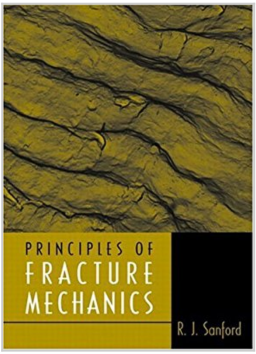

Principles of Fracture Mechanics

By R. J. Sanford

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The book is a self-contained manual on the mechanics aspects of the theory of brittle fracture and fatigue. It includes a guided introduction to the linear theory of elasticity with pivotal results for the circular hole, the elliptical hole and the wedge leading up to the general problem of bodies containing cracks. Typical chapters include problems which extend the mathematical developments presented in the book, applications problems requiring numerical and/or graphic responses, and essay/literature study questions. Additionally, more comprehensive exercises requiring integration of the knowledge throughout the book are included as an appendix. For professionals in fields of engineering mechanics and design.

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Editorial Review

From the Back Cover

Intended for a first course in the mechanics of fracture at the graduate level (or senior undergraduates with a background in engineering mechanics) the focus of the book is on the mathematical principles of linear elastic fracture mechanics and their application to engineering design. The material is presented in a conversational, yet rigorous, manner with the focus on the general formulation of the theory. In this way the origins and limitations of the simplified results presented in other introductory texts is apparent. The selection of topics and order of presentation in the book evolved from a graduate course in fracture mechanics developed by the author over the last two decades.

Key Features of the Book

- Unified mathematical treatment based on the generalized Westergaard formulation provides a coherent basis for the analytical, numerical, and experimental treatment of crack problems in two dimensions.
- Introductory chapter on the linear theory of elasticity with pivotal results for the circular hole, elliptical hole, and the wedge leading up to the general problem of bodies with cracks.
- Thorough treatment of fatigue crack growth behavior including both analytical methods and introductions to the **NASGRO 3.0** and **AFGROW 4.0** computer programs for lifetime prediction analysis using complex empirical fatigue crack growth models.
- Extensive tables of fracture properties for a wide variety of metallic materials in both English and S.I. units derived from the NASA database.
- Broad spectrum of exercises at the end of each chapter ranging from basic analytic derivations to parametric numerical analysis. Also included is a selection of comprehensive open-ended design problems suitable for capstone project assignments or take-home examinations.

About the Author

Professor Emeritus R.J. Sanford has had two careers involving fracture mechanics. He spent 22 years at the Naval Research Laboratory as a research engineer during a period of intense fracture mechanics discovery at NRL under the direction of George R. Irwin. He left NRL in 1982 to join the faculty at the University of Maryland. At the College Park campus his focus has been on graduate education in solid mechanics and fracture. He is a Fellow in the Society for Experimental Mechanics and has received both their Hetenyi Award (for research) and the Frocht Award (for teaching excellence) and is a member of Committee E08 of the American Society for Materials and Testing (ASTM).

OVERVIEW

Fracture mechanics as an engineering discipline was introduced in the 1950s under the leadership of George R. Irwin at the Naval Research Laboratory (NRL). The concepts of fracture mechanics were further developed and refined throughout the 1960s by a collaboration of researchers in universities, government laboratories, and the commercial aircraft and aerospace industries. Definable within the context of the linear theory of elasticity, the fundamentals of fracture mechanics have a wide range of engineering design applications, including the analysis of brittle fracture of low-toughness structural materials and many nonmetallics, and the quantitative prediction of fatigue crack growth in a wide range of engineering materials. This latter application is of major importance in contemporary engineering design since over 80 percent of all brittle fractures have their origins in fatigue crack growth. In its current state of development, the discipline of Linear Elastic Fracture Mechanics (LEFMs) is a mature science that can be and, indeed, is being introduced into the basic programs of instruction in mechanical, civil, aerospace, and engineering mechanics departments.

The focus of this book, intended for a first course in the mechanics of fracture at the graduate level (or for senior undergraduates with a background in engineering mechanics), is on the mathematical principles of linear elastic fracture mechanics and their application to engineering design. The selection of topics and order of presentation in the book evolved from a graduate course in fracture mechanics developed by the author over the last two decades. The material has been tested on several hundred students over that time, and the level of treatment and extent of mathematical development presented in the text are the result of feedback provided by the students. Many of the chapter exercises and comprehensive design problems are taken from examinations given in the course. A Web site at the University of Maryland (**www.wam.umd.edu/~rsanford**) contains supplemental material, including detailed graphics, data sets, and relevant links to supporting material. The site also provides a convenient way to communicate your suggestions and comments to the author.

The material is presented in a conversational, yet rigorous, manner, with the focus on the general formulation of the theory. In this way the origins and limitations of the simplified results presented in other introductory texts are apparent. Throughout the text, key historical results are emphasized to provide a sense of the history of fracture mechanics. This feature makes the book of interest to practicing engineers and researchers interested in a broad overview of the field.

Ideally, the study of LEFM should have as a prerequisite a thorough understanding of the linear theory of elasticity: however, the practicalities of scheduling graduate instruction often result in the student having no choice but to study both topics concurrently. The organization of the book anticipates this possibility by including, early on, a chapter on those elements of solid mechanics necessary for understanding the remainder of the text.

