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Asymmetric Cold Rolling of Thin Strip with Roll Edge Kiss

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***Abstract*-Asymmetric rolling can reduce the thickness of rolled strip and rolling load significantly. In this paper, the asymmetric cold rolling of thin strip with roll edge kiss was analysed theoretically and the rolling pressure, intermediate force between the work roll and backup roll, the work roll edge kiss force, the strip profile after rolling are obtained for this special asymmetric rolling. The rolling pressure, intermediate force, roll edge kiss force and the strip profile are compared for various roll speed ratios, reduction and friction coefficients. Simulation result shows that the roll speed ratio and reduction have a significant influence on the profile of rolled strip, and the calculated rolling forces are consistent with the measured values. The effect of friction in the roll bite on mechanics of the asymmetric cold rolling of thin strip with roll edge kiss is also discussed.**

I. INTRODUCTION

Thin strip produced in symmetric cold rolling has a wide application in electronic and instrument industries. Previous research showed that the asymmetric cold rolling of sheet or strip (see Fig. 1) could reduce the sheet/strip thickness significantly [1-4]. Asymmetric rolling with peripheral speed or roll radius difference will result in a decrease of 30 - 40 % rolling force [5]. The analytical and experimental works [6-8] have been reported before. As a thinner strip is rolled, some problems will be arisen during the rolling, such as the shape, profile and flatness of strip. A good mathematical model applied to the cold strip rolling can improve strip shape or profile. Analysis of asymmetric rolling of a sheet or strip before can be classified as using the slab method, the upper bound method, the finite element method and the experimental method. Slab method can predict rapidly the rolling force and torque, and is suitable for the rolling industry. Tzou and his co-authors [6, 8] developed a series of analytical models taking into account a variety of factors for asymmetric sheet rolling to study the behavior of sheet using a slab method. The rolling force and torque can be obtained and a large amount of CPU time can be saved. However, a major problem for thin strip rolling is the profile and flatness of strip which cannot be delivered from the slab method. Kiuchi et al. [9] developed an upper-bound technique for calculating curvatures in plate rolled with different roll radii and various roll speed ratios as well as different angles of roll entry. A generalized kinematically-admissible velocity field of the plate at the roll gap was formulated to predict the rolling force, the speed of the plate and the shape of the rolled plate. However, the rolling pressure distribution cannot be obtained by an upper-bound method. Rydz et al. [10] and Dyja et al. [11] analysed the asymmetric rolling by using rigid-plastic and elastic-plastic finite element method (FEM). Cao [12] has proposed a 3D elastic-plastic finite element method to explore the stress and strain distributions in asymmetric rolling. Although the FEM is powerful for a complicated problem, it consumes a large amount of CPU time.

An influence function method [13-15] developed for the analysis of the sheet or strip rolling in symmetric rolling not only can solve the rolling force and torque, but also the strip shape. For the rolling of thin strip, the shape and flatness of strip are focused. Jiang et al. [16, 17] calculated the elastic deformation of thin strip, its shape, profile and flatness. Elastic deformation of the rolls brings about problems of shape, profile and flatness [18]. A solution on how to improve the profile and flatness of strip and the dimensional accuracy has always been of a major interest to the steel manufacturers and researchers. Some solutions have been found for these problems by introducing new types of mills, such as continuous variable crown (CVC) and pair cross (PC) mills equipped with roll shifting, roll crossing and work roll bending [19, 20]. These are rolling processes where the work rolls do not contact each other when relatively thick strip is rolled.

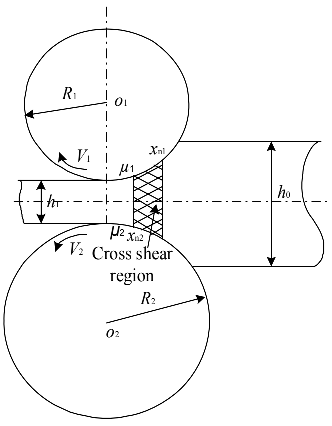

Fig. 1. Asymmetric strip rolling.

