料专业的学生，整个课程会广泛地介绍现代工业应用的一般材料，包括陶瓷、玻璃、高分子，以及复合材料，课时为3个学分（即1周3次课，每课50分钟）。一般在大学三年级完成该课程。

Essentials of Materials Science and Engineering（作者Donald Askeland）事实上是*The Science and Engineering of Materials*的前17章，其内容仅包括第一部分：原子结构；第二部分：微观结构控制与机械性能，第三部分：工程材料。而省去了第四、五部分：工程材料的物理性质。出版这个缩写版的目的是为了降低价格。而且很多材料系的基础材料课并不讲物理性质及腐蚀与磨损这二个部分。它的第一部分主要讲解材料的原子结构，如单胞、密勒指数、X射线结构分析等，这些都是材料学中最为基础也是必须掌握的基本概念。在这个部分里，还初步介绍了晶格缺陷中的位错和塑性变形的基本概念。第一部分中的扩散一章，虽然阐述得十分清楚、详细，但由于课时限制，往往跳过，因为一般大学材料系均会设置专门的扩散理论课。第二部分主要侧重于材料的机械性能的测量、合金强化机制、相图分析、相变与热处理。对于机械性能的测试，可用于所有工程材料，包括陶瓷和高分子材料。关于微观结构的控制、相图分析，以及强化理论的内容，则主要侧重于金属合金。可以认为，第一和第二部分为本书的基础内容，是材料科学与工程中至关重要的核心和基本概念。所以也是“材料科学与工程”课教学中的重点。

第三部分囊括了工业应用中大部分工程材料，并详细介绍金属、陶瓷、玻璃、高分子、复合材料以及建筑材料。这些章节不仅给出了这些重要材料的美国标定、规格和类型，而且阐述了它们的特性，应用范围和制备条件。比如陶瓷玻璃的特殊高温行为、碳化硅晶须的微结构，以及这些材料的热加工过程。对于工业应用中的重要材料——高分子，该部分也做了十分详尽的描述，包括高分子材料的结构特点、合成方法、温变行为，以及力学变形机制。因而，第三部分对于非材料专业的工科学生，尤其对于那些需要在工程实践中广泛接触材料应用的专业，比如航空、机械、土木、环境和化工等专业，在掌握工程材料的一般知识方面有着极为重要的意义。

我在这门课的教学过程中曾经选用过类似的其它教材。但在教学实践中最终选用了这本书。这完全是根据多年的比较、学生的反映和我校课时的特点而决定的。本书条理有序，结构清晰，内容丰富，浅显易懂，十分适于一般工学院的材料导论课程。同时，它也适用

于材料专业的初级课程。我在材料系还为本科生开设了一门“金属导论”的课程，也用这本书的第一、二部分的基础概念和第三部分的金属材料章节，学生反映极好，尤其本书所给出的思考作业题，内容十分广泛，而且重点突出,切题实用，在为其他非材料专业开设的“材料科学与工程导论”课程中，我的教学大纲会包括第一、二部分的一些主要内容，比如晶体结构、点阵缺陷、力学性质、相图分析和微观结构控制，以及第三部分的陶瓷、玻璃和高分子材料。对美国 11 周、3 学分课时的学期建制，选择这些内容是比较合适的。正是由于学时的限制，单一的课程无法囊括本书的所有部分和章节。但我认为，如上所述，第一、二部分应该是材料学初级课程的重点，第三部分的选择，应该根据学生专业的特点和区别择重、择量、择优取用。

University of Missouri – Rolla 以其在金属冶金方面的建树在美国著称。而本书的作者 Donald Askeland 博士也是这个领域十分著名的专家。但我认为，他在本书里不仅对金属材料部分的介绍有独到的见解和非常精彩的阐述，而且对陶瓷、玻璃、高分子以及复合材料等领域也作了极为详尽的描述。

清华大学出版社在中国工业飞速发展的今天，十分及时地选择 *Essentials of Materials Science and Engineering* 一书并作为中国大学材料科学与工程专业的主要英文原版教科书并引进该书的版权，有着非常重要的现实意义。它不仅可以在国内英文教学方面树立一个具有国际工程院系的教学标准，也为大专院校和科技单位的研究工作者提供了一本内容丰富又极具科研价值的参考书。我衷心祝愿本书的英文影印版受到国内师生以及科研同行的欢迎，并在教学和科研中发挥较大的作用。

时东陆
美国俄亥俄州立辛辛那提大学工学院
材料科学与工程教授
2004 年

To Mary Sue and Tyler
—Donald R. Askeland

To Suyash, Aarohee, and Jyotsna
—Pradeep P. Phulé

Preface

This book, *Essentials of Materials Science and Engineering*, is a direct result of the success of the *Fourth Edition* of *The Science and Engineering of Materials*, published in 2003. We received positive feedback on both the contents and the integrated approach we used to develop materials science and engineering foundations by presenting the student with real-world applications and problems.

