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Study on edge crack propagation during cold rolling of thin strip by FEM

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Study on edge crack propagation during cold rolling of thin strip by FEM

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Abstract. Edge crack is one common phenomenon in cold rolling of thin strip which affects qualities of the rolled strip. A three-dimensional elastic-plastic finite element (FE) model for cold flat product rolling has been developed to simulate the edge crack propagation during rolling. Stress field is investigated around the edge crack tip, and the effects of the friction coefficient, the initial crack size, reductions on crack propagation are analysed. The FE simulation provides a better understanding of the crack growth at the edge of thin strip, and could be helpful in developing of cold rolled strip with high performance mechanical properties. The optimum condition to eliminate defects is discussed, and the proposed prediction method of surface defect can be utilised to make defect free products in rolling processes.

Keywords: Cold rolling, thin strip, FEM, stress field, edge crack, crack propagation
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INTRODUCTION

Demand of high quality product is a key point in manufacturing industries, and how to control the strip edge quality is an important issue. High expectation for thin gauge products has imposed increasing challenges to satisfy these quality demands in cold rolling. Edge crack is a commonly observed phenomenon in the cold rolling process of thin strip, which decreases the strength, rigidity, toughness, plasticity and residual life of the steel strips significantly. How to predict and control this process is still a focus both in experiment and calculation. Due to the complexity and difficulty of ductile failure in cold rolling of metals, the finite element method (FEM) is an effective technique that has been used widely. Jiang et al. [1] proposed a 3D finite element method analysis of cold rolling of thin strip with friction variation. Deformation mechanism near crack-tip by finite element analysis and microstructure observation was reported [2, 3]. Necla and Emanuel reported wear mechanisms and finite element crack propagation analysis of high speed roller bearings [4]. Research on the behavior of transversal crack in slab V–H rolling process by FEM was carried out in Ref. [5]. The research [5, 6] was reported on transversal and longitudinal surface cracks in the hot rolling of steel slabs. Refs. [8, 9] reported the analysis of edge crack of metal forming. In comparison with general cold rolling, the ratio of width and thickness is very large during thin strip rolling. However, there are few publications reported the research on edge crack propagation during thin strip rolling. In this study, the stress distribution of the crack tip during cold rolling process is analysed based on 3D finite element method, and the influences of rolling parameters, the friction coefficient and the initial crack size on crack propagation are investigated. The aim of the paper is to study whether it is possible to eliminate the cracks or to minimise their deteriorating influence by cold rolling.

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TABLE 1. Main simulation parameters in rolling process.

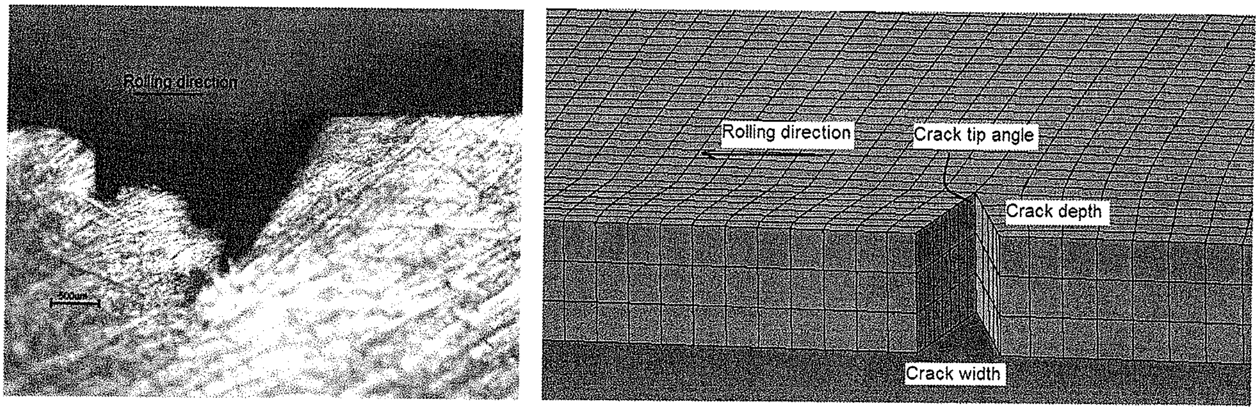
Items	Parameters	Value
Roll	Young's modulus, GPa	210
	Poisson's ratio	0.3
	Density, kg/m3	7850
	Roll diameter, mm	63
Initial crack size	Depth/width, mm	1.5/0.4, 2.0/0.7, 2.5/1.1
	Crack tip opening angle, °	15, 20, 25
Rolling condition	Friction coefficient	0.05, 0.08, 0.1

MATERIALS AND PARAMETERS

Strip with an initial edge crack is used in this study, and the rolling speed of the work roll is 0.24 m/s. The initial strip thickness is 1.5mm with a pass reduction of 10 - 30%, strip width is 100 mm, and the work roll is assumed to be rigid. Main simulation parameters are listed in Table 1.

