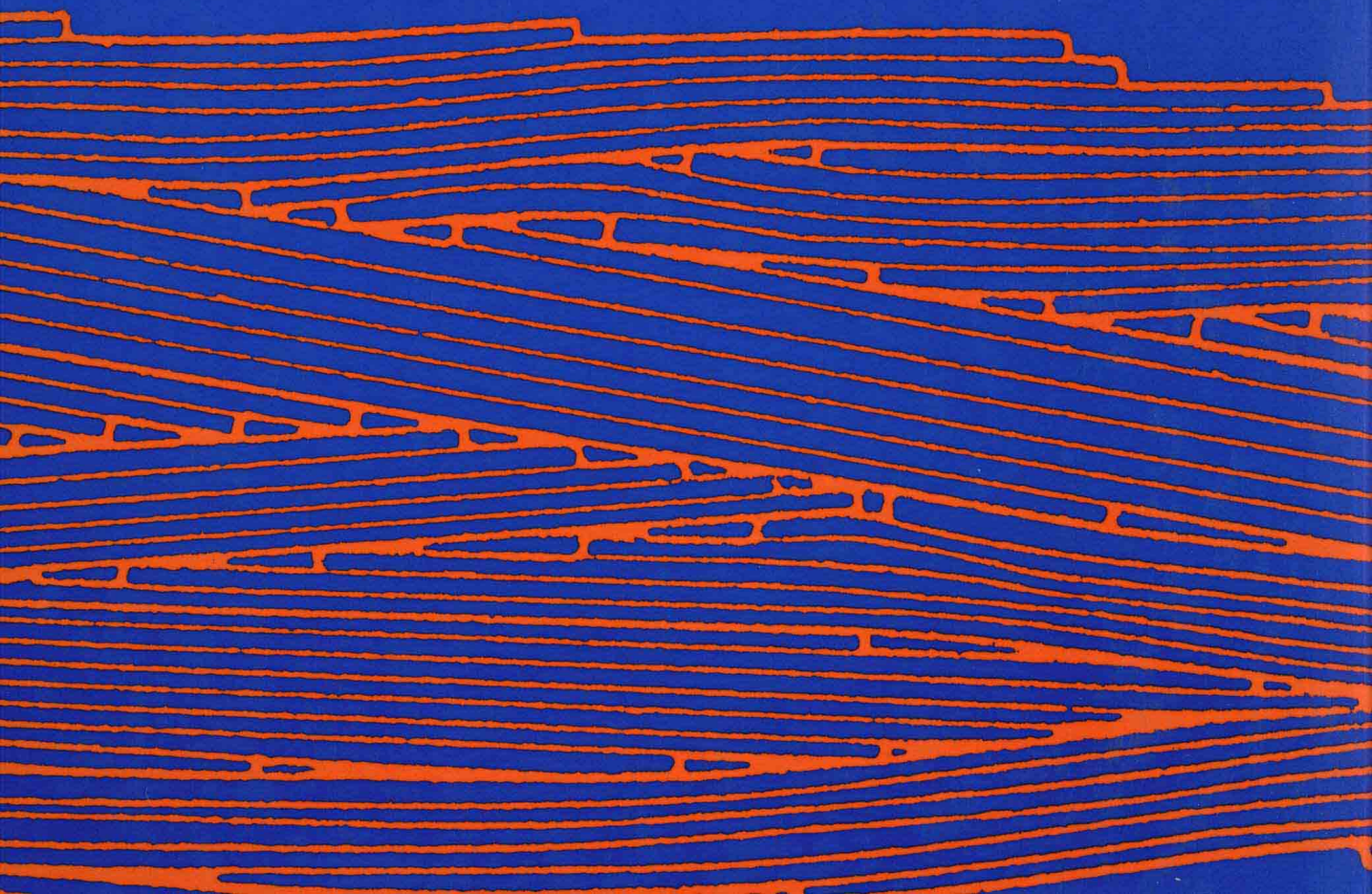
THOMAS H. COURTNEY

MECHANICAL BEHAVIOR OF MATERIALS



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ABOUT THE AUTHOR

Thomas H. Courtney is Professor and Chairman of the Department of Materials Science at the University of Virginia. He received his B.S. and Sc.D. degrees from the Massachusetts Institute of Technology and the M.S. degree from Cornell University.

Professor Courtney's academic career began at the University of Texas-Austin and continued at Michigan Technological University where he served prior to coming to Virginia in 1986. In addition to his academic duties, he also served as Dean of the Graduate School at Michigan Tech from 1983 through 1986. Professor Courtney's research interests include materials processing, microstructural evolution, composite materials, and mechanical behavior. He and his students have published extensively in these areas. Professor Courtney is also a coauthor of an introductory materials science and engineering textbook. While at Texas, he received the Cactus Teaching Excellence Award and was named as distinguished advisor in the Mechanical Engineering Department. At Michigan Tech he received the Research Award and was a finalist in the competition for the Distinguished Teacher Award. He has been a visiting scientist at the Max Planck Institute for Metals Research, Stuttgaart, Federal Republic of Germany, and The University of California—Santa Barbara. He is also a Fellow of ASM International.

