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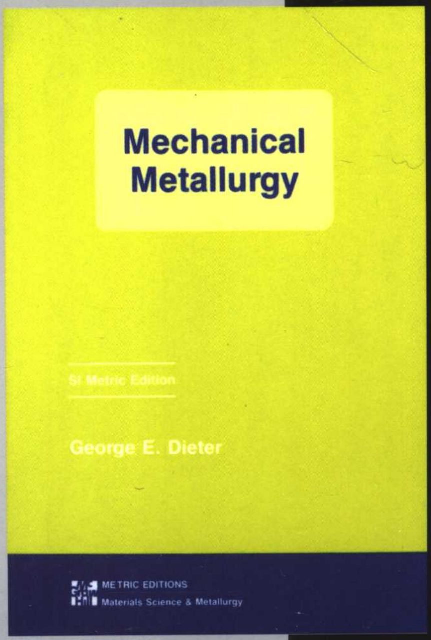
国外大学优秀教材——材料科学与工程系列（影印版）

George E. Dieter

金属力学
（第3版）

Mechanical Metallurgy
(Third Edition)



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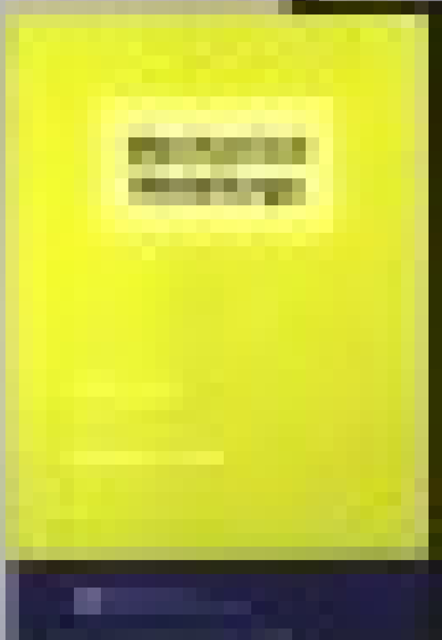

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清华大学出版社
2006 年 11 月

英文影印版序

金属力学是金属学领域的一个重要理论部分，而和冶炼工业应用紧密相关的冶金学则构成了该领域中的重要实践部分，它们都是材料科学，尤其是金属工程专业的必修课程。由美国 McGraw-Hill 公司出版的 *Mechanical Metallurgy* 是目前美国大学材料系工科专业金属力学课程主要教科书之一，用于美国大学的工学院本科高年级以及研究生的基础课。课时为三个学分（每周三次课，每节课 50 分钟）。

金属材料在种类繁多的材料世界里占有极为重要的地位。它们的结构可以从最完整的单晶体到无序的金属玻璃；有强度上超硬的工具钢和在工业和日常生活中都使用广泛的不锈钢；从十分轻巧但高强度的铝合金到可以替换人体骨骼的钛合金；还有用于军事工业的、适于高温、高速的特殊合金、输电电缆、超导金属、铁磁体、电极材料、发动机材料、结构材料、高磁场材料，等等。所以金属材料是一个色彩斑斓、无奇不有、性质多异，但应用十分广泛的领域，也是航空航天、汽车制造、国防、通信、信息等重要领域内至关重要的核心材料的组成部分。金属的机械力学特性与它的晶体结构紧密相关。因而要了解金属的力学性质就必须深刻地掌握典型金属的晶体点阵知识。金属材料的塑性变形，是金属性质和行为的一个非常基础但极为重要的部分。而塑性变形的核心问题是关于位错的理论，它结合金属的晶体学理论、弹性理论，形成了一整套详细、深刻、完整的金属形变理论。在讨论位错理论中，已经建立了比较严谨的数学模型和分析方法。

