MECHANICAL BEHAVIOR OF MATERIALS

SECOND EDITION

This textbook fits courses on mechanical behavior of materials in mechanical engineering and materials science, and it includes numerous examples and problems. It emphasizes quantitative problem solving. This text differs from others because the treatment of plasticity emphasizes the interrelationship of the flow, effective strain, and effective stress, and their use in conjunction with yield criteria to solve problems. The treatment of defects is new, as is the analysis of particulate composites. Schmid's law is generalized for complex stress states. Its use with strains allows for prediction of *R* values for textures. Of note is the treatment of lattice rotations related to deformation textures. The chapter on fracture mechanics includes coverage of Gurney's approach. Among the highlights in this new edition are the treatment of the effects of texture on properties and microstructure in Chapter 7, a new chapter on discontinuous and inhomogeneous deformation (Chapter 12), and the treatment of foams in Chapter 21.

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William F. Hosford

University of Michigan

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Preface

The term *mechanical behavior* encompasses the response of materials to external forces. This text considers a wide range of topics. These include mechanical testing to determine material properties; plasticity, which is needed for FEM analyses of automobile crashes; means of altering mechanical properties; and treatment of several modes of failure.

The two principal responses of materials to external forces are deformation and fracture. The deformation may be elastic, viscoelastic (time-dependent elastic deformation), or plastic and creep (time-dependent plastic deformation). Fracture may occur suddenly or after repeated applications of loads (fatigue). For some materials, failure is time dependent. Both deformation and fracture are sensitive to defects, temperature, and rate of loading.

Key to understanding these phenomena is a basic knowledge of the three-dimensional nature of stress and strain and common boundary conditions, which are covered in Chapter 1. Chapter 2 covers elasticity, including thermal expansion. Chapter 3 treats mechanical testing. Chapter 4 is focused on mathematical approximations to stress–strain behavior of metals, and how these approximations can be used to understand the effect of defects on strain distribution in the presence of defects. Yield criteria and flow rules are covered in Chapter 5. Their interplay is emphasized in problem solving. Chapter 6 treats temperature and strain rate effects and uses an Arrhenius approach to relate them. Defect analysis is used to understand both superplasticity and strain distribution.

Chapter 7 is devoted to the role of slip as a deformation mechanism. The tensor nature of stresses and strains are used to generalize Schmid's law. Lattice rotations caused by slip are covered. The effects of texture on properties and microstructure have been added. Chapters 8 and 9 treat dislocations: their geometry, their movement, and their interactions. There is a treatment of stacking faults in fcc metals and how they affect strain hardening. Hardening by intersections of dislocations is emphasized. Twinning and martensitic shears are treated in Chapter 10. Chapter 11 treats the various hardening mechanisms in metallic materials.

Chapter 12 is a new chapter that covers discontinous and inhomogeneous deformation. Chapter 13 presents phenomenological and qualitative treatment of ductility, whereas Chapter 14 focuses on quantitative coverage of fracture mechanics.

Viscoelasticity (time-dependent elasticity) is treated in Chapter 15. Mathematical models are presented and used to explain stress and strain relaxation as well as damping and rate dependence of the elastic modulus. Several mechanisms of damping are presented. Chapter 16 is devoted to creep (time-dependent plasticity) and stress rupture. The coverage includes creep mechanisms and extrapolation techniques for predicting life.

Failure by fatigue is the topic of Chapter 17. The chapter starts with a phenomenological treatment of the *S-N* curve and the effects of mean stress, variable stress amplitude, and surface condition. The important material aspects, Coffin's law and crack propagation rate, are treated. Chapter 18 covers residual stresses, their origins, their effects, their measurement, and their removal.

Chapters 19, 20, and 21 cover ceramics, polymers, and composites. Separate chapters are devoted to these materials because their mechanical behaviors are very different from that of metals, which were emphasized in the earlier chapters. Because ceramics and glass are brittle and their properties are variable, Weibull analysis is presented here. Chapter 19 also covers methods of improving toughness of ceramics and the role of thermally induced stresses. The most important aspect of the mechanical behavior of polymers is their great time dependence and the associated temperature dependence. The effects of pressure on yielding and the phenomenon of crazing are also unique. Rubber elasticity is very different from Hookean elasticity. Chapter 21 covers composites, including fiber, sheet, and particulate composites. Coverage of the structure and properties of foams has been added to this chapter. Chapter 22 on metal forming covers analyses of bulk-forming and sheet-forming operations.

This text differs from other books on mechanical behavior in several aspects. The treatment of plasticity has greater emphasis on the interrelationship of the flow, effective strain, and effective stress, and their use in conjunction with yield criteria to solve problems. The treatment of defects is new. Schmid's law is generalized for complex stress states. Its use with strains allows for prediction of *R* values for textures. Another feature is the treatment of lattice rotations and how they lead to deformation textures. Most texts treat only strain relaxation and neglect stress relaxation. The chapter on fracture mechanics includes coverage of Gurney's approach. Most texts omit any coverage of residual stresses. Much of the analysis of particulate composites is new. Few texts include anything on metal forming. Throughout the text, there is more emphasis on quantitative problem solving than in most other texts. The notes at the end of the chapters are included to increase reader interest in the subject.

As a consequence of the increased coverage in these areas, the treatment of some other topics is not as extensive as in competing texts. There is less coverage of fatigue failure and fracture mechanics.

This book may contain more material than can be covered in a single course. Depending on the focus of the course, various chapters, or portions of chapters, may be omitted. It is hoped that this book will be of value to mechanical engineers as well as materials engineers. If the book is used in a mechanical engineering course, the instructor may want to skip some chapters. In particular, Chapters 8 through 11 may be omitted. If the book is used in a materials science course, the instructor may want to omit Chapters 10, 18, and 22. Both may want to skip Chapter 11 on twinning and memory metals. Even though it was realized that most users may want to skip this chapter, it was included for completeness and in the hope that it may prove useful as a reference.

It is assumed that the students who use this book will have had both an introductory materials science course and a "strength of materials" course. From the strength of materials course, they can be expected to know basic concepts of stress and strain, how to resolve stresses from one axis system to another, and how to use Hooke's laws in three dimensions. They should be familiar with force and moment balances. From their materials science course, they should understand that most materials are crystalline and that crystalline materials deform by slip resulting from the movement of dislocations. They should also be familiar with such concepts as substitutional and interstitial solid solutions and diffusion. Appendices aI (Miller indices) and aII (Stereographic projection) are available for students not familiar with these topics.

The main difference between this and the first edition is the treatment of the effects of texture on properties and microstructure in Chapter 7, the addition of Chapter 12 on discontinuous and inhomogeneous deformation, and the treatment of foams in Chapter 21.