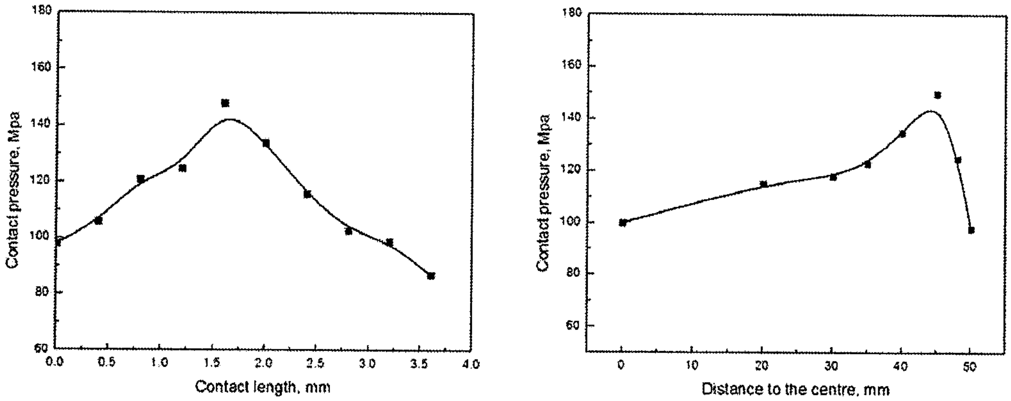
FEM Simulation

Three-dimensional FE analysis has been conducted using ABAQUS software. A quarter of the rolled strip was selected for the analysis by utilizing the symmetrical condition with dimensions 250x50x1.5 mm in rolling, transverse and thickness directions. Element type used for the strip is C3D8R (8 NODE linear brick), and the finite element mesh in the sample includes 109,720 nodes and 81,132 elements with refined elements around edge crack. In the rolling process, the roll rotates with a stable angular velocity, and the strip enters the roll with an initial velocity and exits under the friction force. Shell elements were used for describing the rolls, which are assumed to be rigid. Small elements were used for regions surrounding the crack in order to improve the accuracy of the result. Figure 1 illustrates the optical micrograph and mesh of the edge crack shape of rolled thin strip after cold rolling, and the edge crack is feathered with crack tip opening angle, crack depth and crack width.



(a) Optical micrograph (b) Simulation meshing of edge crack

FIGURE 1. Sketch of edge crack during cold rolling.



(a) Contact pressure distribution along contact length (b) Contact pressure along the rolled strip width

FIGURE 2. Stress distribution during cold rolling of thin strip.

RESULTS AND DISCUSSION

The simulation is conducted under different rolling conditions and various initial crack sizes. The stress distribution is analyzed and the effects of friction coefficients, roll diameter and initial crack size on edge crack propagation are discussed.

Stress Distribution

Figure 2 shows the contact pressure distribution along the contact length and rolled strip width. It can be seen from Fig. 2(b), the rolling pressure begins to increase from the strip center to strip edge, and the rolling pressure reaches the peak value at the position 5mm to the edge of the strip. After that, the pressure decreases. The stress concentration around the strip edge influences the edge crack extension significantly, and accelerates the edge crack propagation.

Influence of Friction Coefficients

The effects of friction coefficients on edge cracks are carried out under different friction coefficients, 0.05, 0.08 and 0.1, respectively. It is clear that the crack width increases significantly when the friction coefficient is high, and large friction shear stresses widens the crack heavily. However, the influence of friction is found to be insignificant on the depth of edge crack. According to the analysis, it should be possible to improve the rolling conditions by decreasing the friction coefficient using lubrication rolling. Figure 3 shows the crack width under a variety of the friction coefficients during rolling, and the influence of the friction coefficient on crack width is obvious.

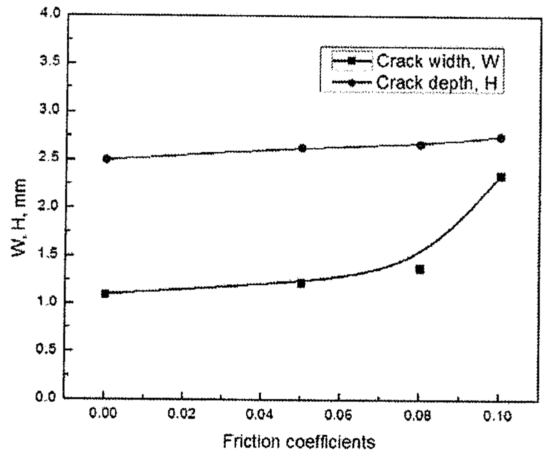
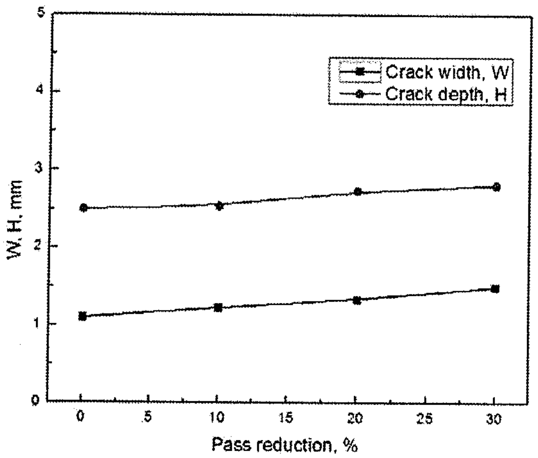