本书第一部分(1～3 章)给出了力学性质中最为基础的部分：金属的应力与应变关系，包括应力矩阵和基本的应力计算方法。这个部分还讨论了屈服的概念、各向异性，以及基本的弹性理论。第二部分(3～7 章)是关于金属学的基本理论，包括塑性变形、位错理论、金属强化理论和断裂理论。第 4，5 章着重讨论塑性变形、晶体缺陷和位错理论。第 4 章着重讨论位错与塑性变形的关系，比如位错的滑移面、滑移方向、滑移系统，以及许多十分经典的形变概念和理论。第 5 章介绍了各种位错类型和典型的层错，并详细地讨论了位错的基本概念，例如：位错反应、位错攀移，以及位错应力场。第 6 章讨论晶体缺陷中的晶界，即面缺陷，并阐述了与晶界相关的材料性质问题，还介绍了一些典型的强化理论和方法。例如：形变时效、纤维强化、马氏体强化、加工硬化，等等。第 7 章讨论了金属材料的断裂行为和十分重要的断裂力学理论，并介绍了断裂力学的试验步骤和手段，以及金属材料中裂纹的形成和扩展行为。第三部分（8～14 章）主要介绍金属材料各种性能的测量方法，包括拉伸试验、硬度测量、扭曲试验、断裂试验、疲劳测试、蠕变测试和冲击试验。该部分不仅详细地给出了试验的步骤、标准和方法，而且提供了理论分析和计算手段，是一个非常实用的教学部分。第四部分（15～21 章，针对国内教学特点，对本书 18，20，21 三章做了删节）是更为接近金属材料制备的工艺过程：金属材料的成型，其中包括了成型

的基本概念，如冲压、滚压、冷拔、拉丝和金属冷加工。

本书的前两部分，即第 1～7 章为金属力学的基础，包括应变应力、弹性理论、范性形变和位错理论。书的后两部分，即第 8～21 章，属于金属力学的应用部分，主要是关于金属材料的力学性质和测试，以及各种常用的金属成型方法。对于一个学期的课时，可以适当选择其中第一、第二部分的一些章节。第三、四部分可以放在第二个学期学习。全书由两个学期分两部分依次修完。

本书的作者 George E. Dieter 博士是美国马里兰大学机械系的资深教授，也是世界上金属材料力学性质方面的著名科学家。本书是他的著名教科书。《金属力学》写于上世纪 60 年代，以后多次再版，成为世界上，尤其是美国大学金属材料力学性质课程的必用教科书。在美国 20 世纪后半叶中毕业的金属专业的学生中，几乎每个人都用过这本书。该书的特点是内容丰富，科目经典，资料详细。它的第 3 版，在保持原来金属经典理论的基础之上，增加了高新科技的最新成果。

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 *Mechanical Metallurgy* 作为中国大学理工科的主要材料学英文原版教科书并引进该书的版权，是有着非常重要的现实意义。它不仅可以在国内科技英文教学方面作为一个具有国际水准的工程院校的教学标准，也为大专院校和科研单位的研究工作者提供了一本内容丰富，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学生、老师，以及科研同行的欢迎，并在教学和科研中起到重大的作用。

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

2006 年

ABOUT THE AUTHOR

George E. Dieter is currently Dean of Engineering and Professor of Mechanical Engineering at the University of Maryland. The author received his B.S. Met.E. degree from Drexel University, and his D.Sc. degree from Carnegie-Mellon University. After a career in industy with DuPont Engineering Research Laboratory, he became Head of the Metallurgical Engineering Department at Drexel University, where he later became Dean of Engineering. Professor Dieter later joined the faculty of Carnegie-Mellon University, as Professor of Engineering and Director of the Processing Research Institute. He moved to the University of Maryland four years later.

A former member of the National Materials Advisory Board, Professor Dieter is a fellow of the American Society for Metals, and a member of AAAS, AIME, ASEE, NSPE, and SME.

PREFACE TO THE THIRD EDITION

The objective of *Mechanical Metallurgy* continues to be the presentation of the entire scope of mechanical metallurgy in a single comprehensive volume. Thus, the book starts with a continuum description of stress and strain, extends this background to the defect mechanisms of flow and fracture of metals, and then considers the major mechanical property tests and the basic metalworking processes. As before, the book is intended for the senior or first-year graduate-student level. Emphasis is on basic phenomena and relationships in an engineering context. Extensive references to the literature have been included to assist students in digging deeper into most topics.

Since the second edition in 1976 extensive progress has been made in all research areas of the mechanical metallurgy spectrum. Indeed, mechanical behavior is the category of research under which the greatest number of papers are published in *Metallurgical Transactions*. Since 1976 the field of fracture mechanics has grown greatly in general acceptance. In recognition of this a separate chapter on fracture mechanics has been added to the present edition, replacing a chapter on mechanical behavior of polymeric materials. Other topics added for the first time or greatly expanded in coverage are deformation maps, finite element methods, environmentally assisted fracture, and creep-fatigue interaction.

As an aid to the student, numerous illustrative examples have been included throughout the book. Answers have been provided to selected problems for the student, and a solutions manual is available for instructors. In this third edition, major emphasis is given to the use of SI units, as is common with most engineering texts today.

I would like to express my thanks for the many useful comments and suggestions provided by Ronald Scattergood, North Carolina State University, and Oleg Sherby, Stanford University, who reviewed this text during the course of its development.