To JOHN WULFF (1903–1985)
A dedicated teacher,
an able mentor,
a kind human being,
and an unparalleled curmudgeon.

PREFACE

This book deals with the mechanical behavior of materials. It emphasizes the relationship among macroscopic properties, material microstructure, and fundamental concepts of bonding and crystal structure. There are two primary reasons why this text was written. First, the last several decades have seen significant advances in application of mechanics concepts at the microstructural level. This area—micromechanics—has enabled quantitative descriptions of structure–property relationships to supplant the qualitative ones of a generation previous. In my judgment, it is timely to transmit these advances in our understanding through a text designed for advanced undergraduate students or entering graduate students. Another compelling reason for writing this book has been the recent emergence of ceramics, composites, and polymerics as structural materials in their own right. They are currently competitive with metals in many applications, and their importance is sure to increase in the future. Many previous treatments of mechanical behavior concentrated unduly on metallic materials. In this book I have attempted, as best as a professional metallurgist can, to give equal justice to nonmetallics.

As mentioned, this book is geared to advanced undergraduates or first-year graduate students. For it to be useful to an undergraduate, he or she must have ample grounding in the basic elements of materials science and engineering as obtained, for example, through sophomore and/or junior level courses common to most materials-based curricula. I believe the book is also suitable for an introductory graduate course for students majoring in materials or related disciplines, but who do not possess an undergraduate degree in a materials area.

The text is essentially concerned with two areas of material mechanical behavior: deformation and fracture. As such it can be logically divided into a two-semester course sequence, with one semester concentrating on deformation and the other on fracture. (It would be possible, via judicious selection of topics, to cover much of the text in a two-quarter course sequence.) Specifically, Chapters 2 through 8 are concerned with deformation of mate-

rials, whereas Chapters 9 through 13 deal with material failure. Chapter 1 is an introduction to the principles of mechanics, and this chapter also provides a brief overview of the topics covered in the remainder of the text.

I have attempted to introduce each chapter or topic at an elementary level. This is followed, though, by development of topics in greater depth and breadth. A summary, reemphasizing the important details and principles, is provided at the conclusion of each chapter as is a fairly extensive selection of problems. The problems are of varying difficulty and scope. Some of them are conceptually quite demanding. Nonetheless, I, and a number of my colleagues, believe that greater student understanding is achieved via solving such problems.

This book was started when I was a member of the faculty of the Metallurgical Engineering Department at Michigan Technological University. I am indebted to that department for providing an atmosphere conducive to my work on the book. A quarter on leave, taken at the University of California—Santa Barbara, provided time to make considerable progress on the text. This time was often taken at the expense of presumed duties at that institution. Professors Anthony Evans, Carlos Levi, and Robert Mehrabian of U.C.S.B. deserve thanks in this regard. Professors Bruce Pletka (of Michigan Tech) and Donald Koss (of Penn State) read the initial drafts of many chapters and made suggestions, some of which have been incorporated in the final version of the book. Professors John Wert and Richard Gangloff of the University of Virginia provided several problems for the book. Ms. Patty Hawk ably and cheerfully typed the manuscript at a level of renumeration hardly commensurate with the onerous task. A group of junior students in a course I taught at Michigan Tech cheerfully served as "test specimens" for a trial run of the deformation portion of the book. The following reviewers provided many valuable comments and suggestions during the development of this manuscript: Michael Bever, Massachusetts Institute of Technology; George Dieter, University of Maryland; Gunter Gottstein, Michigan State University; and Charles Wert, University of Illinois. Finally, my graduate students were subjected to benign neglect while I took time to work on this task. They include Paul Funkenbusch, Dave Kubisch, Yang Leng, Jean Malzahn Kampe, Bhoopaul Harriprashad, Dave Maurice, and Bev Myers. The fact that their professional development seems not to have been hampered by my distraction speaks well of them.

Thomas H. Courtney

MECHANICAL BEHAVIOR OF MATERIALS

CONTENTS

CHAPTER 1

OVERVIEW OF MECHANICAL BEHAVIOR

1.1 INTRODUCTION

This book is concerned with the mechanical behavior of solid materials, particularly as this behavior is affected by processes taking place at the microscopic and/or atomic level. The response of a solid to externally applied or internally generated forces can vary considerably, depending on the magnitude of the applied forces and the material characteristics. For example, if the forces are great the material may fracture. Lesser values of force may result in permanent deformation of the material without fracture, and if the forces are low enough the material may deform only in an elastic way. The treatment of mechanical behavior in this book closely parallels these three possibilities.

While our aim is to relate the mechanical response of a solid to material structure at the microscopic and atomistic level, this response is manifested in a macroscopic way. Thus, to fulfill adequately the objective of the text, a reasonable background in the concepts of mechanical behavior as measured and assessed at a macroscopic level is required. Indeed, it is this coupling between microstructure and properties that constitutes one of the most fruitful areas of materials science and engineering.

Accordingly, for this book to be of maximum benefit to a student using it, prior exposure to the concepts of materials science and mechanics is required. As the text is expected to be used primarily by students of materials science and engineering, many of whom will need refreshing in the concepts of mechanics and strength of materials, this chapter presents a brief overview of this topic. On the other hand, readers with an adequate background and