

Extended Finite Element Method Damage Analysis of Carbon Fiber Reinforced Composites and Crack Propagation in Mixed-Mode Using Multiscale Method and Implementation of the Method Using ABAQUS

A. R.F Swati, B. W.L Hua, C. H.Elahi and D. A.A Khan

Abstract—there are numerous numerical studies of particle interface debonding based on the cohesive zone models. In order to validate the integrity of aerospace structures to fatigue damage the study of existing cracks must be studies closely. By applying multiscale method to fiber reinforced composites to study the multicrack behavior and fracture mechanics by using the cohesive zone modelling in ABAQUS with all the necessary parameters. Getting started with a single crack response followed by delamination and then introduced the study for two cracks to validate the results by simulations and experimentations as the same time. Multiscale modelling of CFRCCs executed as a strong and reliable tool for the study of crack propagation further simulating the structural model in different possible conditions. The structure may pertain to any assembly or part depending upon boundary conditions, loading and other parameters. "Carbon fiber reinforced plastics are mostly used in laminates, which consist of several very thin layers piled over each other. The study of these layers is composed of either unidirectional fibers or textile reinforcements which are inserted in an epoxy resin". This 3D material model is incorporated into a solid-shell finite element. A promising strategy to increase the tensile failure strain of carbon fibre-reinforced composites is to hybridise carbon fibres with other, higher-elongation fibres. The procedure of applying cohesive elements in ABAQUS software's subroutines to model 3D complex crack propagation in different conditions and states.

Index Terms—CFRCCs, eXtended FEM, Finite Element Methods, Homogenization

I. INTRODUCTION

The Extended Finite Element Method (X-FEM) is a numerical technique based on the Finite Element Method (FEM) which is specifically designed for treating discontinuities. Discontinuities are classified as strong and weak on the basis of their intensity and sharpness values. Strong discontinuities are observed in the solution variable. The displacements are the solution variable in structures, strong discontinuities are displacements edges like cracks and holes. Discontinuities in the variable of solution are mostly treated as weak category [1] [2]

A. Extended FEM application to the problem

The Extended Finite Element Method (XFEM) is a versatile tool for the analysis of problems which involves discontinuities, singularities, localized deformations and complex geometries [3][4]. These methods can easily form the solution simplified for many complex situations in material modelling like the propagation of cracks, the evolution of dislocations, the modelling of grain boundaries and the evolution of phase boundaries. By using this method completely independent morphology of these entities and the finite element mesh is independent. 3D crack is shown in figure 1, crack positioning is free of mesh which permits for the different models of the cracks because as a crack propagates and increases any dimension then remeshing is not necessary and not needed [5][6][7]. Micromodel of in figure 2 illustrates the mesh for the XFEM model (Fig. 2a) as a structured mesh which is completely independent of the location of the grain boundaries. Keeping inview, the mesh for a standard FEM model in Fig. 2b, the element edges must conform to the grain boundaries and nodes with same contents must be brought into the model. This depicts the understanding of grain boundaries morphology for 3D modelling of complex shapes and structures.

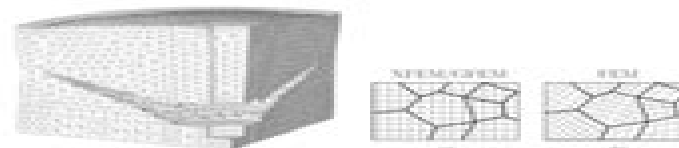


Figure 1: 3D XFEM crack model for 200X magnification

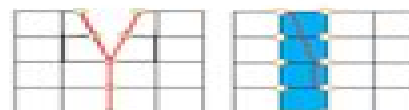


Figure 2: Discretization for XFEM (a) and FEM (b)

The progress of extended Finite Element Method was an extension of the wide research in meshfree methods, [8], [1]. A number of the techniques that are used in extended FEM are directly related to techniques previously developed in meshfree methods. Therefore, we will also point out the relevant literature in meshfree methods. Some prior research

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Extended Finite Element Method Soheil Mohammadi, 2008-04-30 This important textbook provides an introduction to the concepts of the newly developed extended finite element method XFEM for fracture analysis of structures as well as for other related engineering applications One of the main advantages of the method is that it avoids any need for remeshing or geometric crack modelling in numerical simulation while generating discontinuous fields along a crack and around its tip The second major advantage of the method is that by a small increase in number of degrees of freedom far more accurate solutions can be obtained The method has recently been extended to nonlinear materials and other disciplines such as modelling contact and interface simulation of inclusions and holes moving and changing phase problems and even to multiscale analyses The book is self contained with summaries of both classical and modern computational techniques The main chapters include a comprehensive range of numerical examples describing various features of XFEM

