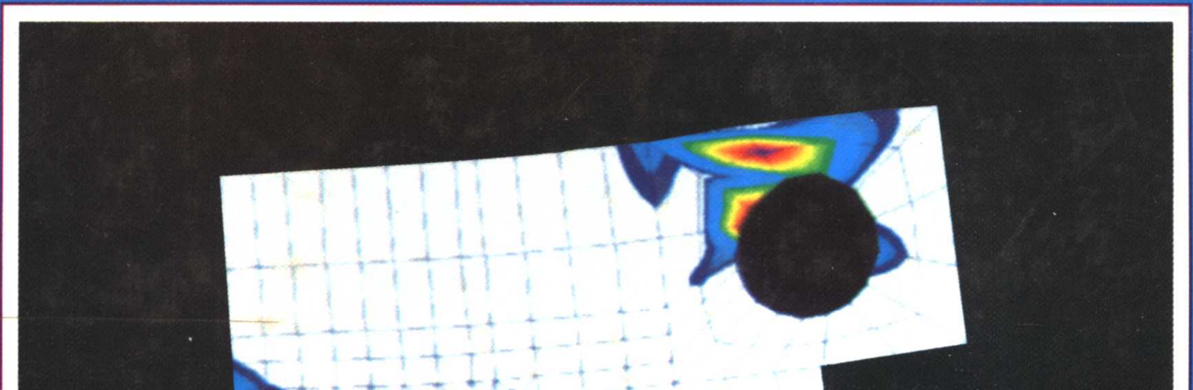
FRACTURE MECHANICS

Fundamentals and Applications



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Fundamentals and Applications

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PREFACE

The field of fracture mechanics was virtually nonexistent prior to World War II, but has since matured into an established discipline. Most universities with an engineering program offer at least one fracture mechanics course on the graduate level, and an increasing number of undergraduates have been exposed to this subject. Applications of fracture mechanics in industry are relatively common, as knowledge that was once confined to a few specialists is becoming more widespread.

While there are a number of books on fracture mechanics, most are geared to a specific audience. Some treatments of this subject emphasize material testing, while others concentrate on detailed mathematical derivations. A few books address the microscopic aspects of fracture, but most consider only continuum models. Many books are restricted to a particular material system, such as metals or polymers. Current offerings include advanced, highly specialized books, as well as introductory texts. While the former are valuable to researchers in this field, they are unsuitable for students with no prior background. On the other hand, introductory treatments of the subject are sometimes simplistic and misleading.

This book provides a comprehensive treatment of fracture mechanics that should appeal to a relatively wide audience. Theoretical background and practical applications are both covered in detail. This book is suitable as a graduate text, as well as a reference for engineers and researchers. Selected portions of this book would also be appropriate for an undergraduate course in fracture mechanics.

The subject matter is organized in a unique fashion. The book is intended to be readable without being superficial. The fundamental concepts are first described qualitatively, with a minimum of higher level mathematics. This enables a student with a reasonable grasp of undergraduate calculus to gain physical insight into the subject. For the more advanced reader, appendices at the end of certain chapters give the detailed mathematical background.

In outlining the basic principles and applications of fracture mechanics, I have attempted to integrate materials science and solid mechanics to a much greater extent than previous texts. Although continuum theory has proved to be a very powerful tool in fracture mechanics, one cannot ignore microstructural aspects. Continuum theory can predict the stresses and strains near a crack tip, but it is the material's microstructure that determines the critical conditions for fracture.

The first chapter introduces the subject of fracture mechanics and provides an overview; this chapter includes a review of dimensional analysis, which proves to be a useful tool in later chapters. Chapters 2 and 3 describe the fundamental concepts of linear elastic and elastic-plastic fracture mechanics, respectively. One of the most important and most often misunderstood concepts in fracture mechanics is the single parameter assumption, which enables the prediction of structural behavior from small scale laboratory tests. When a single parameter uniquely describes the crack tip conditions, fracture toughness, which is a critical value of this parameter, is independent of specimen size. When the single parameter assumption breaks down, fracture toughness becomes size dependent, and a small scale fracture toughness test may not be indicative of structural behavior. Chapters 2 and 3 describe the basis of the single parameter assumption in detail, and outline the requirements for its validity. Chapter 3 includes the results of recent research that quantifies the size dependence of fracture toughness for cleavage in metals. The main bodies of Chapters 2 and 3 are written in such a way as to be accessible to the beginning student. Appendices 2 and 3, which follow Chapters 2 and 3, respectively, give mathematical derivations of several important relationships in linear elastic and elastic-plastic fracture mechanics. Most of the material in these appendices requires a graduate-level background in solid mechanics.

