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Daining Fang
Jinxi Liu

压电与铁电体的断裂力学

Fracture Mechanics of Piezoelectric and Ferroelectric Solids



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With 209 figures



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内 容 简 介

本书是关于压电/铁电材料断裂力学的专著,从理论分析、数值计算和实验观察三个方面比较全面、系统地阐述了压电/铁电材料的电致断裂问题,强调静态、动态和界面断裂问题的力学提法以及力电耦合效应所导致的电致断裂的物理本质。本书的主要特色是:从晶体学的角度简要介绍了压电/铁电材料的基本特征;详细描述了压电材料的基本方程以及与断裂问题相关的一般解;以图的形式提供了大量的数值结果;给出了主题词和作者索引;用简洁的语言解释了复杂的电致断裂问题。本书可帮助固体力学、材料科学、应用物理和机械工程领域的读者很容易地抓住问题的物理本质并把握压电/铁电材料断裂力学的研究现状。

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Daining Fang
Jinxi Liu

**Fracture Mechanics of Piezoelectric and
Ferroelectric Solids**

Foreword

Mechanical-electrical coupling and anisotropy of piezoelectric/ferroelectric solids complicate studies of their damage and fracture. Therefore, the solution of fracture mechanics problems for such materials is challenging. It has become an important subject in solid mechanics and materials physics to understand the physical mechanisms of fracture of piezoelectric/ferroelectric solids and improve the fracture resistance of such materials. This book discusses the characteristics and engineering background of piezoelectric/ferroelectric solids, the electromechanical coupling fracture behavior and failure modes from a systematic point of view, which combines solid mechanics and material physics. The establishment of fracture criteria is the embodiment of the research findings and theoretical system formed in recent years, which not only enriches the subject of studies in solid mechanics, but also underlies important academic values. This book is featured with the subject of “How Electromechanical Coupling Effect Influences Fracture Behavior of Piezoelectric/Ferroelectric Materials”, and addresses clear physical concepts and prudent mathematic mechanics, leverages theoretical approaches, experimental technology and actual materials as a valuable reference for postgraduates and researchers in solid mechanics and materials physics.

The authors of the book, Professors Daining Fang and Jinxi Liu are both young scholars with high academic accomplishments as well as solid and profound foundation in the mechanic theories of intelligent materials and expertise in materials physics. Their work has focused on theories and experimental research in deformation and fracture of piezoelectric/ferroelectric materials and ferromagnetic materials, where they made a series of important innovations with significant impact both at home and abroad. Based on their years of research and studies of relevant literature in China and abroad, they have systematically interpreted the fundamental theories and research approaches as applied to fracture of piezoelectric/ferroelectric solids in the form of a monograph with unique and rich

content, wide coverage of literature, step-by-step discussion, clean and prudent structure and high academic standards. It is an excellent academic book and I hereby would highly recommend it to the readers.

A handwritten signature in black ink, consisting of three stylized Chinese characters: 黄克智 (Huang Kezhi).

Kezhi Huang
At Tsinghua University

Preface

Rapid changes in the information technology have led to the development of mature technology for MEMS (microelectromechanical systems), microelectronics and packaging, sensing, actuation and the intelligent structure of control since the end of the 20th century. As a result, new scientific problems in multi-field coupling of functional materials and micro information structural mechanics are proposed. For stress, strain and strong interaction between heat and electromagnetic phenomena, mechanical rules become extremely important to the design of the above MEMS, microelectronics and intelligent structures. Therefore, the reliability of these devices is attracting increasing attention. Fragility of piezoelectric/ferroelectric ceramics and defect formation during their preparation, such as voids and cracks, generally lead to the loss of expected functions and even damage of piezoelectric/ferroelectric components or piezoelectric/ferroelectric intelligent structures in terms of the single or synergic functions of mechanical and electric loading. Such challenges urge us to understand the physical mechanisms of fracture of piezoelectric/ferroelectric materials in order to provide theoretical basis for the reliability analysis and life cycle prediction of piezoelectric/ferroelectric materials. The science of fracture mechanics of piezoelectric/ferroelectric solids has undergone significant development since the end of 1980s. In the second half of last century, researchers in mechanics, physics and materials both in China and abroad made wide and in-depth investigations, which resulted in major breakthroughs. Although there are still disputes on some problems, it is possible to say that the theoretical framework of fracture mechanics of piezoelectric/ferroelectric solids has been well established.