In cold rolling mills, for example, it has been found that the edges of the work rolls kiss and deform when a thin strip is rolled. Work roll edge kiss forms a new deformation

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feature for an asymmetric rolling of thin strip. In this case, the model of the deformation mechanics is significantly different from the traditional analysis of thin strip rolling. When the work rolls kiss beyond the edges of the strip, it will change the distribution of the roll pressure, the deformation of work rolls [15], friction at the interface of the rolls and the strip and the work roll wear. The determination of the rolling pressure, intermediate force, roll edge kiss force and the strip profile for the roll edge kiss is focused in the analysis of this asymmetric rolling. In the paper, a modified influence function method has been developed to simulate this special rolling process. Based on the numerical simulation, the effects of the roll speed ratio, reduction and friction in the roll bite on the specific forces and strip shape are obtained.

II. MODIFIED INFLUENCE FUNCTION METHOD

Due to symmetry, the calculation process involves only one half of a roll system along the roll barrel as shown in Fig. 2. The profiles of the deformed work roll and backup roll are obtained by calculating the roll deflections due to the bending and shear force. Local deformations due to the flattening in the contact region between the work roll and backup roll, the work roll and strip, and the upper and lower work rolls are added to the roll deflections [15].

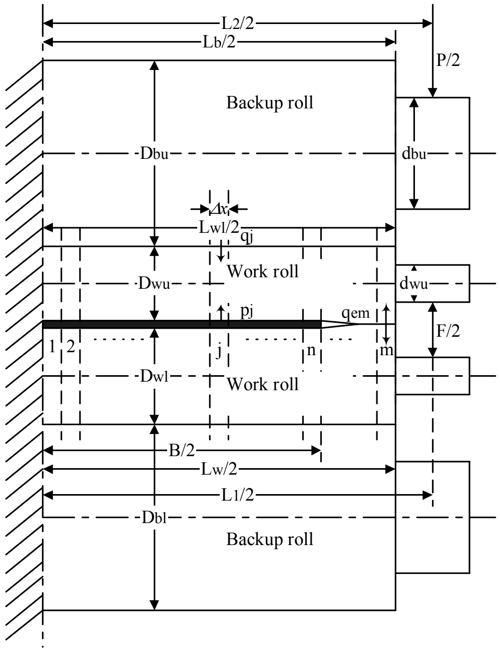

Fig. 2. Slit beam deflection model for asymmetric rolling.

Refer to Reference [15], the load is divided into a number of concentrated loads in the middle of each element, the deformation of the beam at an element i caused by an arbitrary load distribution along the beam can be calculated by

$$y(i) = \sum_{j}^{m} g(i, j) p_j \qquad (1)$$

where the influence function, $g(i, j)$ is defined as the deflection in the middle of element i due to a unit load in the middle of element j. The deformation, $y(i)$, in (1) not only stands for the deflection of the rolls, but also includes the flattening in the contact zone.

Under the rolling load, the deformation of the work roll, backup roll and the strip are described in Reference [15]. Compatibility for contact of the work roll and backup roll varies with the sum of the contour of the deformed work roll and backup roll and the local roll flattening. It can be calculated by (2) and (3).

$$y_{wbu}(i) = y_{wbu}(0) + y_{bu}(i) - y_{wu}(i) - m_{bu}(i) - m_{wu}(i) \qquad (2)$$

$$y_{wbl}(i) = y_{wbl}(0) + y_{bl}(i) - y_{wl}(i) - m_{bl}(i) - m_{wl}(i) \qquad (3)$$

where the parameters can refer to Reference [15], u and l stand for upper and down rolls respectively.

The contour of the work roll surface in contact with the strip is determined by the combined influence of the rolling load, machined and thermal crown and the local flattening between the work roll and the strip. The exit thickness of the strip at any point is the same as the loaded gap height at that point. Therefore, the compatibility for the contact of the work roll and the strip can be expressed by (4).

$$\begin{aligned} h(i) = h(0) + y_{wsu}(i) - y_{wsu}(0) + m_{wu}(i) \\ - y_{wu}(i) + y_{wsl}(i) - y_{wsl}(0) + m_{wl}(i) - y_{wl}(i) \end{aligned} \qquad (4)$$

where $h(0)$ is the central thickness of the strip.

When rolling a thin strip, the edges of the work rolls beyond the strip may kiss and deform. The compatibility (5) for the edge kiss of the upper and lower work rolls is calculated from the deformed work roll profile and the centreline value of the flattening between the work roll and the strip.

$$\begin{aligned} y_{ww}(i) = y_{wsu}(0) + y_{wu}(i) - m_{wu}(i) + \\ y_{wsl}(0) + y_{wl}(i) - m_{wl}(i) - h(0) \end{aligned} \qquad (5)$$

where u and l stand for upper and lower work rolls respectively.