Chapter 4 introduces dynamic and time-dependent fracture mechanics. The section on dynamic fracture includes a brief discussion of rapid loading of a stationary crack, as well as rapid crack propagation and arrest. The C^*, $C(t)$, and C_t parameters for characterizing creep crack growth are introduced, together with analogous quantities that characterize fracture in viscoelastic materials.

Chapter 5 outlines micromechanisms of fracture in metals and alloys, while Chapter 6 describes fracture mechanisms in polymers, ceramics and composites. These chapters emphasize the importance of

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microstructure and material properties on the fracture behavior. An appendix at the end of Chapter 5 illustrates that the micromechanism of fracture can have a profound effect on the validity of the single parameter assumption.

The applications portion of this book begins with Chapter 7, which gives practical advice on fracture toughness testing in metals. This chapter describes standard test methods, such as K_{IC}, J_{IC}, and CTOD, as well as recent research results. Chapter 7 includes a section on weldment testing, which has yet to be standardized in the U.S. Chapter 8 describes fracture testing of nonmetallic materials. Most of these test methods are still experimental in nature, since this is a relatively new field. Currently, a number of researchers are characterizing fracture behavior of plastics with test methods that were originally developed for metals; Chapter 8 discusses the validity of such tests for polymers, and suggests improvements in current methodology. Chapter 9 outlines the available methods for applying fracture mechanics to structures, including linear elastic approaches, the EPRI J estimation scheme, the R-6 method, and the British Standards PD 6493 approach. A brief description of probabilistic fracture mechanics is also included, as well as a discussion of the shortcomings of existing analyses. Chapter 10 describes the fracture mechanics approach to fatigue crack propagation, and discusses some of the critical issues in this area, including crack closure and the behavior of short cracks. Chapter 11 outlines some of the most recent developments in computational fracture mechanics. Procedures for determining stress intensity and the J integral in structure are described, with particular emphasis on the energy domain integral approach.

Chapter 12 provides reference material that is usually found in fracture mechanics handbooks. This material includes stress intensity factors for common configurations, as well as limit load, elastic compliance, and fully plastic J solutions. Chapter 13 contains a series of practice problems that correspond to material in Chapters 1 to 11.

If this book is used as a college text, it is unlikely that all of the material can be covered in a single semester. Thus the instructor should select the portions of the book that suit the needs and background of the students. The first three chapters, excluding appendices, should form the foundation of any course. In addition, I strongly recommend the inclusion of at least one of the materials chapters (5 or 6), regardless of whether or not materials science is the students' major field of study. A course that is oriented toward applications could include Chapters 7 to 10, in addition to the earlier chapters. A graduate level course in a solid mechanics curriculum might include Appendices 2 and 3, Chapter 4, Appendix 4, and Chapter 11.

Desk-top publishing enthusiasts may be interested to know that this book was produced on a Macintosh personal computer. The text was written in Microsoft Word 4.0 and the graphics were produced with Canvas 2.1 and KaleidaGraph 2.0. The final camera-ready copy was printed on a 300 dpi LaserWriter II NT. Since I am responsible for virtually all of the key strokes and mouse movements that went into this book, I have no one to blame but myself for any mistakes that may have occurred.

I do, however, have many people to thank. I am grateful to Joel Claypool, Russ Hall and Sandy Perlman at CRC Press for their support and advice. A number of colleagues and friends reviewed portions of the draft manuscript and/or provided photographs and homework problems, including W.L. Bradley, M. Cayard, R Chona, M.G. Dawes, R.H. Dodds Jr., A.G. Evans, S.J. Garwood, J.P. Gudas, E.G. Guynn, A.L. Highsmith, R.E. Jones Jr., J. Keeney-Walker, Y.W. Kwon, E.J. Lavernia, A. Letton, R.C. McClung, D.L. McDowell, J.G. Merkle, M.T. Miglin, D.M. Parks, P.T. Purtscher, R.A. Schapery, and C.F. Shih. I apologize to anyone whose name I have inadvertently omitted from this list. I received valuable assistance from Twyla Ray and Amy Cummings, who performed some of the tedious clean-up work on the manuscript. Mr. Sun Yongqi produced a number of SEM fractographs especially for this book. I would like to express my appreciation to Walter Bradley, the Head of the Mechanical Engineering Department at Texas A&M University, for providing an environment conducive to the preparation of this book. Finally I wish to express my gratitude and apologies to my wife Sarah and my daughter Molly for enduring this past year, when much of my time and energy that should have been devoted to them was instead focused on this book.

T.L. Anderson

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