The author of the book has been engaged in the study of deformation and fracture mechanisms of piezoelectric/ferroelectric materials for over ten years and, as a result, gained significant experience and made distinct achievements in this area. This book attempts to give a systematic discussion on the fracture mechanics of piezoelectric/ferroelectric materials based on the research done by the author in combination with references to research done both at home and abroad. It explores some basic problems in mechanics of piezoelectric/ferroelectric solids under the

topic of “How Electromechanical Coupling Effect Influences Fracture Behavior of Piezoelectric/Ferroelectric Materials”. There are 13 chapters in the book, of which the first four chapters introduce applications of piezoelectric/ferroelectric materials, experimental methods and findings related to piezoelectric/ferroelectric fracture, characteristics of electromechanical coupling and basic formulas of piezoelectrics. The fifth chapter discusses the general resolutions of electromechanical coupling formula of piezoelectric materials. The last eight chapters discuss fracture behavior of piezoelectric/ferroelectric materials, covering the nature of tip-field, interfacial fracture, dynamic fracture, non-linear fracture, electromechanical coupling numerical methods, electrically induced fatigue crack extension, electrode induced, electroelastic field concentration, and mechatronic coupling fracture criteria.

The main purpose of the book is to induce new thinking that would benefit future developments in this field. Therefore, this book attempts to describe fracture mechanics of piezoelectric/ferroelectric materials from several perspectives not only addressing theoretical analysis of fracture, but also the findings of numerical simulations and experiments. Electromechanical coupling effects and anisotropic fracture features of piezoelectric/ferroelectric solids complicate the study of the fracture characteristics. Therefore, it is challenging to solve the problems in electromechanical coupling fracture mechanics. The authors attempt to cover theories and experiments, principles and applications, and present critique and new thoughts at the same time. This book is not only a complete and systematic treatise, but it also relates theory to practice in order to reflect the latest progress in this field.

Although the literature cited by the authors covers wide-ranging field, it is far from exhaustive. Owing to the abundance and complicated nature of the literature on this subject, it is inevitable that some studies are not included in this book and we regret if we missed to cite some achievements in this field. The authors sincerely hope that the publication of the book shall facilitate the applications of piezoelectric/ferroelectric materials and the development of new functional materials in China. At the same time, it shall also serve as a high level reference book for teachers, graduates and professional technicians conducting research in solid mechanics, materials science, dielectric physics, mechanical and electrical engineering. Due to the limited theoretical capability and practical experience of the authors, there may be errors and inappropriateness in the book and the authors sincerely hope to receive corrections and critiques from specialists and readers.

The studies conducted by the authors themselves and described in this book have been awarded sponsorship as Key Project of “9th Five-Year-Plan”, Outstanding Youth Funding, Innovative Collective Project and International Cooperation Project under National Natural Science Foundation of China (NSFC) as well as the sponsorship for key project of Ministry of Education of China (MEC) and Doctorate Fund Projects of MEC. The authors are deeply grateful for such sponsorships, without which it would be difficult to complete such studies. The book also contains achievements made by the team members of the authors in post-doctorate/graduate programs over the last 12 years. The authors would like to

thank their team members for their diligence, talents, contributions and cooperation in these studies. In their research, the authors have been cooperating with Professor A.K. Soh from Hong Kong University, Professor C.T. Sun from Prudent University of USA, Professor J.Y. Li from Washington University. The author of this book has benefited tremendously from their profound expertise and extends his sincere gratitude to them. The author also sincerely thanks his dear colleagues, Huang Kezhi and Yang Wei, who are also Academicians of Chinese Academy of Sciences, for their encouragement, assistance and support over many years. Finally, the author is especially grateful to Mr. Mao Guanzhong, Mr. Wei Weiyi, Mr. He Huijing and Ms. Zhao Xiaofang for their great support in typing the manuscript, amending the graphs and charts, and setting up the literature index.

By the first author
At Beijing Tsinghua Park

Contents

Chapter 1 Introduction	1
1.1 Background of the research on fracture mechanics of piezoelectric/ferroelectric materials.....	1
1.2 Development course and trend	3
1.3 Framework of the book and content arrangements.....	4
References	6
Chapter 2 Physical and Material Properties of Dielectrics	9
2.1 Basic concepts of piezoelectric/ferroelectric materials.....	9
2.2 Crystal structure of dielectrics	12
2.3 Properties of electric polarization and piezoelectricity.....	16
2.3.1 Microscopic mechanism of polarization	17
2.3.2 Physical description of electric polarization	17
2.3.3 Dielectric constant tensor of crystal and its symmetry	20
2.4 Domain switch of ferroelectrics.....	21
2.4.1 Electric domain and domain structure	21
2.4.2 Switching of electric domain and principles for domain switch ...	26
References	31
Chapter 3 Fracture of Piezoelectric/Ferroelectric Materials — Experiments and Results	33
3.1 Experimental approaches and techniques under an electromechanical coupling field	35
3.1.1 High-voltage power supply.....	35
3.1.2 High voltage insulation	35
3.1.3 Moire interferometry.....	40
3.1.4 Digital speckle correlation method	42
3.1.5 Method of polarized microscope	43
3.1.6 Experimental facilities	44
3.2 Anisotropy of fracture toughness.....	45
3.3 Electric field effect on fracture toughness	46
3.4 Fracture behavior of ferroelectric nano-composites	52
3.5 Measurement of strain field near electrode in double-layer structure of piezoelectric ceramics.....	55
3.6 Observation of crack types near electrode tip.....	58