Extended Finite Element Method Amir R. Khoei, 2015-02-23 Introduces the theory and applications of the extended finite element method XFEM in the linear and nonlinear problems of continua structures and geomechanics Explores the concept of partition of unity various enrichment functions and fundamentals of XFEM formulation Covers numerous applications of XFEM including fracture mechanics large deformation plasticity multiphase flow hydraulic fracturing and contact problems Accompanied by a website hosting source code and examples

Multiscale Methods in Computational Mechanics René de Borst, Ekkehard Ramm, 2010-10-09 This work gives a modern up to date account of recent developments in computational multiscale mechanics Both upscaling and concurrent computing methodologies will be addressed for a range of application areas in computational solid and fluid mechanics Scale transitions in materials turbulence in fluid structure interaction problems multiscale multilevel optimization multiscale poromechanics A Dutch German research group that consists of qualified and well known researchers in the field has worked for six years on the topic of computational multiscale mechanics This text provides a unique opportunity to consolidate and disseminate the knowledge gained in this project The addition of chapters written by experts outside this working group provides a broad and multifaceted view of this rapidly evolving field

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Extended Finite Element Method Zhuo Zhuang, Zhanli Liu, Binbin Cheng, Jianhui Liao, 2014-03-24 Extended Finite Element Method provides an introduction to the extended finite element method XFEM a novel computational method which has been proposed to solve complex crack propagation problems The book helps readers understand the method and make effective use of the XFEM code and software

plugins now available to model and simulate these complex problems The book explores the governing equation behind XFEM including level set method and enrichment shape function The authors outline a new XFEM algorithm based on the continuum based shell and consider numerous practical problems including planar discontinuities arbitrary crack propagation in shells and dynamic response in 3D composite materials Authored by an expert team from one of China's leading academic and research institutions Offers complete coverage of XFEM from fundamentals to applications with numerous examples Provides the understanding needed to effectively use the latest XFEM code and software tools to model and simulate dynamic crack problems

Extended Finite Element and Meshfree Methods Timon Rabczuk, Jeong-Hoon Song, Xiaoying Zhuang, Cosmin Anitescu, 2019-11-13 Extended Finite Element and Meshfree Methods provides an overview of and investigates recent developments in extended finite elements with a focus on applications to material failure in statics and dynamics This class of methods is ideally suited for applications such as crack propagation two phase flow fluid structure interaction optimization and inverse analysis because they do not require any remeshing These methods include the original extended finite element method smoothed extended finite element method XFEM phantom node method extended meshfree methods numerical manifold method and extended isogeometric analysis This book also addresses their implementation and provides small MATLAB codes on each sub topic Also discussed are the challenges and efficient algorithms for tracking the crack path which plays an important role for complex engineering applications Explains all the important theory behind XFEM and meshfree methods Provides advice on how to implement XFEM for a range of practical purposes along with helpful MATLAB codes Draws on the latest research to explore new topics such as the applications of XFEM to shell formulations and extended meshfree and extended isogeometric methods Introduces alternative modeling methods to help readers decide what is most appropriate for their work

Dynamic Extended Finite Element Method (XFEM) Analysis of Discontinuous Media Milad Toolabi, 2015

The Finite Element Method: Its Basis and Fundamentals O. C. Zienkiewicz, R. L. Taylor, J. Z. Zhu, 2005-05-26 The Sixth Edition of this influential best selling book delivers the most up to date and comprehensive text and reference yet on the basis of the finite element method FEM for all engineers and mathematicians Since the appearance of the first edition 38 years ago The Finite Element Method provides arguably the most authoritative introductory text to the method covering the latest developments and approaches in this dynamic subject and is amply supplemented by exercises worked solutions and computer algorithms The classic FEM text written by the subject's leading authors Enhancements include more worked examples and exercises With a new chapter on automatic mesh generation and added materials on shape function development and the use of higher order elements in solving elasticity and field problems Active research has shaped The Finite Element Method into the pre eminent tool for the modelling of physical systems It maintains the comprehensive style of earlier editions while presenting the systematic development for the solution of problems modelled by linear differential equations Together with the second and third self