The minimum mathematical background required to gain a full appreciation of the material is a one-semester introductory course in partial differential equations (often taught at the undergraduate junior level) or its equivalent. Some familiarity with complex variables and functions, but not necessarily a comprehensive knowledge, is also required. Also, some of the exercises assume proficiency in computer-based problem solving at the PC or workstation level.

KEY FEATURES OF THE BOOK

The book is a self-contained manual on the mechanics aspects of the theory of brittle fracture and fatigue and is suitable for either self-study or classroom instruction. It includes a guided introduction to the linear theory of elasticity with pivotal results for the circular hole, the elliptical hole, and the wedge, leading up to the general problem of bodies containing cracks.

The book draws upon extensive original material on the mathematical formulation of the stress field around crack tips, the numerical analysis of bodies with finite dimensions, and the use of experimental methods to determine the stress intensity factor, based on the author's nearly 40 years experience in the field.

Designed around pedagogical needs, the exercises at the end of each chapter provide a mixture of problematic approaches that can be emphasized, depending on the instructor's focus. A typical chapter includes problems that extend the mathematical developments presented in the chapter, applications problems that require numerical and/or graphical responses, and essay/literature study questions. In addition, more comprehensive exercises requiring integration of the knowledge presented throughout the text of the book are included as an appendix. The majority of these comprehensive exercises were adapted from take-home final exams given by the author over the years and are suitable for that purpose. To protect the integrity of these questions they will not be included in the solutions manual.

Curiously missing from all of the existing introductory textbooks on fracture mechanics is even a modest tabulation of elastic and fracture properties of engineering materials. Included in this text are two appendices listing (a) strength and fracture properties and (b) fatigue data for a wide variety of metallic materials, adapted from the NASA/NASGRO database.

All of the above features of the book notwithstanding, the single most unique feature of the book is the use throughout of a unified mathematical treatment based on the generalized Westergaard formulation of the elastic problem of stresses in bodies containing cracks. This mathematically complete formulation, developed by the author in 1978 and extended to multiple categories of problems in the years since, provides all of the rigor needed to carry out the theme of the book without demanding mathematical proficiency beyond that of most potential readers (and instructors). An appendix on the use of complex variables in elasticity describes the simple complex-variable operations required with this method. The Westergaard method presented in this book differs from that presented in every other book on fracture mechanics, including even the most recent topical monographs, in that the formulation presented here is mathematically equivalent to any of the alternative complex-variable formulations but is significantly less difficult to manipulate. As a consequence, readers of this book will be able to derive very general mathematical expressions and solve complex problems, even if they have had only nominal mathematical training. In addition, this formulation is highly compatible with symbolic manipulation languages such as Mathematica™ and MathCAD™. Consistent with the self-contained philosophy of the book, an appendix contains an extensive tabulation of Westergaard stress functions and the corresponding *K* solutions.

OUTLINE OF THE BOOK

The book consists of 11 chapters and 5 appendices. The main body of the book divides naturally into two roughly equal parts that focus on the two complementing concepts of fracture mechanics; namely, the stress state at the crack tip and the material's resistance to fracture. The appendices provide supplemental material necessary for completeness and self-sufficiency as a textbook.

The first focal concept presented in the book, discussed in Chapters 1 through 5, is the development of the mathematical theory of the state of stress at the crack tip. By the middle of Chapter 3 the reader is introduced to the universal nature of this stress state and its characterizing parameter, the geometric stress intensity factor, *K*. The remainder of the chapter demonstrates analytical methods (exact and approximate) to determine K without formally solving the complete elasticity problem for each new geometry. In Chapters 4 and 5 the theoretical basis for various numerical (Chapter 4) and experimental (Chapter 5) methods to compute *K* is developed and demonstrated by practical examples. The goal of these two chapters is to encourage creativity in extracting the stress intensity factor and other key variables for realistic geometries.

The second focal concept, encompassing Chapters 6 through 11, is the development of appropriate theories of failure based principles of elastic mechanics. In Chapter 6 the concept of a critical stress intensity factor as a material property, distinct from the geometric stress intensity factor, is introduced, and the consequences explored. Chapter 7 follows a similar development for the strain energy release rate. Having defined new material properties in the preceding chapters, Chapter 8 describes established and novel ways to determine them.

In Chapter 9 the focus shifts from brittle, sudden fracture to its frequent precursor, sub-critical fatigue crack growth. The emphasis in this chapter necessarily is on the origin and rationale behind the various empirical fatigue crack growth laws. Starting from the Paris law, the historical progression of fatigue laws is presented, including the latest variant of the Foreman-Neuman-de Konig form used in the NASA/NASGRO 3.0 computer program for fatigue life prediction, which is treated in detail.

The incorporation of a fracture-resistant mentality into the design process by adding the fracture failure analysis scenario into the design calculation sequence is described in Chapter 10 and demonstrated with an example taken from the literature. The philosophy and requirements of the U.S. Air Force damage-tolerant design model are presented. The role of nondestructive evaluation (NDE) in the design process is also introduced in Chapter 10. Finally, the lessons to be learned from reviewing case studies in fracture are discussed, and several examples are presented.

The final chapter, Chapter 11, is intended as an introduction to the intermediate mechanism of failure lying between brittle fracture and general yielding—specifically—elastoplastic fracture or ductile tearing. The intent of this chapter is to introduce the reader to the basic concepts and the terminology of elastoplastic fracture mechanics (EPFM).

Users Review

From reader reviews:

Herbert Willams:

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