III. RESULTS

Based on an analysis of the modified influence function method, a simulation program for this asymmetric rolling was developed. For different work roll speed ratios, reduction and the friction at the upper and lower work rolls, the rolling pressure, intermediate force, work roll kiss force and the strip profile can be obtained. The deformation resistance of strip can be described by the following equation,

$$k_s = 740 \cdot (\varepsilon_m + 0.01)^{0.23} \quad \text{(MPa)} \tag{6}$$

where ε_m is an average reduction that can be calculated by the slab, entry and exit strip thickness.

A. Roll speed ratio effect

The roll peripheral speed ratio affects the roll speeds of the upper and lower work rolls. For the peripheral speed ratio case (the diameters of the two work rolls are same), the slab thickness is 0.5 mm, the entry and exit thickness of strip are 0.2 and 0.12 mm respectively, the roll bending force, front and back tensions are 0 kN. Based on the parameters of Hille 100 rolling mill, the radii of upper and lower work rolls are 31.5 mm, the diameters of upper and lower backup rolls 228 mm, the barrel length of upper and lower work rolls 249 mm, the barrel length of upper and lower backup rolls 249 mm, the crown of the upper and lower work rolls 0 mm, the crown of upper and lower backup rolls 0 mm, the strip width 160 mm, the friction coefficient at the upper and lower rolls contact region 0.1. The peripheral speed ratio V_2/V_1 is 1.0, 1.1, 1.2 and 1.3 respectively.

The effect of the roll peripheral speed ratio on the rolling pressures is shown in Fig. 3. It can be seen that the rolling pressure decreases near the neutral points significantly with an increase of V_2/V_1, and the cross shear region is zero for $V_2/V_1 = 1.0$, but it increases significantly when the V_2/V_1 is 1.3 and the neutral points at the upper and lower work rolls vary significantly. This result demonstrates the rolling load reduces for the asymmetric rolling when the work roll edge kisses. It can also been seen that the rolling pressure (p_d) at the edge of strip is greater than that at the centre of strip.

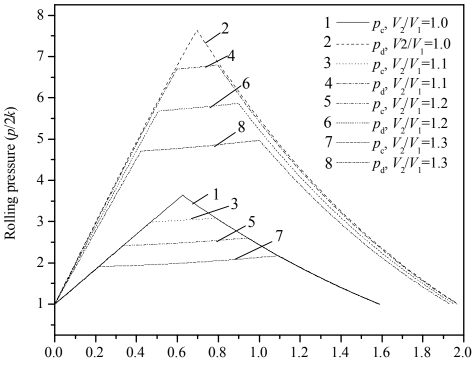

Fig. 3. Effect of V_2/V_1 on rolling pressure.

The effect of the work roll speed ratio on the intermediate force between the upper work roll and backup roll and the work roll edge kiss forces between the upper and lower work rolls is shown in Fig. 4. It can be seen that the distribution of the intermediate force along the strip width is non-uniform. For higher roll speed ratio, the intermediate force and roll kiss force at the edge reduce significantly, and the roll edge kiss length also reduces (see Fig. 4), which can reduce the work roll edge wear and energy cost. Due to decrease of the rolling force with an increase of the roll speed ratio, the deflection of the work roll reduces. As a result, the work roll edge kiss decreases, and the service life of work roll can be improved dramatically. Therefore, the strip profile becomes better (see Fig. 5).

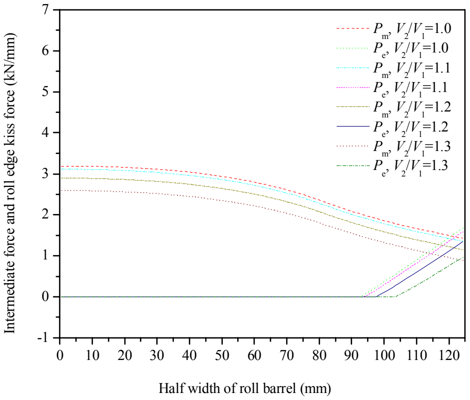

Fig. 4. Effect of V_2/V_1 on intermediate force and roll edge kiss force.