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Recent Advances in Mechanics of Functional Materials and Structures Poonam Kumari,Santosha Kumar Dwivedy,2024-08-23 This book comprises the select peer reviewed proceedings of the 8th Asian Conference on Mechanics of Functional Materials and Structures ACMFMS 2022 It aims to provide a comprehensive and broad spectrum picture of the state of the art research and development in diverse areas such as contact mechanics biomechanics and biomaterials fracture and damage mechanics impact mechanics and dynamic materials structural health monitoring and mechanics of functional and smart structures among others This book is a valuable resource for researchers and professionals working in academia and industry in the areas of mechanical engineering Extended Finite Element Method for Crack Propagation Sylvie Pommier,Anthony Gravouil,Nicolas Moes,Alain Combescure,2013-03-04 Novel techniques for modeling 3D cracks and their evolution in solids are presented Cracks are modeled in terms of signed distance functions level sets Stress strain and displacement field are determined using the extended finite elements method X FEM Non linear constitutive behavior for the crack tip region are developed within this framework to account for non linear effect in crack propagation Applications for static or dynamics case are provided

Enriched Numerical Techniques Azher Jameel,Ghulam Ashraf Ul Harmain,Indra Vir Singh,Magd Abdel Wahab,2024-05-09 Enriched Numerical Techniques Implementation and Applications explores recent advances in enriched numerical techniques including the extended finite element method meshfree methods extended isogeometric analysis and coupled numerical techniques Techniques for

implementation and programming issues are discussed with other sections discussing applications for enriched numerical techniques in solving a range of engineering problems The level set methodologies for complex shaped irregularities is presented as are enriched numerical methodologies for various complex and advanced problems such as Nonlinear Structural Analysis Fracture and Fatigue in Structures Elasto Plastic Crack Growth Large Deformation Analysis Frictional Contact Problems Thermo Mechanical Problems Fluid Flow Investigations Composite Materials and Bio mechanics Features explanations on how to use enriched numerical techniques to model problems in fracture mechanics continuum mechanics fluid flow and biomechanics Explains methods through the use of worked examples throughout Provides practical advice on how to tackle programming issues

Fundamentals of Enriched Finite Element Methods Alejandro M. Aragón,C. Armando Duarte,2023-11-09 Fundamentals of Enriched Finite Element Methods provides an overview of the different enriched finite element methods detailed instruction on their use and also looks at their real world applications recommending in what situations they re best implemented It starts with a concise background on the theory required to understand the underlying functioning principles behind enriched finite element methods before outlining detailed instruction on implementation of the techniques in standard displacement based finite element codes The strengths and weaknesses of each are discussed as are computer implementation details including a standalone generalized finite element package written in Python The applications of the methods to a range of scenarios including multi phase fracture multiscale and immersed boundary fictitious domain problems are covered and readers can find ready to use code simulation videos and other useful resources on the companion website to the book Reviews various enriched finite element methods providing pros cons and scenarios for best use Provides step by step instruction on implementing these methods Covers the theory of general and enriched finite element methods

Partition of Unity Methods Stéphane P. A. Bordas,Alexander Menk,Sundararajan Natarajan,2023-10-16 PARTITION OF UNITY METHODS Master the latest tool in computational mechanics with this brand new resource from distinguished leaders in the field While it is the number one tool for computer aided design and engineering the finite element method FEM has difficulties with discontinuities singularities and moving boundaries Partition of unity methods addresses these challenges and is now increasingly implemented in commercially available software Partition of Unity Methods delivers a detailed overview of its fundamentals in particular the extended finite element method for applications in solving moving boundary problems The distinguished academics and authors introduce the XFEM as a natural extension of the traditional finite element method FEM through straightforward one dimensional examples which form the basis for the subsequent introduction of higher dimensional problems This book allows readers to fully understand and utilize XFEM just as it becomes ever more crucial to industry practice Partition of Unity Methods explores all essential topics on this key new technology including Coverage of the difficulties faced by the finite element method and the impetus behind the development of XFEM The basics of the finite element method with discussions of finite element formulation of

linear elasticity and the calculation of the force vector An introduction to the fundamentals of enrichment A revisit of the partition of unity enrichment A description of the geometry of enrichment features with discussions of level sets for stationary interfaces Application of XFEM to bio film gradient theories and three dimensional crack propagation Perfect for researchers and postdoctoral candidates working in the field of computational mechanics Partition of Unity Methods also has a place in the libraries of senior undergraduate and graduate students working in the field Finite element and CFD analysts and developers in private industry will also greatly benefit from this book

