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Preface

A decade after its introduction, the extended finite element method (XFEM) has now become the primary numerical approach for analysis of a wide range of discontinuity applications, including crack propagation problems. The simplicity of the idea of enrichment for reproducing a singular/discontinuous nature of the field variable, the flexibility in handling several cracks and crack propagation patterns on a fixed mesh, and the level of accuracy with minimum additional degrees of freedom (DOFs) have transformed XFEM into the most efficient computational approach for handling various complex discontinuous problems. Concepts of XFEM are now even taught in a number of postgraduate courses, for instance advanced fracture mechanics and meshless methods, in major engineering departments, such as Civil, Mechanical, Material, Aerospace and so on, all over the world.

On the other hand, the highly flexible design of composites allows attractive prescribed tailoring of material properties, fitted to the engineering requirements for a wide range of engineering and industrial applications; from advanced aerospace and defence systems to traditional structural strengthening techniques, and from large scale turbines and power plants to nanoscale carbon nanotubes (CNTs) applications. Despite excellent characteristics, composites suffer from a number of shortcomings, mainly in the form of unstable cracking which can be initiated and propagated under different production imperfections and service circumstances. Therefore, the study of the crack stability and load bearing capacity of these types of structures, which directly affect the safety and economics of many important industries, has become one of the important topics of research for the computational mechanics community.

This text is dedicated to discussing various aspects of the application of the extended finite element method for fracture analysis of composites on the macroscopic scale. Nevertheless, most of the discussed subjects can be similarly used for fracture analysis of other materials, even on microscopic scales. The book is designed as a textbook, which provides all the necessary theoretical bases before discussing the numerical issues.

The book can be classified into four parts. The first part is dedicated to the basics. The introduction chapter provides a general overview of the problem in hand and summarily reviews available analytical and numerical techniques for fracture analysis of composites. The second chapter deals with the basics of the theory of elasticity, and is followed by discussions on asymptotic solutions for displacement and stress fields in different fracture modes, basic concepts of stress intensity factors, energy release rate, various forms of the J contour integral and mixed mode fracture criteria.

The second part, Chapter 3, is a redesigned and completed edition of the same chapter in my previous book, and presents a detailed discussion on the extended finite element method.

After presenting the basic formulation, the chapter continues with three sections on available options for strong discontinuity enrichment functions, weak discontinuity enrichments for material interfaces, and a collection of several crack-tip enrichments for various engineering applications. It concludes with sample simulations of a wide range of problems, including classical in-plane mixed mode fracture mechanics, cracking in plates and shells, simulation of shear band creation and propagation, self-similar fault rupture, sliding contact, hydraulic fracture, and dislocation dynamics, to assess the accuracy, performance, robustness and efficiency of XFEM.

The main part of the book includes four comprehensive chapters dealing with various aspects of fracture in composite structures. Static crack analysis in orthotropic materials, dynamic fracture mechanics for stationary and moving cracks, inhomogneous functionally graded materials and bimaterial delamination analysis are discussed in detail. After a review of anisotropic and orthotropic elasticity, all chapters begin with a complete discussion of available analytical solutions for near crack-tip fields in the corresponding orthotropic problem, followed by orthotropic mixed mode fracture mechanics and associated forms of the interaction integral. XFEM enrichment functions for each class of orthotropic materials are obtained and numerical issues related to XFEM discretization are addressed. A number of illustrative numerical simulations are presented and discussed at the end of each chapter to assess the performance of XFEM compared to alternative analytical and numerical techniques.

The final part reviews a number of ongoing research topics for orthotropic materials. First, the orthotropic version of the extended isogeometric analysis (XIGA) is presented by briefly explaining the basic concepts of NURBS and IGA methodology and discussing a number of simple isotropic and orthotropic simulations. Then, the newly developed idea of plane strain anisotropic dislocation dynamics is briefly presented and related XFEM formulation and necessary enrichment functions for the self-stress state of edge dislocations are explained. The book concludes with two brief introductory sections on orthotropic biomaterial applications of XFEM and the piezoelectric problems.

I would like to express my sincere gratitude to Prof. T. Belytschko, for his valuable friendly comments and encouraging message after the publication of the first book on XFEM, and to Prof. A.R. Khoei, as a friend, a colleague and a referee with excellent comments and discussions on various subjects of computational mechanics, especially XFEM. In preparing the present book, particularly the first two parts, I have used the available contributions from brilliant research works by many others, and I have done my best to properly and explicitly acknowledge their achievements within the text, relevant figures, tables and formulae. I am much indebted to their outstanding works, and I apologize sincerely for any unintentional failure in appropriately acknowledging them.

My special thanks to many of my former and present M.Sc. and Ph.D. students who have endeavored many aspects of XFEM over the past decade. First, Dr A. Asadpoure, with whom we started to explore XFEM and new orthotropic enrichment functions in 2002. The results for the dynamic fracture of stationary and moving cracks were obtained by Dr D. Motamedi, and Ms S. Esna Ashari developed the orthotropic bimaterial enrichment functions and simulated all the delamination and interlaminar crack problems. Most of the results for FGM problems were prepared by Mr H. Bayesteh, who actively contributed in many other parts of the book. Mr S.S. Ghorashi and Mr N. Valizadeh skillfully developed the XIGA methodology and Mr S. Malekafzali implemented XFEM for anisotropic dislocation dynamics. Other results were obtained by my students: S.H. Ebrahimi, A. Daneshyar, M. Parchei, M. Goodarzi, S.N. Rezaei, S.N. Mahmoudi and M.M.R. Kabiri.

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The inspiration and power for completing this work have been the love and understanding of my family, as they had to comply with all my commitments. After a life-time engagement in mathematics, physics and engineering, satisfaction is not obtained just in academic or professional progress, novelty and innovation; it should perhaps be sought in ethics, responsibility, love and freedom. This book has been completed at the twilight of a long hard winter, with a hope for a bright flourishing spring of prosperity and freedom to come. I would like to proudly dedicate this work to all spirited noble Iranian students who accomplish academic achievements while challenging for more DOFs!

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