NUMERICAL AND EXPERIMENTAL INVESTIGATION OF FRICTION IN COLD STRIP ROLLING

Cheng Lu/University of Wollongong, Australia  A. Kiet Tieu/University of Wollongong, Australia

ABSTRACT

To obtain a better understanding of friction and contact mechanism in cold strip rolling, a refined asperity ploughing model and an asperity elastic deformation model have been developed. It is found that the asperity angles \( \alpha_1 \) and \( \alpha_2 \) significantly affect the tangential force and the coefficient of friction respectively. The theoretical prediction is in good agreement with the experimental results in Ref.[7]. The developed models can predict a reasonable frictional coefficient if it is applied to the cold rolling process.

INTRODUCTION

A complete understanding of the friction is still lacking despite the great efforts done in this field during the last decades. One of the difficulties to accurately model the friction is contact mechanism. Lenard’s experimental work [1] has shown that in cold strip rolling the asperity ploughing dominates the interfacial contact at higher rolling speeds. The friction theoretical prediction in the cold rolling process based on the ploughing model was not reported before. The idealized asperity ploughing process has been investigated by the slip line method [2], the upper bound method [3] and FEM [4]. In this paper the upper bound method has been improved via considering the residual depth. The elastic deformation of the asperity has also been analyzed. The developed models are coupled with the rolling deformation model to predict the coefficient of friction in the cold rolling process.

NOMENCLATURE

- \( d \) depth of indentation
- \( h_{12} \) vertical distance between points 1 and 2
- \( l_{12} \) horizontal distance between points 1 and 2
- \( F_n, F_t \) normal force and tangential force
- \( F_t/F_n \) force ratio
- \( R_{aL}, R_{aT} \) average roughness in the longitudinal and transverse direction
- \( u_0 \) workpiece velocity outside the blocks
- \( \dot{w} \) work rate
- \( \alpha_1 \) asperity angle in the transverse direction
- \( \alpha_2 \) asperity angle in the moving direction
- \( \sigma \) yield stress of the workpiece

The upper bound method is used to model the ploughing process in this paper. It is assumed that the stationary roll asperity has a rhombus-based pyramidal shape as shown in Fig.1. The rigid-perfectly plastic workpiece flows by 5 rigid tetrahedron blocks (ONEF, ONEA, OABN, OABK, ABJK) around each side of the asperity and forms a side ridge and a frontal ridge. The workpiece moves up at the rear face of the asperity from point O to point K, which forms a lateral piling-up. Each block moves in linear motion. Therefore, the energy only consumes at the interfaces between blocks, asperity and undeformed workpiece.

![Fig.1 Schematic of the asperity ploughing process](image-url)
work rate under the volume constancy conditions. The tangential force $F_t$ can be expressed as $F_t = \min(w)/u_0$. The normal force $F_n$ can be calculated based on the force balance on the volume ABJK, OABK, OABN and OANEFG.

The elastic deformation of the roll asperity is taken into account in this paper. It is assumed that the asperity surfaces remain flat during the deformation and the contact stress is uniform along the asperity-block interface. The displacements of the points O, A, E and K is estimated by the Hertzian solution [5]. And then the asperity angles ($\alpha_1$ and $\alpha_2$) under the deformation can be determined. The ploughing model and the elastic deformation model of the asperity are coupled with the rolling deformation model [6] to predict the coefficient of friction in the cold rolling process.

Ref.[7] carried out some ploughing experiments by a prototype simulation testing machine. Fig.2 shows that the predicted values are in good agreement with the their experimental results. From Figs.3 and 4 it can be seen that the force ratio ($F_t/F_n$) decreases with $\alpha_1$ and $\alpha_2$, and the dimensionless tangential force $F_t/(\sigma_0d^2)$ increase with $\alpha_1$. Effect of $\alpha_2$ on the dimensionless tangential force is contrary to that of $\alpha_1$ and not monotone. The dimensionless tangential force decreases to a certain value with increasing $\alpha_2$ and then increases. It is clear that $\alpha_1$ and $\alpha_2$ significantly affect the tangential force and the force ratio respectively.

Experiments have been conducted on an experimental rolling mill Hille 100. The strip surfaces are ground before rolling and the initial roughness in the longitudinal or transverse direction is varied from 0.2 to 2 $\mu$m. The average coefficient of friction is estimated by the inverse method. It is found from Fig.5 that the coefficient of friction decreases with reduction and appears to be independent of the initial strip roughness, which implies that the ploughing dominates the contact mechanism. A comparison between the theoretical and experimental results has shown that the developed models can predict a reasonable coefficient of friction and give a same trend as indicated by experiments with consideration of the asperity elastic deformation. Combination of modeling of the asperity ploughing and flattening is expected to improve the prediction.

**ACKNOWLEDGMENTS**

The authors gratefully acknowledge the financial support from an Australia Research Council Discovery Grant

**REFERENCES**