3.7	Experimental results and analysis related to ferroelectric single crystal out-of-plane polarized	60
3.7.1	Restorable domain switch at crack tip driven by low electric field	61
3.7.2	Cyclic domain switch driven by cyclic electric field	64
3.7.3	Electric crack propagation and evolution of crack tip electric domain	65
3.8	Experimental results and analysis concerning in-plane polarized ferroelectric single crystal	67
3.8.1	Response of specimen under a positive electric field	67
3.8.2	Crack tip domain switch under low negative electric field	68
3.8.3	Domain switching zone near crack tip under negative field	69
3.8.4	Evolution of electric domain near crack tip under alternating electric field	72
	References	75
Chapter 4	Basic Equations of Piezoelectric Materials	77
4.1	Basic equations	77
4.1.1	Piezoelectric equations	77
4.1.2	Gradient equations and balance equations	83
4.2	Constraint relations between various electroelastic constants	84
4.3	Electroelastic constants of piezoelectric materials	85
4.3.1	Coordinate transformation between vector and tensor of the second order	85
4.3.2	Coordinate transformation of electroelastic constants	86
4.3.3	Electroelastic constant matrixes of piezoelectric crystals vested in 20 kinds of point groups	88
4.4	Governing differential equations and boundary conditions of electromechanical coupling problems	92
4.4.1	Governing differential equations of electromechanical coupling problems	92
4.4.2	Boundary conditions of electromechanical coupling	95
	References	95
Chapter 5	General Solutions to Electromechanical Coupling Problems of Piezoelectric Materials	97
5.1	Extended Stroh formalism for piezoelectricity	97
5.1.1	Extended Stroh formalism	98
5.1.2	Mathematical properties and important relations of Stroh formalism	102
5.2	Lekhniskii formalism for piezoelectricity	107
5.3	General solutions to two-dimensional problems of transversely isotropic piezoelectric materials	112

5.3.1	The general solutions to the anti-plane problems of transversely isotropic piezoelectric materials	112
5.3.2	The general solutions to the in-plane problems of transversely isotropic piezoelectric materials—Stroh method	113
5.3.3	The general solutions to the in-plane problems of transversely isotropic piezoelectric materials—Lekhniskii method.....	116
5.4	General solutions to three-dimensional problems of transversely isotropic piezoelectric materials	119
	References	123

Chapter 6 Fracture Mechanics of Homogeneous Piezoelectric

Materials	125
6.1 Anti-plane fracture problem	127
6.2 In-plane fracture problem	130
6.3 Three dimensional fracture problem.....	135
6.3.1 Description of problem	136
6.3.2 Derivation of electroelastic fields	138
6.4 Electromechanical coupling problem for a dielectric elliptic hole	142
6.4.1 Anti-plane problem of transversely isotropic piezoelectric material containing dielectric elliptic holes	142
6.4.2 Generalized plane problems of piezoelectric materials containing a dielectric elliptic hole.....	149
6.5 Influence on crack tip field imposed by electric boundary conditions along the crack surface	158
References	158

Chapter 7 Interface Fracture Mechanics of Piezoelectric Materials..... 161

7.1 Interfacial cracks in piezoelectric materials under uniform electromechanical loads	163
7.1.1 Tip field of interfacial crack.....	163
7.1.2 Full field solutions for an impermeable interfacial crack	167
7.2 Effect of material properties on interfacial crack tip field.....	170
7.3 Green's functions for piezoelectric materials with an interfacial crack	172
7.3.1 Brief review of Green's functions for piezoelectric materials.....	172
7.3.2 Green's functions for anti-plane interfacial cracks	174
References	179

Chapter 8 Dynamic Fracture Mechanics of Piezoelectric Materials..... 183

8.1 Scattering of elastic waves in a cracked piezoelectrics	185
8.1.1 Basic concepts concerning propagation of elastic wave in a piezoelectrics.....	185

