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Abstract

To investigate roll bite behaviors in cold foil rolling process, a 2D elasto-plastic finite model is established using FEM software ABAQUS. Contact pressure distribution and roll contour in roll bite are also presented, which demonstrate that foil rolling process is different from conventional strip rolling process. The contact area is composed of entry elastic zone, entry plastic zone, an extensive neutral zone, exit plastic zone and exit elastic zone. It conforms to the results of Fleck foil rolling theory. Elastic deformation and work hardening of foil in roll bite are taken into account. The effect of rolling parameters, such as friction coefficient, entry thickness and reduction rate on distribution of contact pressure and vertical displacement are also discussed.

Keywords

foil, cold, behaviors, process, bite, rolling, roll, analysis, element, finite

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Finite Element Analysis of Roll Bit Behaviors in Cold Foil Rolling Process

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Abstract. To investigate roll bite behaviors in cold foil rolling process, a 2D elasto-plastic finite model is established using FEM software ABAQUS. Contact pressure distribution and roll contour in roll bite are also presented, which demonstrate that foil rolling process is different from conventional strip rolling process. The contact area is composed of entry elastic zone, entry plastic zone, an extensive neutral zone, exit plastic zone and exit elastic zone. It conforms to the results of Fleck foil rolling theory. Elastic deformation and work hardening of foil in roll bite are taken into account. The effect of rolling parameters, such as friction coefficient, entry thickness and reduction rate on distribution of contact pressure and vertical displacement are also discussed.

Keywords: Cold Foil Rolling, Elasto-plastic Deformation, Roll Bite Behaviors, Finite Element Method.

INTRODUCTION

Cold rolling theories of Bland and Ford are universally applied in cold strip rolling process with an assumption that arc remains a circular with enlarged radius given by Hitchcock formula and strip slips relatively with roll in the roll bite except the neutral point. However, it fails in thin strip and foil rolling process where there is significant elastic deformation of roll comparing with thickness of strip.

A theory by Fleck and Johnson in 1987 [1] simplifies ‘mattress model’ for deformation of roll. It suggests that the work rolls deform to a non-circular profile and no-slip region between strip and work roll exits in the roll bite. Later, Fleck et al in 1992 [2,3] present a new theory for cold foil rolling. It assumes that plastic reduction takes place in two zones at entry and exit, which are separated by a neutral zone in which the rolls are compressed flat and there is no slip between rolls and the foil. L.C. ZHANG [4] uses the slab method in conjunction with an incremental analysis to explore the interaction between the rolls and foil. H.R. Le and M.P.F. Sutcliffe et al [5- 7] follow the approach of Fleck et al, but relax their assumption of a central flat neutral zone. An explicit equation for the contact pressure variation is obtained from sticking condition in this region. T.A.M. Langlands et al [8] apply an Inverse Hilbert Transform to solve Fleck foil rolling model. In their works above, elastic zone at entry and exit, work hardening of foil are all neglected, in addition to that, iterative non-convergence problem may occur in some cases.

In this paper, cold foil rolling process is simulated by non-linear capabilities of software package ABAQUS/Explicit code [9] to attain a deep insight in this process.

FINITE ELEMENT MODEL

Since the foil width is far greater than its thickness and geometric symmetry, an upper half model of 2D plane strain is built. Parameters of model and yield stress-strain curve of foil are shown in **TABLE 1** and **FIGURE 1** respectively.

TABLE (1). Model Parameters

Roll	Work roll diameter/mm	260
	Rolling velocity/(mm • s-1)	7000
	Roll Young’s modulus/MPa	206000
	Poisson ratio	0.3
	Density/tonne • mm3	7.8×10-9

Foil	Entry foil thickness/mm	0.1
	Reduction/%	50
	Young's modulus/MPa	68000
	Density/tonne • mm ³	2.7×10^{-9}
	Poisson ratio	0.34

FIGURE 1. Yield Stress-strain Curve of Foil

Upper work roll is modeled as an elastic body whereas upper half foil is modeled as an elasto-plastic body. Considering that thickness of foil is very thin, an extremely fine discretization of the work roll sleeve near the contact region is essential to obtain reliable data. A value of $100\mu\text{m}$ has been chosen for work roll element length in contact surface. The corresponding foil surface element is less than $50\mu\text{m}$. The friction between the foil surface and work roll surface is modeled by utilizing the coulomb friction law with a friction value of 0.05. Explicit dynamic algorithms are chosen for this case. The mesh generation of model is shown in **FIGURE2 (a)**. Transition between coarse and fine meshed region is given in **FIGURE 2 (b)**.

(a) Meshing Work Roll and Foil (b) Transition between Coarse and Fine Region
FIGURE 2. Mesh Generation of the Model

NUMERICAL RESULTS

Contact Pressure and Roll Contour in Roll Bite

By using parameters in **TABLE (1)**, the Mises stress distribution inside the foil and work roll in steady state is demonstrated in **FIGURE 3**.

