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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 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 XFEM 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

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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