Acknowledgment is given to Professor Ronald Armstrong, University of Maryland, for providing many stimulating problems, and Dr. A. Pattniak, Naval Research Laboratory, for assistance in obtaining the fractographs. Special thanks goes to Jean Beckmann for her painstaking efforts to create a perfect manuscript.

George E. Dieter

PREFACE TO THE SECOND EDITION

In the 12 years since the first edition of *Mechanical Metallurgy* at least 25 textbooks dealing with major segments of the book have appeared in print. For example, at least 10 books dealing with the mechanics of metalworking have been published during this period. However, none of these books has dealt with the entire scope of mechanical metallurgy, from an understanding of the continuum description of stress and strain through crystalline and defect mechanisms of flow and fracture, and on to a consideration of the major mechanical property tests and the basic metalworking processes.

Important advances have been made in understanding the mechanical behavior of solids in the period since the first edition. The dislocation theory of plastic deformation has become well established, with excellent experimental verification for most of the theory. These advances have led to a better understanding of the strengthening mechanisms in solids. Developments such as fracture mechanics have matured to a high level of technical sophistication and engineering usefulness. An important development during this period has been the "materials science movement" in which crystalline solids, metals, ceramics, and polymers are considered as a group whose properties are controlled by basic structural defects common to all classes of crystalline solids.

In this revision of the book the emphasis is as before. The book is intended for the senior or first-year graduate-student level. Extensive revisions have been made to up-date material, to introduce new topics which have emerged as important areas, and to clarify sections which have proven difficult for students to understand. In some sections advanced material intended primarily for graduate students has been set in smaller type. The problems have been extensively revised and expanded, and a solutions manual has been prepared. Two new chapters, one dealing with the mechanical properties of polymers and the other with the machining of metals, have been added, while the chapters of statistical methods and residual stresses have been deleted. In total, more than one-half of the book has been rewritten completely.

George E. Dieter

PREFACE TO THE FIRST EDITION

Mechanical metallurgy is the area of knowledge which deals with the behavior and response of metals to applied forces. Since it is not a precisely defined area, it will mean different things to different persons. To some it will mean mechanical properties of metals or mechanical testing, others may consider the field restricted to the plastic working and shaping of metals, while still others confine their interests to the more theoretical aspects of the field, which merge with metal physics and physical metallurgy. Still another group may consider that mechanical metallurgy is closely allied with applied mathematics and applied mechanics. In writing this book an attempt has been made to cover, in some measure, this great diversity of interests. The objective has been to include the entire scope of mechanical metallurgy in one fairly comprehensive volume.

The book has been divided into four parts. Part One, Mechanical Fundamentals, presents the mathematical framework for many of the chapters which follow. The concepts of combined stress and strain are reviewed and extended into three dimensions. Detailed consideration of the theories of yielding and an introduction to the concepts of plasticity are given. No attempt is made to carry the topics in Part One to the degree of completion required for original problem solving. Instead, the purpose is to acquaint metallurgically trained persons with the mathematical language encountered in some areas of mechanical metallurgy. Part Two, Metallurgical Fundamentals, deals with the structural aspects of plastic deformation and fracture. Emphasis is on the atomistics of flow and fracture and the way in which metallurgical structure affects these processes. The concept of the dislocation is introduced early in Part Two and is used throughout to provide qualitative explanations for such phenomena as strain hardening, the yield point, dispersed phase hardening, and fracture. A more mathematical treatment of the properties of dislocations is given in a separate chapter. The topics covered in Part Two stem from physical metallurgy. However, most topics are discussed in greater detail and with a different emphasis than when they are first covered in the usual undergraduate course in physical metallurgy. Certain topics that are more physical metallurgy than mechanical metallurgy are included to provide continuity and the necessary background for readers who have not studied modern physical metallurgy.

Part Three, Applications to Materials Testing, deals with the engineering aspects of the common testing techniques of mechanical failure of metals. Chapters are devoted to the tension, torsion, hardness, fatigue, creep, and impact tests. Others take up the important subjects of residual stresses and the statistical analysis of mechanical-property data. In Part Three emphasis is placed on the interpretation of the tests and on the effect of metallurgical variables on mechanical behavior rather than on the procedures for conducting the tests. It is assumed that the actual performance of these tests will be covered in a concurrent laboratory course or in a separate course. Part Four, Plastic Forming of Metals, deals with the common mechanical processes for producing useful metal shapes. Little emphasis is given to the descriptive aspects of this subject, since this can best be covered by plant trips and illustrated lectures. Instead, the main attention is given to the mechanical and metallurgical factors which control each process such as forging, rolling, extrusion, drawing, and sheet-metal forming.