FIGURE 3. Mises Stress Distribution inside the Foil and Work Roll in Steady State

The profile contact surface and contact pressure are shown in **FIGURE 4**. It should be emphasized that the roll profile in contact area with foil is consistent with contact foil surface because of coupling relationship. A neutral zone of finite length, namely a central flattened region exists in roll bite in which contact pressure reaches peak and no slip between foil and roll. It coincides with the results of FLECK et al assumptions about foil rolling. However, entry elastic zone and exit elastic zone are included in this model. In the whole contact arc length, it consists of entry elastic zone (arc length AB), entry plastic zone (arc length BC), a central flattened zone (arc length CD), exit plastic zone (arc length DE) and exit elastic zone (arc length EF). It is clearly seen from **FIGURE 4**, Entry and exit elastic zone is an obvious proportion part of roll bite.

FIGURE 4. Distribution of Contact Surface and Vertical Foil Displacement

Effect of Entry Thickness on Behaviors in Roll Bite

In order to investigate the effect of entry foil thickness on behaviors in roll bite, a set of four groups from (a) entry thickness 0.2mm to (d) 0.04mm are presented in FIGURE 5. Other rolling parameters, such as reduction rate, rolling speed and friction coefficient are held constant.

In FIGURE 5 (a), the roll profile at contact surface is approximate to be circular arc. Slip occurs through the whole roll bite except at the neutral section where contact pressure reaches peak, which satisfies Bland and Ford rolling theory.

In FIGURE 5 (b), the roll profile at contact surface is to be non-circular and contact pressure becomes sharper. A neutral zone exists in roll bite where no slip occurs.

In FIGURE 5 (c) and (d), with the decrease of entry thickness, the proportion of neutral zone for the whole roll bite increases. Entry plastic reduction occurs in shorter zone whereas exit plastic reduction occurs in relative longer zone.

FIGURE 5 Effect of Entry Thickness on Distribution of Contact Pressure and Vertical Displacement.

Effect of Friction Coefficient on Behaviors in Roll Bite

The friction between the work roll and the foil is a key parameter in cold rolling process [10-12]. The values of the friction coefficient may change significantly at different stages of rolling and also has significant effect on the distribution of contact force and work roll flattens. With rolling parameters in TABLE 1 and other two friction coefficient 0.03 and 0.07, distribution of contact pressure and vertical displacement are shown in FIGURE 6.

FIGURE 6 Effect of Friction Coefficient on Behaviors in Roll Bite.
(a) Contact Pressure Distribution; (b) Vertical Displacement Distribution

In **FIGURE 6**, it is shown that friction coefficients have great influenced on contact pressure and vertical displacement. With the increase of friction coefficient, Contact arc length reduces and contact pressure peak moves to entry side. When the friction coefficient is 0.03, the contact arc is nearly circular; but non-circular with neutral zone appears under 0.05 and 0.07 coefficients. Vertical displacement reduces obviously whereas neutral zone increases when the friction coefficient increases.

Effect of reduction rate on Behaviors in Roll Bite

Rolling parameters in **TABLE 1** and other two different reductions rates, 10% and 30% are applied to simulate respectively.

FIGURE 7. Effect of Reduction Rate on Behaviors in Roll Bite.
(a) Contact Pressure Distribution; (b) Vertical Displacement Distribution

FIGURE 7(a) shows the effect of reduction rate on distribution of contact pressure. It can be seen that contact arc length becomes longer and ‘pressure distribution hill’ gets sharper as the reduction rate increases. **FIGURE 7 (b)**, when the reduction rate is 10%, the contact arc profile is nearly circular. It changes to be non-circular with 30% and 50% reduction rate. Length of neutral zone at 50% is greater than that of 30%.

CONCLUSIONS

(1) A 2D elasto-plastic finite model is developed to simulate foil rolling process. The results prove the prediction of Fleck et al about cold foil rolling. Entry and exit elastic deformation zone are also include in this model. An extensive neutral zone exists in foil rolling

(2) Effect of entry thickness on behaviors in roll bite is discussed. Roll contact profile is approximate to be circular arc with 0.2 mm entry thickness. With the decrease of entry foil thickness, contact arc profile changes to be non-circular and the proportion of neutral zone for the whole roll bite increases. Entry plastic reduction occurs in shorter zone whereas exit plastic reduction occurs in relative longer zone.

(3) Contact arc length reduces and contact pressure peak moves to entry side when the friction coefficient increases. The contact arc is nearly circular at 0.03 friction coefficient; but non-circular with neutral zone appears under 0.05 and 0.07 coefficients. Vertical displacement reduces obviously whereas neutral zone increases when the friction coefficient increases

(4) As the reduction rate increases, 'contact pressure distribution hill' gets sharper; contact arc length and neutral zone become longer.

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