

时代教育 • 国外高校优秀教材精选

(英文版)

材料力学行为

Mechanical Behavior of Materials

(美) Thomas H. Courtney 著



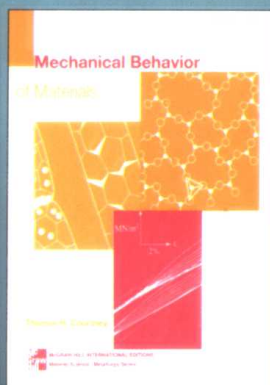
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本书主要讨论材料在各种条件下的变形与断裂。内容翔实丰富，将宏观力学性能与微观组织结构变化有机结合，特别是对高分子、陶瓷和复合材料的力学性能作了较多的补充，并与金属材料有对比，全书每章之后均有小结和大量习题，习题难易搭配，便于教学。



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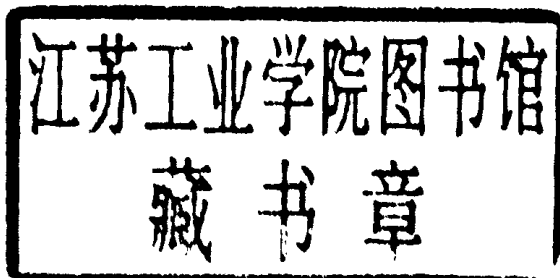
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随着我国加入 WTO,国际间的竞争越来越激烈,而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才,加快我国教育改革的步伐,国家教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机,机械工业出版社陆续推出了一系列国外影印版教材,其内容涉及高等学校公共基础课,以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材,在有条件的学校推动开展英语授课或双语教学,自然也引进了先进的教学思想和教学方法,这对提高我国自编教材的水平,加强学生的英语实际应用能力,使我国的高等教育尽快与国际接轨,必将起到积极的推动作用。

为了做好教材的引进工作,机械工业出版社特别成立了由著名专家组成的国外高校优秀教材审定委员会。这些专家对实施双语教学做了深入细致的调查研究,对引进原版教材提出了许多建设性意见,并慎重地对每一本将要引进的原版教材一审再审,精选再精选,确认教材本身的质量水平,以及权威性和先进性,以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中,审定委员会还结合我国高校教学课程体系的设置和要求,对原版教材的教学思想和方法的先进性、科学性严格把关。同时尽量考虑原版教材的系统性和经济性。

这套教材出版后,我们将根据各高校的双语教学计划,举办原版教材的教师培训,及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议,使我们更好地为教学改革服务。

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影 印 前 言

《材料力学行为》主要讨论材料在各种条件下的变形与断裂。这些条件包括载荷、温度和环境等因素。本书的结构除第1章力学性能概述外,可分为两大部分。第一部分(第2~8章)是阐述材料的变形,包括:弹性变形(第2章);常温下的塑性变形,其中晶体材料的变形和非晶材料的变形各自独立为第4章与第8章;至于温度的影响,低温的影响集中在第10章讨论,而高温时的变形见第7章。为了了解塑性变形的物理基础,增加了第3章位错及第5章晶体材料的强化机制。第6章复合材料,实际上是在讨论复合材料的力学行为,而不是讲述具体的各种复合材料,这是由第二相(纤维或颗粒)和基体(金属、陶瓷、高分子)不同特性的组合而造成的。本书的第二部分则是讨论材料的断裂问题(第9~13章),包括了静载下的断裂(第9~10章),高温蠕变断裂(第11章),疲劳断裂(第12章)及环境介质引起的脆断。所以,本书就其结构而言是全面完整的,层次是清晰严谨的。

研究材料力学行为可以从力学角度,也可以从物理角度,这两方面都很重要,例如有断裂力学也有断裂物理,断裂力学给出了带裂纹材料的断裂判据,断裂物理则指出了材料的韧化途径,为发展新材料提供依据。过去“材料科学与工程”专业在该门课程教学中,无论是本科生还是研究生教学,都比较侧重于力学概念,着重于力学上的宏观规律及其在工程上的应用,而对力学行为的微观解释、变形与断裂的微观机制则认为应由物理冶金课讲授,这种处理方法有一定好处,便于学生接受消化。但是,本书则采用另一种方式,即侧重于从物理角度来讨论材料力学行为。最明显的是第9章断裂力学,其思路不是传统的力学推导应力强度因子 K 而是简便些用断裂功 G ,虽然 K_{Ic} 和 G_{Ic} 是等价的,但 G_{Ic} 物理概念明确,该章只强调了断裂力学在工程上的应用,举出压力容器、火箭发动机及带裂纹零件这三个典型应用实例,然后就转向了断裂物理,从断裂的微观过程讨论了材料的韧化机制。从物理角度讨论材料宏观力学性能的微观机制,将宏观性能与微观组织结构的变化联系起来,这一直是物理冶金学家探索的事,要两者结合得好并非易事,因为这是力学和物理两个学科跨学科的结合,这本书能立足于工程实际的背景,将两者结合得使学生容易理解,相对地说,是做得比较好的。