This positive feedback gave use the inspiration to develop *Essentials of Materials Science and Engineering*. The main objective of this book is to provide a *concise* overview of the principles of materials science and engineering for undergraduate students in varying engineering and science disciplines. This *Essentials* text contains the same integrated approach as the *Fourth Edition*, using real-world applications to present and then solve fundamental material science and engineering problems.

The contents of *Essentials of Materials Science and Engineering* book have been carefully selected such that the reader can develop key ideas that are essential to a solid understanding of materials science and engineering. This book also contains several new examples of modern applications of advanced materials such as those used in information technology, energy technology, nanotechnology microelectromechanical systems (MEMS), and biomedical technology.

The concise approach used in this book will allow instructors to complete an introductory materials science and engineering course in one semester.

We feel that while reading and using this book, students will find materials science and engineering very interesting, and they will clearly see the relevance of what they are learning. We have presented many examples of modern applications of materials science and engineering that impact students' lives. Our feeling is that if students recognize that many of today's technological marvels depend on the availability of engineering materials they will be more motivated and remain interested in learning about how to apply the essentials of materials science and engineering.

Audience and Prerequisites

This book has been developed to cater to the needs of students from different engineering disciplines and backgrounds other than materials science and engineering (e.g., mechanical, industrial, manufacturing, chemical, civil, biomedical, and electrical engineering). At the same time, a conscious effort has been made so that the contents are very well suited for undergraduates majoring in materials science and engineering and closely related disciplines (e.g., metallurgy, ceramics, polymers, and engineering physics). In this sense, from a technical and educational perspective, the book has not been "watered down" in any way. The subjects presented in this text are a careful selection of topics based on our analysis of the needs and feedback from reviewers. Many of the topics

related to electronic, magnetic, thermal, and optical properties have not been included in this book to keep the page length down. For instructors and students who wish to develop these omitted concepts, we suggest using the *Fourth Edition* of *The Science and Engineering of Materials.*

This text is intended for engineering students who have completed courses in general physics, chemistry, physics, and calculus. Completion of a general introduction to Engineering or Engineering Technology will be helpful, but not necessary. The text does not presume that the students have had any engineering courses related to statics, dynamics, or mechanics of materials.

Features

We have many unique features to this book.

CD-ROM Included with the Text The accompanying CD-ROM contains many useful illustrations in the form of microphotographs and animations. Some of these are especially useful for visualization of crystal structures, atomic level defects, phase diagrams, and microstructures of many materials. A limited number of video clips (e.g., solidification of sodium acetate) are also included. The contents of the CD-ROM are coordinated with different sections of the textbook. Students can also conduct a topic search and quickly find out more about a topic discussed in many places in the book.

Have You Ever Wondered? Questions The opening chapter photo is followed by a section entitled "*Have You Ever Wondered*?" These questions are designed to arouse the reader's interest, put things in perspective, and form the framework for what the reader will learn in that chapter.

Examples Many real-world Examples have been integrated to accompany the chapter discussions. These Examples specifically cover design considerations, such as operating temperature, presence of corrosive material, economic considerations, recyclability, and environmental constraints. The examples also apply to theoretical material and numeric calculations to further reinforce the presentation.

Glossary All of the Glossary terms that appear in the chapter are set in boldface type the first time they appear within the text. This provides an easy reference to the definitions provided in the end of each chapter Glossary.

Answers to Selected Problems The answers to the selected problems are provided at the end of the text to help the student work through the end-of-chapter problems.

Appendices and Endpapers Appendix A provides a listing of selected physical properties of metals and Appendix B presents the atomic and ionic radii of selected elements. The Endpapers include SI Conversion tables and Selected Physical Properties of elements.