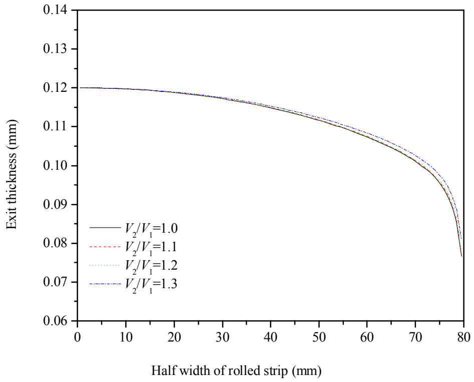

Fig. 5. Effect of V_2/V_1 on strip profile.

B. Reduction effect

When the exit thickness of strip 0.12 mm, the strip width 160 mm, the friction coefficient of upper and lower contact regions 0.1, the peripheral speed ratio of lower and upper work rolls V_2/V_1 1.2, and the entry strip thickness are 0.18, 0.2, 0.22 and 0.25 mm respectively, other parameters are the same as the section III.A. The effect of the reduction on the rolling pressure is shown in Fig. 6. It can be seen that the rolling pressure increases significantly with reduction (entry strip thickness), and the length and position of the cross shear region vary dramatically with reduction. It can also been seen that the rolling pressure (p_d) at the edge of strip is greater than that at the centre of strip. Fig. 7 shows the effect of the reduction on the intermediate force and roll edge kiss force. It can be seen that the intermediate force, roll edge kiss force and the roll edge kiss length increase dramatically with an increase of reduction. This will increase the work roll edge wear.

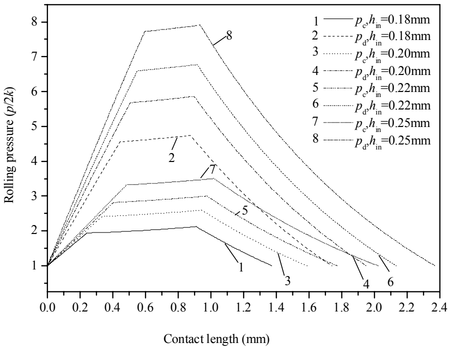

Fig. 6. Effect of reduction on rolling pressure.

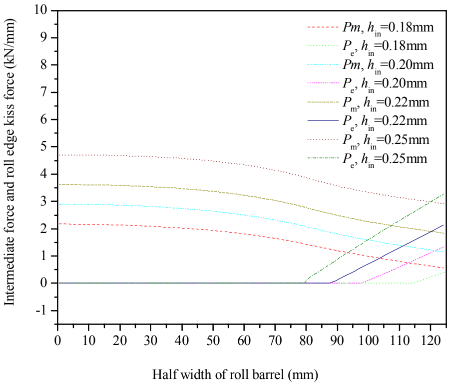

Fig. 7. Effect of reduction on intermediate force and work roll edge kiss force.

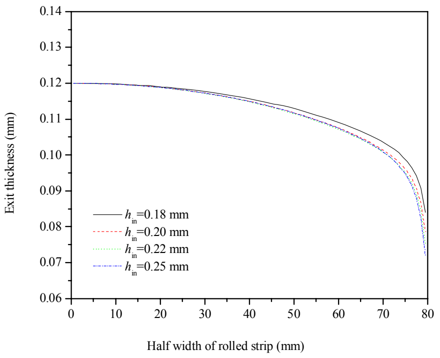

Fig. 8. Effect of reduction on exit strip thickness.

The change of the strip profile is also significant when the reduction increases (see Fig. 8). This result is useful in determining the effect of reduction and in reducing the rolling load and roll wear with a suitable rolling schedule in asymmetric cold rolling of thin strip.

C. *Friction effect*

When the radii of upper and lower work rolls are 31.5 mm, the peripheral speed ratio of lower and upper work rolls V_2/V_1 1.2, reduction 40 %, friction coefficients of upper and lower contact region are 0.05, 0.08, 0.1 and 0.13 respectively, other parameters are the same as the section III.A. Fig. 9 shows the effect of friction coefficient on rolling pressure. It can be seen that the friction coefficient increases, the rolling pressure at the centre and the edge of the strip all increases, and the position of the cross shear region varies with a change of friction coefficient in the roll bite.