8.1.2	Dominant research work on elastic wave scattering caused by cracks in piezoelectrics	188
8.1.3	Scattering of Love wave caused by interfacial cracks in layered elastic half-space of piezoelectrics	190
8.2	Moving cracks in piezoelectric medium	197
8.2.1	Anti-plane problems of moving interfacial cracks	198
8.2.2	The plane problem of moving cracks	203
8.3	Transient response of a cracked piezoelectrics to electromechanical impact load	210
8.3.1	Anti-plane problems of cracked piezoelectrics under impact electromechanical loads	211
8.3.2	Transient response of crack mode-III in strip-shaped piezoelectric medium	216
8.3.3	In-plane problems of cracked piezoelectrics under the action of impact electromechanical loads	217
8.4	Dynamic crack propagation in piezoelectric materials	222
8.4.1	Dynamic propagation of conducting crack mode-III	223
8.4.2	Dynamic propagation of dielectric crack mode-III	229
	References	233

Chapter 9 Nonlinear Fracture Mechanics of Ferroelectric Materials..... 235

9.1	Nonlinear fracture mechanical model	236
9.1.1	Electrostriction model	236
9.1.2	Dugdale model (strip saturation mode)	244
9.2	Domain switching toughening model	248
9.2.1	Decoupled isotropy model	249
9.2.2	Anisotropy model for electromechanical coupling	252
9.3	Nonlinear crack opening displacement model	262
9.3.1	Definition of crack opening displacement	263
9.3.2	Crack opening displacement δ_0 caused by piezoelectric effect	265
9.3.3	Effect $\Delta\delta$ of domain switching on crack opening displacement	266
9.4	Interaction between crack tip domain switching of BaTiO ₃ single crystal and crack growth under electromechanical load	272
9.4.1	Experiment principle and technology	273
9.4.2	Experimental phenomena	273
9.4.3	Analysis of domain switching zone	276
9.4.4	Ferroelastic domain switching toughening	285
	References	289

Chapter 10 Fracture Criteria..... 293

10.1	Stress intensity factor criterion	294
------	---	-----

10.2	Energy release rate criterion	294
10.2.1	Total energy release rate criterion	294
10.2.2	Mechanical strain energy release rate criterion.....	297
10.3	Energy density factor criterion	301
10.4	Further discussion on stress intensity factor criterion.....	305
10.5	COD criterion	308
	References	310

Chapter 11 Electro-elastic Concentrations Induced by Electrodes in

	Piezoelectric Materials	313
11.1	Electroelastic field near surface electrodes.....	314
11.1.1	Electroelastic field near stripe-shaped surface electrodes.....	314
11.1.2	Electroelastic field near circular surface electrodes	322
11.2	Electroelastic field near interface electrode	328
11.2.1	General solution to the interface electrode of anisotropic piezoelectric bi-materials	329
11.2.2	Electroelastic field near the interface electrode in transversely isotropic piezoelectric bi-materials	332
11.3	Electroelastic field in piezoelectric ceramic-electrode layered structures.....	334
11.3.1	Laminated structure model, experimental set-up and finite element calculation model	334
11.3.2	Numerical calculation and experimentally measured results	337
	References	340

Chapter 12 Electric-Induced Fatigue Fracture

12.1	Experimental observation and results	344
12.1.1	Electrically induced fatigue experiment by Cao and Evans (1994).....	344
12.1.2	Electrically induced fatigue experiment of samples containing penetrating cracks	346
12.2	Phenomenological model	356
12.2.1	Model I	356
12.2.2	Model II	360
12.3	Domain switching model.....	361
12.3.1	Electrically induced fatigue investigated by means of crack tip intensity factor.....	361
12.3.2	Investigation of electrically induced fatigue by means of crack opening displacement (COD).....	369
	References	375

Chapter 13 Numerical Method for Analyzing Fracture of Piezoelectric and Ferroelectric Materials	377
13.1 Generalized variation principle.....	380
13.1.1 Generalized variation principle of linear elastic mechanics.....	380
13.1.2 Variation principle of electromechanical coupling problem	382
13.2 Finite element method for piezoelectric material fracture.....	384
13.2.1 Basic format of finite element for piezoelectric fracture	384
13.2.2 Calculation example: the electromechanical field around the circular hole in an infinite piezoelectric matrix	387
13.2.3 Calculation example: model of piezoelectric material with two-sided notches	389
13.3 Meshless method for piezoelectric material fracture	391
13.3.1 Basic format of electromechanical coupling meshless method	391
13.3.2 Some problems about electromechanical coupling meshless method	393
13.3.3 Numerical example	397
13.4 Nonlinear finite element analysis of ferroelectric material fracture	397
13.4.1 Solution of field quantity with given electric domain distribution	398
13.4.2 New electric domain distribution and finite element iterative process determined by field quantity.....	404
13.4.3 Calculation example: Ferroelectric crystal containing insulating circular hole plus vertical electric field	406
13.4.4 Calculation example: Ferroelectric crystal containing insulating crack plus electric field ($E = 0.72E_c$) perpendicular to crack surface	411
References	415
Appendix The Material Constants of Piezoelectric Ceramics.....	417