Strategies for Teaching from the Book

Most of the material presented here can be covered in a typical one-semester course. By selecting the appropriate topics, however, the instructor can emphasize the desired materials (i.e., metals, alloys, ceramics, polymers, composites, etc.), provide an overview of materials, concentrate on behavior, or focus on physical properties. In addition, the text provides the student with a useful reference for subsequent courses in manufacturing, design, and materials selection. For students specializing in materials science and engineering, or closely related disciplines, sections related to synthesis and processing could be discussed in greater detail.

Supplements

Supplements for the student include:

- A student website at: www.engineering.thomson.com

Supplements for the instructor include:

- The Instructor's Solutions Manual that provides complete, worked-out solutions to selected text problems and additional text items.
- PDF files of all figures from the textbook in a multimedia presentation format.

Acknowledgments

It takes a team of many people and a lot of hard work to create a quality textbook. We are indebted to all of the people who provided the assistance, encouragement, and constructive criticism leading to the preparation of this book.

First, we wish to acknowledge the many instructors who have provided helpful feedback to our initial survey for the *Fourth Edition* of *The Science and Engineering of Materials*:

C. Maurice Balik, North Carolina State University

Deepak Bhat, University of Arkansass, Fayetteville

Brian Cousins, University of Tasmania

Raymond Cutler, Ceramatec Inc.

Arthur F. Diaz, San Jose State University

Phil Guichelaar, Western Michigan University

Richard S. Harmer, University of Dayton

Prashant N. Kumta, Carnegie Mellon University

Rafael Manory, Royal Melbourne Institute of Technology

Sharon Nightingale, University of Wollongong, Australia

Christopher K. Ober, Cornell University

David Poirier, University of Arizona

Ramurthy Prabhakaran, Old Dominion University
Lew Rabenberg, The Unviersity of Texas at Austin
Wayne Reitz, North Dakota State University
John Schlup, Kansas State University
Robert L. Snyder, Rochester Institute of Technology
J. Rasty, Texas Tech University
Lisa Friis, University of Kansas
Blair London, California Polytechnic State University, San Luis Obispo
Yu-Lin Shen, University of New Mexico
Stephen W. Stafford, University of Texas at El Paso
Rodney Trice, Purdue University
David S. Wilkinson, McMaster University
Indranath Dutta, Naval Postgraduate School

Thanks most certainly to everyone at Thomson Engineering for their encouragement, knowledge, and patience in seeing this text to fruition: Julie Ruggiero, John More, and Vernon Boes.

We wish to thank three people, in particular, for their diligent efforts: Many thanks to Bill Stenquist, our publisher, who set the tone for excellence and who provided the vision, expertise, and leadership to create such a quality product; to Rose Kernan, our developmental and production editor, who worked long hours to improve our prose and produce this quality text from the first pages of manuscript to the final, bound product; and to Dr. Deepa Godbole and Mayur Pangrekar, whose valiant efforts, hard work, and dedication can never be repaid.

Pradeep Phulé would like specifically to thank his wife, Dr. Jyotsna Phulé and children, Aarohee and Suyash, for their patience, understanding, and encouragement. Pradeep Phulé would also like to thank his parents Prabhakar and Pratibha Fulay for their support and encouragement. Thanks are also due to Professor S.H. Risbud, University of California–Davis, for his advice and encouragement and to all of our colleagues who provided many useful illustrations.

