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Application of Extended Finite Element Method for Studying Crack Propagation of Welded Strip Steel in the Cold Rolling Process

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Abstract: In the cold rolling process, edge cracks, particularly those near the welded zone, can inadvertently lead to strip rupture. This study employed the extended finite element method (XFEM) to analyze the crack propagation behavior in welded strip steel during cold rolling. Various tests such as the tensile test, essential work of fracture (EWF) test, spherical indentation method, and elastoplastic finite element simulations were conducted to determine the maximum principal stress and fracture energy utilized in XFEM for the base metal and weld metal, respectively. A continuous cold rolling model was established to investigate the crack propagation behaviors in the base metal, weld metal, and the interface between the base and weld metal. In the continuous rolling process, the crack propagation and expansion speed in the base metal are much larger than that of the weld zone. In addition, the base metal at the back end of the rolled piece is more prone to fracture than the base metal at the front end.

Keywords: extended finite element method; crack propagation; welded strip steel; cold rolling; numerical simulation



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1. Introduction

Cold rolling is an important production process affecting the quality and efficiency of strip steel fabrication [1]. Before the strip steel enters into the cold rolling mill, the cutting operation would be carried out to remove the edge defects to ensure the strip steel integrity. However, a cutting operation cannot eliminate all edge defects and sometimes it will introduce new edge flaws due to the inappropriate cutting parameters [2]. These initial defects may cause edge cracking or even a strip steel rupture during the cold rolling process, which will lead the halt of whole production line. Previous studies showed that the edge cracking or strip rupture easy occur near the weld zone due to the complexity of the material combination [3]. How to avoid edge cracking and strip rupture in the cold rolling process has been a crucial factor in cold rolling.

Research on the causes of cold-rolled edge cracks and corresponding protective measures has achieved some results. The main reasons for the edge cracks of cold-rolled sheet are as follows: edge defects of cold-rolled substrate, uneven structure of cold-rolled substrate and cold-rolling process control problems, cold-rolling mill load distribution and improper control of tension between stands, discordant deformation of cold rolled sheets [4], and trimming the amount of edges [5].

With the assistance of the finite element method, researchers have studied different fracture behaviors of strip steel under cold and hot rolling condition. Compared with other numerical methods, the finite element method has distinct advantages especially for arbitrary geometric shape, boundary condition, and geometric nonlinearity. Several scholars have studied the crack surface morphology based on the extended finite element method. Yu et al. [6] analyzed the deformation behavior and crack initiation when the strip

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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 Partition of Unity Methods Stéphane P. A. Bordas, Alexander Menk, Sundararajan Natarajan, 2023-10-19 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

Thermo-mechanical Fatigue Using the Extended Space-time Finite Element Method Ryan T. Schlinkman, 2019 Thermomechanical high cycle fatigue is a major failure mechanism for many engineering components in a diverse range of industries such as aerospace automotive and nuclear among others Engineers trying to determine the fatigue life of a component typically rely on commercial fatigue analysis software which uses traditional fatigue criteria that are limited in their applicability For instance they are poor at handling multiaxial and variable amplitude loading Furthermore adding variable amplitude thermal loading into the mix makes using these traditional fatigue criteria even less appealing In recent years there have been attempts to establish methods for simulating high cycle fatigue based on finite element calculations

rather than using it as a post processing step These include cohesive zone and continuum damage mechanics models However all of these methods employ cycle jumping strategies to cut down on the enormous computational time required However cycle jumping is not applicable for a random loading history or with random or out of phase temperature variation Motivated by these current developments this thesis proposes the use of the extended space time finite element method XTFEM in combination with a two scale progressive fatigue damage model for the direct numerical simulation of thermomechanical high cycle fatigue Instead of using the conventional explicit or implicit finite difference time integration methods temporal approximations are introduced with FEM mesh and enriched based on the extended finite element method After outlining the basic theory for XTFEM with thermomechanical coupling the effectiveness of the computational framework is demonstrated in numerical examples including a coupled thermomechanical fatigue simulation of a plate and hat stiffener model representative of a hypersonic aircraft s structure

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Table of Contents Application Of Extended Finite Element Method For Fatigue

1. Understanding the eBook Application Of Extended Finite Element Method For Fatigue
 - The Rise of Digital Reading Application Of Extended Finite Element Method For Fatigue
 - Advantages of eBooks Over Traditional Books
2. Identifying Application Of Extended Finite Element Method For Fatigue
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Application Of Extended Finite Element Method For Fatigue
 - User-Friendly Interface
4. Exploring eBook Recommendations from Application Of Extended Finite Element Method For Fatigue
 - Personalized Recommendations
 - Application Of Extended Finite Element Method For Fatigue User Reviews and Ratings
 - Application Of Extended Finite Element Method For Fatigue and Bestseller Lists

5. Accessing Application Of Extended Finite Element Method For Fatigue Free and Paid eBooks
 - Application Of Extended Finite Element Method For Fatigue Public Domain eBooks
 - Application Of Extended Finite Element Method For Fatigue eBook Subscription Services
 - Application Of Extended Finite Element Method For Fatigue Budget-Friendly Options
6. Navigating Application Of Extended Finite Element Method For Fatigue eBook Formats
 - ePub, PDF, MOBI, and More
 - Application Of Extended Finite Element Method For Fatigue Compatibility with Devices
 - Application Of Extended Finite Element Method For Fatigue Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Application Of Extended Finite Element Method For Fatigue
 - Highlighting and Note-Taking Application Of Extended Finite Element Method For Fatigue
 - Interactive Elements Application Of Extended Finite Element Method For Fatigue
8. Staying Engaged with Application Of Extended Finite Element Method For Fatigue
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Application Of Extended Finite Element Method For Fatigue
9. Balancing eBooks and Physical Books Application Of Extended Finite Element Method For Fatigue
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Application Of Extended Finite Element Method For Fatigue
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Application Of Extended Finite Element Method For Fatigue
 - Setting Reading Goals Application Of Extended Finite Element Method For Fatigue
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Application Of Extended Finite Element Method For Fatigue
 - Fact-Checking eBook Content of Application Of Extended Finite Element Method For Fatigue
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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