现举一些具体章节加以说明。

1. 第5章晶体材料的强化。除了经常被引用的机制,如加工硬化、晶界强化、固溶强化、沉淀或弥散相强化外,新补充了应变梯度硬化。这是由材料在变形不均匀时,需产生几何必须位错来协调所导致的硬化。在晶界附近,不变形第二相周围都存在有大量的几何必须位错;在固溶强化方面,同时考虑了原子尺寸和弹性模量两个因素,并得出无论是间隙式还是置换式固溶,所产生的强化都和溶质浓度的平方根成正比。书中还指出,当位错切过第二相时,无论是

哪种机制(共格硬化、化学硬化、模量硬化等),其强化的表达式都具有与固溶强化相似的形式。书中还把晶粒大小对强度的影响(Hall-Petch 关系)推至纳米晶体材料范围。

2. 第 8 章讨论了非晶材料的变形,包括了金属玻璃、无机玻璃及高分子材料的变形。它们的共同特点是低于某一温度呈线弹性,高于某一温度呈粘性流动,中间温度呈粘弹性。其中对非晶态高分子材料的变形有详细的论述,对冷拉、剪切带及银纹这三种变形方式及产生的条件作了细致的分析。冷拉是在屈服后材料先在局部地区发生缩颈,但缩颈区随后沿试样整个长度扩展;剪切带一般产生在材料宏观屈服前沿最大切应力方向不均匀地变形;银纹(Crazing)(光镜下呈发亮的细裂纹)其法线方向平行于最大主应力。银纹和剪切带是两种相互竞争的变形方式,取决于应力状态温度等条件。

3. 本书第 10 章是作者的精心写作,分别讨论了金属、陶瓷复合材料和高分子材料的韧化方法。其中最值得注意的是陶瓷材料的韧化。陶瓷的韧化有三种途径:裂纹韧化、相变增韧和裂纹搭桥。所谓裂纹韧化并不是指材料预先存在裂纹,它是使用中产生的主裂纹在其扩展过程中,其周围萌发次生裂纹。次生裂纹消耗能量阻止主裂纹扩展,这种增韧方法是有条件的,对晶粒尺寸和次生裂纹萌生范围都有一定要求(见图 10.9)。相变增韧已为我们熟悉。而裂纹搭桥则是指陶瓷断裂都是沿晶界并不完全分离,残留应力起增韧作用。这一增韧方式在复合材料中很重要,当脆性纤维在基体中遇有裂纹时先在界面上脱开结合增加了一部分切变断裂,继而纤维断裂,随后从基体中拉出,拉出功是脆性纤维构成的复合材料的主要部分,而塑性纤维则主要来自塑性变形的贡献。

该章把低温拉伸脆断分为三种类型(图 10.6)。断裂时没有塑性变形的称为 M I,它可以是穿晶也可以是沿晶断裂。断裂时有显微的塑性变形称为 M II 型,断裂时有整体塑性变形的称为 M III 型。书中讨论了体心立方和密排六方及离子晶体 M II 脆断的区别。

4. 材料在高温下的变形与断裂,在一般的力学性能书中只占很次要的地位,但在本书中却给予相当的篇幅,见第 7 章、第 11 章。书中讨论了三种蠕变机制。在应力低、温度高、晶粒细的条件下,其蠕变机制主要是 Nabarro-Herring 机制,由材料受拉伸地区空位流的扩散所引起,这在陶瓷材料中常见;若温度降低则发生 Coble 蠕变,主要是空位流沿晶界扩散并伴随着晶界滑动;当应力高、温度较低,经常发生幂指数型蠕变(也称位错蠕变),因为蠕变速率和应力呈幂指数关系,其具体机制有溶质拖曳蠕变和位错攀移—滑动蠕变,这在金属中常见。对各种材料已作出变形机制图。结合蠕变机制,书中还对超塑性的产生作了细致的分析。

对于材料在高温下的断裂,可分为:①断面收缩率 100% 的韧断,它常与动态再结晶有关;②穿晶蠕变断裂;③沿晶蠕变断裂,这是一种宏观上的脆性断裂,作者对晶界上的空穴形核与生长有较多的说明。

5. 在最后一章中讨论了各种脆化类型,除了辐照损伤外,其它种形式都可视为化学脆。金属各种形式化学脆都导致塑性与断裂应力降低,也常伴随着断裂类型改变,如由穿晶韧断变为晶间断裂甚至解理。化学脆要求脆化物质能传输到裂纹尖端,最终引起断裂。对杂质原子(如 S、P、O)要求预先扩散到晶界,其扩展速率很慢,所以对静疲劳及裂纹扩展率试验不敏感;而对其它种化学脆(金属脆、应力腐蚀、氢脆)在 $K_I < K_{Ic}$ 情况下能观察到裂纹的缓慢扩展,当 K 小于某一临界值时裂纹不扩展,大于此数值时裂纹在应力与环境交互作用下迅速扩展,此称为