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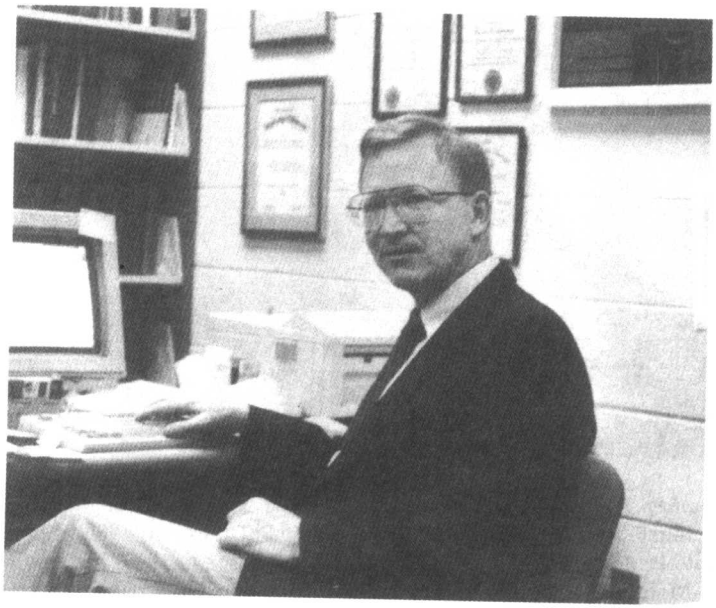
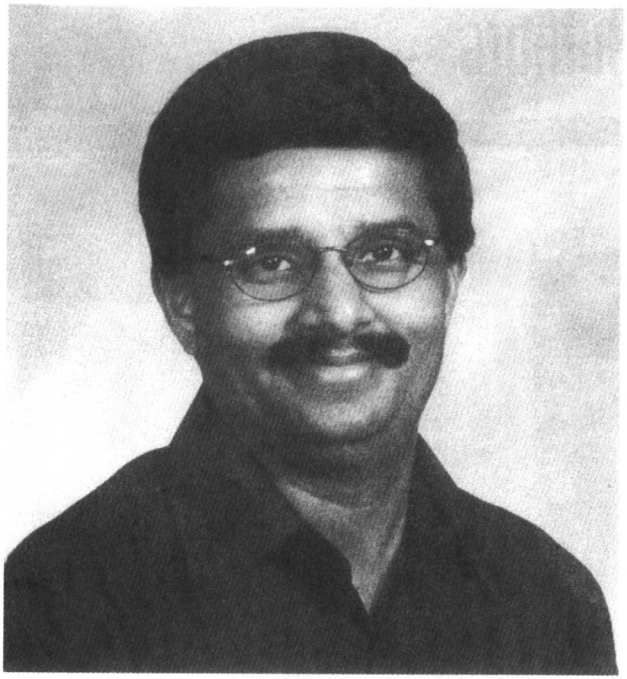
University of Missouri–Rolla, Emeritus

Pradeep P. Phulé
University of Pittsburgh

About the Authors



Donald R. Askeland is a Distinguished Teaching Professor Emeritus of Metallurgical Engineering at the University of Missouri–Rolla. He received his degrees from the Thayer School of Engineering at Dartmouth College and the University of Michigan prior to joining the faculty at the University of Missouri–Rolla in 1970. Dr. Askeland taught a number of courses in materials and manufacturing engineering to students in a variety of engineering and science curricula. He received a number of awards for excellence in teaching and advising at UMR. He served as a Key Professor for the Foundry Educational Foundation and received several awards for his service to that organization. His teaching and research were directed primarily to metals casting and joining, in particular lost foam casting, and resulted in over 50 publications and a number of awards for service and best papers from the American Foundry Society.



Pradeep P. Phulé is a Professor of Materials Science and Engineering at the University of Pittsburgh. He joined the University of Pittsburgh in 1989, was promoted to Associate Professor in 1994, and then to full professor in 1999. Dr. Phulé received a Ph.D. in Materials Science and Engineering from the University of Arizona (1989) and a B. Tech (1983) and M. Tech (1984) in Metallurgical Engineering from the Indian Institute of Technology Bombay (Mumbai) India.

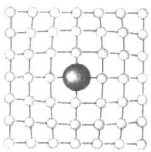
He has authored close to 60 publications and has two U.S. patents issued. He has received the Alcoa Foundation and Ford Foundation research awards.

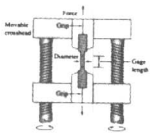
He has been an outstanding teacher and educator and was recently listed on the Faculty Honor Roll at the University of Pittsburgh (2001) for outstanding services and assistance. From 1992–1999, he was the William Kepler Whiteford Faculty Fellow at the University of Pittsburgh. From August to December 2002, Dr. Phulé was a visiting scientist at the Ford Scientific Research Laboratory in Dearborn, MI.

Dr. Phulé's primary research areas are chemical synthesis and processing of ceramics, electronic ceramics and magnetic materials, development of smart materials and systems. He was the President of Ceramic Educational Council (2003–2004) and a Member of the Program Committee for the Electronics Division of the American ceramic society since 1996.

He has also served as an Associate Editor for the *Journal of the American Ceramic Society* (1994–2000). He has been the lead organizer for symposia on ceramics for sol-gel processing, wireless communications, and smart structures and sensors. In 2002, Dr. Phulé was elected as a Fellow of the American Ceramic Society. Dr. Phulé's research has been supported by National Science Foundation (NSF) and other organizations.

Contents





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