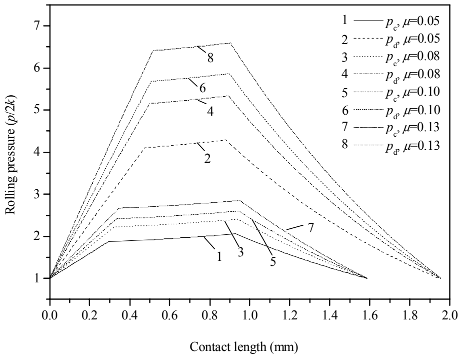

Fig. 9. Effect of friction coefficient on rolling pressure.

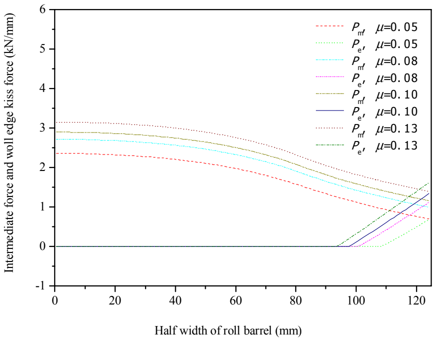

Fig. 10. Effect of friction coefficient on intermediate force and work roll edge kiss force.

The effect of friction coefficient on intermediate force and roll edge kiss force is shown in Fig. 10. It can be seen that the intermediate force, work roll edge kiss force and the work roll edge kiss length increase with an increase of friction coefficient. The strip profile becomes small when the friction coefficient increases (see Fig. 11). This indicates that the friction coefficient can improve the strip profile even thorough the rolling load, intermediate force and work roll edge kiss force of the asymmetric cold rolling of thin strip increases slightly.

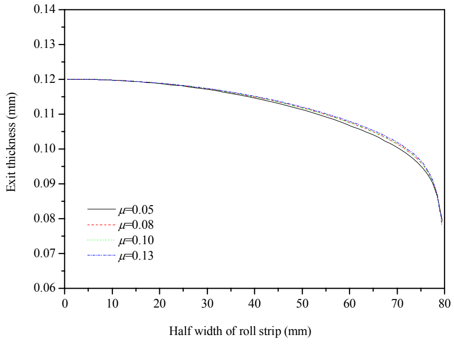

Fig. 11. Effect of friction coefficient on strip profile.

In order to verify the simulation results, an experimental verification was carried out on laboratory. When the rolling speed is 0.272 m/s, entry thickness of strip is 0.55 mm, strip width 100 - 130 mm, and V_2/V_1 1.2, a low carbon steel was rolled on Hille 100 rolling mill, the oil lubricant was applied on sample surface, the friction coefficient is 0.1, and its deformation resistance is

$$k_s = 579.21 \cdot (\varepsilon_m - 0.00301)^{0.18672}\,(\text{MPa}) \tag{7}$$

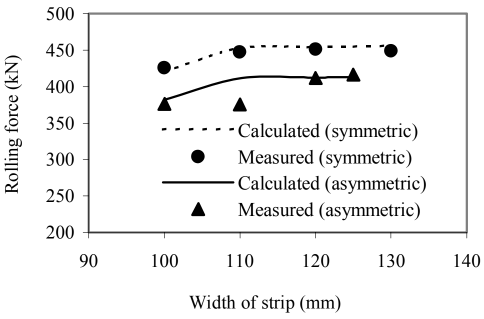

Fig. 12. Comparison of calculated rolling forces with measured values.

Comparison of the calculated rolling forces with the measured values is shown in Fig. 12. It can be seen that the calculated rolling force increases with the strip width, and the calculated rolling forces are consistent with the measured values. It can also be seen that the rolling force reduces significantly for asymmetric rolling of thin strip with work roll edge kiss. This also verifies the feature of reducing the rolling force during asymmetric rolling. Therefore, the developed model is useful in determining the work roll edge kiss area and in improving the profile of thin strip with a suitable asymmetric rolling condition.

IV. CONCLUSIONS

The analysis of asymmetric rolling of thin strip with work roll edge kiss was carried out effectively by a modified influence function method. The results show that the rolling pressure, intermediate force and the work roll edge kiss force for this special rolling are significantly different when the work roll speed ratio, reduction and friction coefficient in the roll bite vary. The work roll edge contact length and strip profile are significantly affected by the roll speed ratio.