裂纹扩展第一阶段。在第二阶段扩展速率几乎与 K 无关，这是因为受到脆化物质传输到裂尖的限制，是杂质的传输速率控制着裂纹扩展率。

过去国内曾影印过《Deformation and Fracture Mechanics of Engineering Materials》以及《Mechanical Metallurgy》，对材料科学与工程专业的“材料力学性能”课程的教学影响较大，虽然现在这两本书都已有新版，但比较起来，这本书内容更加翔实丰富，将宏观力学性能与微观组织结构变化结合得更好一些，特别是对高分子、陶瓷和复合材料的力学性能作了较多的补充，并与金属材料有对比，使读者能了解与认识得更全面些，而这一方面恰恰可以弥补我们当前教学的不足。另外，本书在每章之后都有小结，并附有大量习题，习题是难易搭配的，教学方法上值得借鉴。

本书可作为材料科学与工程专业本科生、研究生教材。对本专业的科技人员也同样有较多的参考价值。

石德珂
于西安交通大学

A B O U T T H E A U T H O R

THOMAS H. COURTNEY is Professor in the Department of Metallurgical and Materials Engineering at Michigan Technological University. He received his B.S. and Sc.D. degrees from the Massachusetts Institute of Technology and his M.S. degree from Cornell University.

Professor Courtney has held academic positions first at the University of Texas—Austin and subsequently at Michigan Tech and the University of Virginia. He served as Department Chair at both of these latter institutions and, in addition, served three years as Dean of the Graduate School at Michigan Tech. Professor Courtney's research interests include materials processing (with an emphasis on powder processing), microstructural evolution, and mechanical behavior of materials. He and his students have published extensively in these areas. Professor Courtney is also the co-author of a previously published introductory materials science and engineering textbook.

Professor Courtney has held visiting faculty/scientist positions at the Max Planck Institute for Metals Research (Stuttgart, Germany), The University of California—Santa Barbara, and The Hong Kong University of Science and Technology.

When Tom Casson of WCB/McGraw-Hill contacted me late in 1997 relative to a second edition of this book, I leaped at the opportunity because immediately following publication of the first edition I realized how much better that edition could have been. I was not, in late 1997, even discouraged by the daunting schedule Tom specified. He was hoping that all of the rewriting could be accomplished in a one-year period. I more or less met his schedule. Now, exhausted by the enterprise, I realize the wisdom of that trite phrase, "Look before you leap."

This book has been substantially revised. A superficial comparison of the two editions will spot quickly some changes; example problems and certain chapters now sporting frontispieces being most prominent. The problems were added at the suggestion of reviewers of the proposed second edition. And the frontispieces were inserted to provide some appeal in this age of the required "visual impact." But there have also been more substantive changes made.

Even though the order of the book remains rather much as it was in the first edition, almost every chapter has been altered. The most prominent changes are to Chaps. 9 and 10, which deal with low-temperature fracture and these chapters have been completely rearranged. Chapter 9 (Fracture Mechanics) now focuses on the engineering science, and application of, fracture mechanics and auxiliary measures of fracture resistance such as the impact test. Chapter 10 (Toughening Mechanisms and the Physics of Fracture) now mainly deals with toughening mechanisms and fracture mechanisms in flaw-free materials. The sections on toughening mechanisms pay considerably more attention to ceramics and composites than was provided in the first edition.

Since material has been added to many of the chapters, in an (almost successful) attempt to keep the length of the book within bounds some material has been deleted. A litany-like listing of the changes made in the remaining chapters follows. In Chap. 1 (Overview of Mechanical Behavior), I have deleted much of the "mechanics" contained in the first edition, although discussion of yield criteria and a brief description of Mohr's circle are retained. A brief section on fracture toughness measurement has been added. In Chap. 2 (Elastic Behavior), moduli variations among the material classes are compared and the physical bases for these variations rationalized. The treatment of polymer elasticity has also been expanded. The changes made to Chap. 3 (Dislocations) are minor; discussion of twinning has been expanded and the evolution of dislocation arrangements with plastic strain is now treated in more detail. Chapter 4 (Plastic Deformation in Single and Polycrystalline Materials) now considers in more detail the plastic-flow behavior in the different material classes and compares plastic flow (e.g., wavy vs. planar slip) and work-hardening characteristics of the fcc and the bcc transition metals. The treatment of particle hardening in Chap. 5 (Strengthening of Crystalline Materials) has been expanded and is now more up-to-date. Here I have attempted to emphasize the