This book is written for the senior or first-year graduate student in metallurgical or mechanical engineering, as well as for practicing engineers in industry. While most universities have instituted courses in mechanical metallurgy or mechanical properties, there is a great diversity in the material covered and in the background of the students taking these courses. Thus, for the present there can be nothing like a standardized textbook on mechanical metallurgy. It is hoped that the breadth and scope of this book will provide material for these somewhat diverse requirements. It is further hoped that the existence of a comprehensive treatment of the field of mechanical metallurgy will stimulate the development of courses which cover the total subject.

Since this book is intended for college seniors, graduate students, and practicing engineers, it is expected to become a part of their professional library. Although there has been no attempt to make this book a handbook, some thought has been given to providing abundant references to the literature on mechanical metallurgy. Therefore, more references are included than is usual in the ordinary textbook. References have been given to point out derivations or analyses beyond the scope of the book, to provide the key to further information on controversial or detailed points, and to emphasize important papers which are worthy of further study. In addition, a bibliography of general references will be found at the end of each chapter. A collection of problems is included at the end of the volume. This is primarily for the use of the reader who is engaged in industry and who desires some check on his comprehension of the material.

The task of writing this book has been mainly one of sifting and sorting facts and information from the literature and the many excellent texts on specialized aspects of this subject. To cover the breadth of material found in this book would require parts of over 15 standard texts and countless review articles and individual contributions. A conscientious effort has been made throughout to give credit to original sources. For the occasional oversights that may have developed during the "boiling-down process" the author offers his apologies. He is indebted to many authors and publishers who consented to the reproduction of illustrations. Credit is given in the captions of the illustrations.

Finally, the author wishes to acknowledge the many friends who advised him in his work. Special mention should be given to Professor A. W. Grosvenor, Drexel Institute of Technology, Dr. G. T. Horne, Carnegie Institute of Technology, Drs. T. C. Chilton, J. H. Faupel, W. L. Phillips, W. I. Pollock, and J. T. Ransom of the du Pont Company, and Dr. A. S. Nemy of the Thompson-Ramo-Wooldridge Corp.

George E. Dieter

LIST OF SYMBOLS

A area; amplitude
a linear distance; crack length
a_0 interatomic spacing
B constant; specimen thickness
b width or breadth
$\mathbf{b}$ Burgers vector of a dislocation
C generalized constant; specific heat
C_{ij} elastic coefficients
c length of Griffith crack
D diameter, grain diameter
E modulus of elasticity for axial loading (Young's modulus)
e conventional, or engineering, linear strain
exp base of natural logarithms (= 2.718)
F force per unit length on a dislocation line
G modulus of elasticity in shear (modulus of rigidity)
$\mathcal{G}$ crack-extension force
H activation energy
h distance, usually in thickness direction
(h, k, l) Miller indices of a crystallographic plane
I moment of inertia
J invariant of the stress deviator; polar moment of inertia
K strength coefficient
K_f fatigue-notch factor
K_t theoretical stress-concentration factor
K_{Ic} fracture toughness
k yield stress in pure shear
L length

l, m, n direction cosines of normal to a plane
ln natural logarithm
log logarithm to base 10
M_B bending moment
M_T torsional moment, torque
m strain-rate sensitivity
N number of cycles of stress or vibration
n strain-hardening exponent
n' generalized constant in exponential term
P load or external force
Q activation energy
p pressure
q reduction in area; plastic-constraint factor; notch sensitivity index in fatigue
R radius of curvature; stress ratio in fatigue; gas constant
r radial distance
S total stress on a plane before resolution into normal and shear components
S_{ij} elastic compliance
s engineering stress
T temperature
T_m melting point
t time; thickness
t_r time for rupture
U elastic strain energy
U_0 elastic strain energy per unit volume
u, v, w components of displacement in x, y, and z directions
$[uvw]$ Miller indices for a crystallographic direction
V volume
v velocity
W work
Z Zener-Hollomon parameter
α linear coefficient of thermal expansion; phase angle
$\alpha, \beta, \theta, \phi$ generalized angles
Γ line tension of a dislocation
γ shear strain
Δ volume strain or cubical dilatation; finite change
δ deformation or elongation; deflection; logarithmic decrement; Kronecker delta
ε general symbol for strain; natural or true strain
$\bar{\varepsilon}$ significant, or effective, true strain
$\dot{\varepsilon}$ true-strain rate