FIGURE 3. Influence of fraction coefficients.

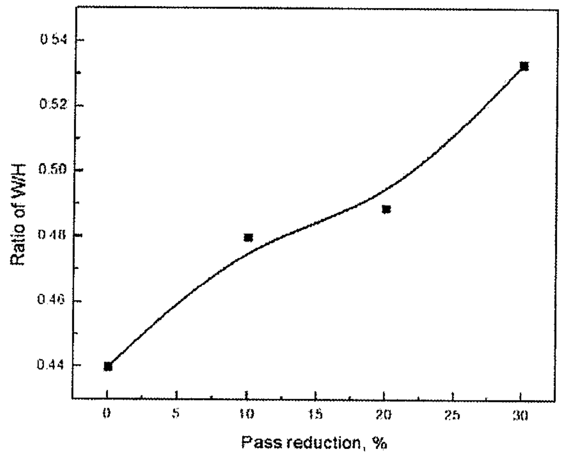
During rolling, lubricant oil is forced into the crack by rotating rolls, which will improve the friction conditions between the roll and the strip. This is attributable to the drop of stress concentration at the tip of the initial edge crack. Lubrication rolling can delay the edge crack propagation.

Influence of Reduction

Figure 4 shows the relationship between crack sizes and pass reduction, which indicates the effect of rolling schedule on edge crack at rolling speed of 0.24 m/s. The friction coefficient has been kept a constant 0.2. The crack size increases with an increasing of rolling reduction. This is because that more reduction causes more inhomogeneous deformation between the strip centre and the edge.

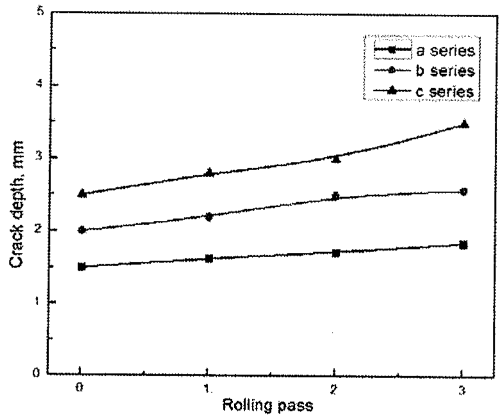


(a) Crack size with pass reduction



(b) Ratio of crack width/crack depth with pass reduction

FIGURE 4. Relationship between the crack size and pass reduction.



(a: w/h=0.4/1.5, b: w/h=0.7/2.0, c: w/h=1.1/2.5)

FIGURE 5. Effect of initial crack sizes on crack depth.

It can be seen from Figure 4(b), with an increase of pass reduction from 10 to 30%, the ratio of crack width to crack depth changes from 0.48 to 0.54. During heavier reduction rolling, increasing stress concentration of the materials near crack tip is sufficient to result in the edge crack propagation.

Influence of Initial Edge Crack Size

The schedules are investigated to analyze the influence of crack size on the growth of crack under same pass reduction and friction coefficient. Three kinds of different crack sizes are analyzed with crack depth/crack width, 1.5/0.4, 2.0/0.7, 2.5/1.1, respectively. Figure 5 shows the effects of different initial crack sizes on edge crack propagation. It can be seen that the crack depth increases with rolling pass. With an increase of initial crack size, the crack grows up significantly. At the same time, the crack tip opening angle increases with the rolling process. However, when the angle arrives at around 28°, the crack tip opening angle keep a constant, not increase any more. When the strip is bite into the rolls, the strip velocity is rapidly changed from horizontal to be parallel to the tangential velocity of the roll, and the edge crack is widened.

CONCLUSIONS

A new way is proposed to simulate the edge crack propagation in cold rolling of thin strip by 3D finite element method. The increasing contact pressure around the strip edge accelerates the edge crack propagation. The influence of the friction coefficient on crack width is obvious. In addition, more reduction causes more inhomogeneous deformation between the strip centre and the edge, thus affect the edge crack extension significantly. The ratio of crack width to crack depth increases with an increase of pass reduction. Light pass reductions and lubrication rolling are recommended for reducing the edge crack propagation. The simulation results provide further important information for improving the rolled strip edge quality.

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