Mechanical Behavior of Materials

Third Edition

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Mechanical Behavior of Materials

THIRD EDITION

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Lovingly dedicated to the memory of my parents, Henri and Marie-Anne.

Marc André Meyers

Lovingly dedicated to the memory of my parents, Manohar L. and Sumitra Chawla.

Krishan Kumar Chawla

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Preface to the Third Edition

We are very pleased to offer this third edition of *Mechanical Behavior of Materials*. The first edition was published by Prentice-Hall in 1998. The second edition, a Cambridge University Press imprint, came out in 2009. The third edition is now seeing the light of the day in 2025. Needless to say, we have maintained the same fundamental theme of the book, viz., the fundamental mechanisms responsible for the mechanical properties of different materials under a variety of environmental conditions. The unique feature of the book is the presentation in a unified manner of important principles responsible for mechanical behavior of materials, metals, polymers, ceramics, composites, biological materials, electronic materials. The underlying theme is that structure (at the micro or nanometer level) of the material controls the properties of the material.

Although the basic theme of the book remains unchanged, the third edition has been updated with:

- State-of-the-art coverage of the major developments in materials, such as steels, ceramics, polymers, composites, biologic materials. Specifically, we discuss: unique characteristics of biological materials including the Arzt heptahedron and structural design elements which enable a quantitative engineering treatment in Chapter 1; the Euler equation, elasticity averaging methods of isostress and isostrain (Voigt and Reuss), and anisotropic effects to matrix formulation of stiffness in Chapter 2; High-Entropy Alloys in Chapter 10; Micropillar mechanical testing, EBSD (electron back-scattered diffraction), a powerful characterization method, and coincidence site lattice update in Chapter 5; fracture toughness of biological materials in Chapter 7.
- Many new figures to improve the presentation and to clarify the concepts presented.
- Fresh worked examples and exercises that help the students test their understanding.

The book is principally meant for use in the upper division and graduate level courses of mechanical engineering, and materials science and engineering departments. However, it will also be a great source of reference material to the practicing engineer, scientist, and researcher. We have kept the level of mathematics quite simple, and suggest the reader to refer back to Chapter 1 if needed, as it provides the basic materials-level information necessary to study this subject.

MAM would like to thank Sheron Tavares and Aomin Huang for their competent and dedicated work in the revision and permissions. This third edition would never have seen the day if it were not for them. He also thanks Boya Li for

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xviii Preface to the Third Edition

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Preface to the Second Edition

The second edition of Mechanical Behavior of Materials has revised and updated material in every chapter to reflect the changes occurring in the field. In view of the increasing importance of bioengineering, a special emphasis is given to the mechanical behavior of biological materials and biomaterials throughout this second edition. A new chapter on environmental effects has been added. Professors Fine and Voorhees¹ make a cogent case for integrating biological materials into materials science and engineering curricula. This trend is already in progress at many US and European universities. Our second edition takes due recognition of this important trend. We have resisted the temptation to make a separate chapter on biological and biomaterials. Instead, we treat these materials together with traditional materials, viz., metals, ceramics, polymers, etc. In addition, taking due cognizance of the importance of electronic materials, we have emphasized the distinctive features of these materials from a mechanical behavior point of view.

The underlying theme in the second edition is the same as in the first edition. The text connects the fundamental mechanisms to the wide range of mechanical properties of different materials under a variety of environments. This book is unique in that it presents, in a unified manner, important principles involved in the mechanical behavior of different materials: metals, polymers, ceramics, composites, electronic materials, and biomaterials. The unifying thread running throughout is that the nano/microstructure of a material controls its mechanical behavior. A wealth of micrographs and line diagrams are provided to clarify the concepts. Solved examples and chapter-end exercise problems are provided throughout the text.

This text is designed for use in mechanical engineering and materials science and engineering courses by upper division and graduate students. It is also a useful reference tool for the practicing engineers involved with mechanical behavior of materials. The book does not presuppose any extensive knowledge of materials and is mathematically simple. Indeed, Chapter 1 provides the background necessary. We invite the reader to consult this chapter off and on because it contains very general material.

In addition to the major changes discussed above, the mechanical behavior of cellular and electronic materials was incorporated. Major reorganization of material has been made in the following parts: elasticity; Mohr circle treatment; elastic constants of fiber reinforced composites; elastic properties of biological and of biomaterials; failure criteria of composite materials; nanoindentation technique

¹ M. E. Fine and P. Voorhees, "On the evolving curriculum in materials science & engineering," *Daedalus*, Spring 2005, 134.

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and its use in extracting material properties; etc. New solved and chapter-end exercises are added. New micrographs and line diagrams are provided to clarify the concepts.

We are grateful to many faculty members who adopted the first edition for classroom use and were kind enough to provide us with very useful feedback. We also appreciate the feedback we received from a number of students. MAM would like to thank Kanika Chawla and Jennifer Ko for help in the biomaterials area. The help provided by Marc H. Meyers and M. Cristina Meyers in teaching him the rudiments of biology has been invaluable. KKC would like thank K. B. Carlisle, N. Chawla, A. Goel, M. Koopman, R. Kulkarni, and B. R. Patterson for their help. KKC acknowledges the hospitality of Dr. P. D. Portella at Federal Institute for Materials Research and Testing (BAM), Berlin, Germany, where he spent a part of his sabbatical. As always, he is grateful to his family members, Anita, Kanika, Nikhil, and Nivi for their patience and understanding.

A Note to the Reader

Our goal in writing *Mechanical Behavior of Materials* has been to produce a book that will be the pre-eminent source of fundamental knowledge about the subject. We expect this to be a guide to the student beyond his or her college years. There is, of course, a lot more material than can be covered in a normal semester-long course. We make no apologies for that in addition to being a classroom text, we want this volume to act as a useful reference work on the subject for the practicing scientist, researcher, and engineer.

Specifically, we have an introductory Chapter 1 (Materials: Structure, Properties, and Performance) dwelling on the themes of the book: structure, mechanical properties, and performance. This section introduces some key terms and concepts that are covered in detail in later chapters. We advise the reader to use this chapter as a handy reference tool, and consult it as and when required. We strongly suggest that the instructor use this first chapter as a self-study resource. Of course, individual sections, examples, and exercises can be added to the subsequent material as and when desired.

Enjoy!

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