Advanced Joining Processes Lucas F. M. da Silva, Mohamad S. El-Zein, Paulo A.F. Martins, 2020-10-31 *Advanced Joining Processes* Welding Plastic Deformation and Adhesion brings together a range of advanced thermal mechanical and chemical methods of joining offering an up to date resource for those looking to understand and utilize the very latest techniques Efficient joining techniques are critical to a range of innovative applications with technology in constant development The first section of the book provides in depth information on advanced welding techniques including friction stir explosive ultrasonic laser electron beam and computational weld analysis and fatigue of structures The second section highlights key developments in joining by plastic deformation adhesive bonding and hybrid joining The coverage of each technique is supported by practical guidance detailed analysis and finite element simulations This is an essential reference for researchers and advanced students in joining welding adhesion materials processing mechanical engineering plastics engineering manufacturing civil engineering and automotive aerospace engineering as well as engineers scientists and R D professionals using joining welding and adhesion methods across a range of industries Presents the latest research findings and developments across welding joining by plastic deformation and adhesion Includes state of the art methods such as laser ultrasonic and electron beam welding hybrid joining and the use of electromagnetic pulses Offers practical guidance detailed analysis and finite element simulations for all techniques covered

Analysis of Composite Laminates Dinghe Li, 2022-03-08 *Composite Laminated Theories and Their Applications* presents the latest methods for analyzing composite laminates and their applications The title introduces the most important analytical methods in use today focusing on fracture damage multi physics and sensitivity analysis Alongside these methods it presents original research carried out over two decades on laminated composite structures and gives detailed coverage of laminate theories analytic solutions and finite element models Specific chapters cover An introduction to composites Elasticity Shear State space theory Layerwise theories The extended layerwise method Fracture and damage mechanics Multi physical fracture problems Analytical methods of stiffened sandwich structures Progressive failure analysis and more This volume offers a comprehensive guide to the state of the art in the analysis and applications of composite laminates which play a critical role in all types of engineering from aerospace to subsea structures including in medical prosthetics circuit boards and sports equipment Presents a guide to the analysis and application of advanced composite materials Gives detailed exposition of plate shell theories and their implementation in finite element code architecture

Considers the robustness effectiveness and applications aspects of laminated plate shell methods Gives hands on experience of code architecture providing composite analysis software which can be plugged in to commercial applications Presents experimental research alongside methods laminate theories analytic solutions and finite element models

Deformation and Fracture in Materials Anoop Kumar Mukhopadhyay, Dhaneshwar Mishra, 2024-08-27 This book provides information on the basics of deformation and fracture in materials and on current state of the art experimental and numerical theoretical methods including data driven approaches in the deformation and fracture study of materials The blend of experimental test methods and numerical techniques to study deformation and fracture in materials is discussed In addition the application of data driven approaches in predicting material performance in different types of loading and loading environments is illustrated Features Includes clear insights on deformation and fracture in materials with clear explanations of mechanics and defects relating to them Provides effective treatments of modern numerical simulation methods Explores applications of data driven approaches such as artificial intelligence machine learning and computer vision Reviews simple and basic experimental techniques to understand the concepts of deformation and fracture in materials Details modeling and simulation strategies of mechanics of materials at different scales This book is aimed at researchers and graduate students in fracture mechanics finite element methods and materials science

Computational Methods for Fracture Timon Rabczuk, 2019-10-28 This book offers a collection of 17 scientific papers about the computational modeling of fracture Some of the manuscripts propose new computational methods and or how to improve existing cutting edge methods for fracture These contributions can be classified into two categories 1 Methods which treat the crack as strong discontinuity such as peridynamics scaled boundary elements or specific versions of the smoothed finite element methods applied to fracture and 2 Continuous approaches to fracture based on for instance phase field models or continuum damage mechanics On the other hand the book also offers a wide range of applications where state of the art techniques are employed to solve challenging engineering problems such as fractures in rock glass concrete Also larger systems such as fracture in subway stations due to fire arch dams or concrete decks are studied

Advanced Computational Materials Modeling Miguel Vaz Junior, Eduardo A. de Souza Neto, Pablo A. Munoz-Rojas, 2011-09-22 With its discussion of strategies for modeling complex materials using new numerical techniques mainly those based on the finite element method this monograph covers a range of topics including computational plasticity multi scale formulations optimization and parameter identification damage mechanics and nonlinear finite elements

Progress in the Analysis and Design of Marine Structures Carlos Guedes Soares, Y. Garbatov, 2017-04-28 Progress in the Analysis and Design of Marine Structures collects the contributions presented at MARSTRUCT 2017 the 6th International Conference on Marine Structures Lisbon Portugal 8 10 May 2017 The MARSTRUCT series of Conferences started in Glasgow UK in 2007 the second event of the series having taken place in Lisbon Portugal in March 2009 the third in Hamburg Germany in March 2011 the fourth in Espoo Finland in March 2013 and

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