similarity in the expressions for strength due to different particle hardening mechanisms and to also indicate their similarity to expressions for the strength arising from solid-solution hardening. A case study on the development of microalloyed steels has been added. Off-axis behavior of aligned fiber composites is now treated in more detail (Chap. 6, Composite Materials), and there is more discussion on “Modern” composites in this chapter. Chapter 7 (High-Temperature Deformation of Crystalline Materials) remains much the same. However, a major omission in the first edition—solute drag creep and the Portevin-LeChatelier effect—are included in the current edition. And a case study on tungsten light bulb filaments has been added. Details on polymer molecular architecture (which can be found in elementary materials science and engineering texts) have been deleted from Chap. 8 (Deformation of Noncrystalline Materials) and the rheological details of polymer deformation are not discussed to the same extent they were in the first edition. However, discussion of silicate and metallic glasses has been slightly expanded. Chapter 11 (High-Temperature Fracture) has been reduced in length. This was achieved by eliminating the detailed mathematical description of void growth. At the time of the first edition, I had thought that this promising approach to prediction of creep fracture times and strains would soon see engineering implementation. However, the lack of ancillary physical property data and our inability to realistically mimic void spacing and the like during creep suggested a more condensed treatment was in order. Chapter 12 (Fatigue of Engineering Materials) has, I believe, been improved by including a section treating design against fatigue fracture in “flawed” and in “flaw-free” materials. This chapter also now considers the relationships among the endurance limit, the fatigue threshold stress intensity factor, and material fracture toughness. How these relationships differ in the different material classes is also discussed. And a brief description of substructure evolution (e.g., persistent slip bands) during cyclical straining of metals has been added. Chapter 13 (Embrittlement) has not been changed much. However, corrosion fatigue in “flawed” and “flaw-free” materials is now treated.

This book, I hope, comprehensively treats the mechanical behavior of materials. The extended treatment is intentional. Individual faculty members deem certain topics more important than others do. However, (as in many academic matters) seldom do faculty members agree on what these more important topics are. Thus, the breadth and depth of this book is an attempt to permit individual instructors to select those topics they wish to emphasize and to do so at a level they consider appropriate. Because the book is comprehensive, to adequately cover all of the material in it at the level at which it is addressed in the text would likely require two full semesters of a typical three-credit course. Most curricula do not have the luxury of allocating this amount of time to mechanical behavior of materials. Some experience indicates the following types of scenarios are possible with the book. A two-quarter three-credit course or a four-credit semester course could address most of the topics covered in the book. This would require some selectivity on the part of the instructor, both with respect to chapters covered and within individual chapters as well. A logical “division” is that approximately half of the course would consider deformation and half of it fracture. A four-credit quarter course or a three-credit semester course would call for further culling in individual chapters and perhaps deletion of some material (e.g., Chaps. 13).

I believe the book can be used in either an undergraduate upper division course

(or courses) or in an introductory graduate course. Of course, the flavor and emphases would differ between these situations. This, I think, is possible with this text. In the undergraduate courses I have taught using this book, I have de-emphasized mathematical developments in an attempt to inculcate in students an appreciation for the “material” aspects of mechanical behavior. And there are some topics (e.g., tensile fracture in flaw-free materials is but one of them) that would be covered in much less depth in an undergraduate course.

As in the first edition, a relatively large number of problems are provided with each chapter. They range in difficulty; some are straightforward whereas others are, should we say, “challenging.” And some are not only challenging, but lengthy as well. These are easily spotted in the sections at chapter ends, and one might ask, What is their purpose? During the last several years I have departed from the practice of conventional examinations. Instead, students work in teams (typically two-student teams for a graduate course and three-student teams for an undergraduate course) on (usually) four assignments per quarter. Each assignment ordinarily consists of three problems with one or two of these problems being of the “lengthy and challenging” variety. I can’t say that I have never pulled my hair out when grading some of the problem “solutions” handed in by the students. On the other hand, far more often the solutions presented (even by undergraduate juniors) have been so well done that I wanted to stand up and cheer.

As always in an undertaking such as this, numerous people have helped. Jeff Spencer, an undergraduate in our department at Michigan Tech, helped immeasurably with the photography. Emily Grey and Jean Lou Hess of WCB/McGraw-Hill were persistent, albeit gently demanding at times, “cheerleaders.” Professor A. K. Mukherjee of the University of California–Davis provided me with some timely reprints on the topics of creep and superplasticity. He also pointed out a critical flaw in one of the figures of the first edition. Likewise, Professor Lloyd A. Heldt, of Michigan Technological University, supplied me with several topical articles on stress corrosion cracking. I have also used some problems developed by Professor John A. Wert, a former colleague at the University of Virginia. At this point, I don’t recall the specific problems that originated with him, but thanks anyway, John.

Thomas H. Courtney

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