The length of cross shear region in the roll bite increases and the neutral points at the upper and lower work rolls vary significantly when the roll speed ratio increases. This result demonstrates the rolling load reduces for the asymmetric rolling when the roll edge kisses. An increase of the roll speed ratio can reduce the rolling pressure and improve the strip profile. When the roll speed ratio increases, the roll edge kiss force and its length reduce. In this case, the roll wear and energy cost in rolling can be reduced, and the service life of the rolls can be improved. The length and position of the cross shear region vary significantly with the friction coefficient. Higher friction coefficient can improve the strip profile. This model is useful in determining the work roll edge kiss area and in improving the profile of thin strip with a suitable asymmetric rolling condition.

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REFERENCES

[1] Y.M. Huang and G.Y. Tzou, "Analytical and experimental study on asymmetrical sheet rolling," *Int. J. Mech. Sci.,* Vol. 39(3), pp. 289-303, 1997.

[2] G.Y. Tzou, "Relationship between frictional coefficient and frictional factor in asymmetrical sheet rolling," *J. Mater. Proc. Technol.,* vol. 86, pp. 271-277, 1999.

[3] G.Y. Tzou, and M.N. Huang, "Study on minimum thickness for asymmetrical hot-and-cold PV rolling of sheet considering constant shear friction," *J. Mater. Proc. Technol.,* vol. 119, pp. 229-233, 2001.

[4] M. Salimi, and F. Sassani, "Modified slab analysis of asymmetrical plate rolling," *Int. J. Mech. Sci.,* vol. 44(9), pp. 1999-2023, 2002.

[5] D. Pan and D.H. Sansome, "An experimental study of the effect of roll speed mismatch on the rolling load during the cold rolling of the thin strip." *J. Mech. Work. Technol.,* vol. 16, pp. 361-371, 1982.

[6] Y.M. Huang and G.Y. Tzou, "An analytical approach to asymmetrical cold strip rolling using the slab method," *J. Mater. Eng. Perforem.,* vol. 2(4), pp. 597-606, 1993.

[7] H. Yamamoto, Y. Uebori and K. Nakajima, "Effect of peripheral roll speed and friction coefficients on asymmetric rolling characteristics." *J. Jpn. Soc. Technol. Plasticity*, vol. 25, pp. 987, 1984.

[8] G.Y. Tzou and Y.M. Huang, "Effect of hybrid friction on the characteristics of asymmetrical strip rolling using an analytical approach," *J. Chin. Soc. Mech. Eng.*, vol. 16(5), pp. 499-509, 1995.

[9] M. Kiuchi and S.H. Hsiang, *The general analytical model in asymmetrical rolling process*, Proc. 34th Joint Conf. of the Japanese

Society for the Technology of Plasticity, pp. 105-108, 1983.

[10] D. Rydz, H. Dyja and M. Krakowiak, “The influence of the thickness of a bimetallic layer (18G2A+0H18N10T) on the distribution of the relative flow rate in asymmetrical rolling,” *J. Mater. Proc. Technol.*, vol. 138(1-3), pp. 120-122, 2003.

[11] H. Dyja, J. Markowski and D. Stoiski, “Asymmetry of the roll gap as a factor improving work of the hydraulic gauge control in the plate rolling mill,” *J. Mater. Proc. Technol.*, vol. 60(1-4), pp. 73-80, 1996.

[12] G.R. Cao, *Finite element simulation of material flow in asymmetrical rolling process*, Proc. 4th Int. Conf. on Technology of Plasticity, Beijing, September 1993, pp. 752-757, 1993.

[13] Z.Y. Jiang, H.T. Zhu and A.K. Tieu, “Effect of rolling parameters on cold rolling of thin strip during work roll edge contact,” *J. Mater. Proc. Technol.*, vol. 140(1-3), pp. 537-543, 2003.

[14] Z.Y. Jiang, H.T. Zhu and A.K. Tieu, “Effect of roll edge local perturbation of deformation on thin strip rolling,” Steel GRIPS J. Steel and Related Materials, vol. 2, pp. 65-70, 2004.

[15] Z.Y. Jiang, H.T. Zhu, A.K. Tieu and W.H. Sun, “Modelling of work roll edge contact in thin strip rolling,” *J. Mater. Proc. Technol.*, vol. 155-156, 1280-1285, 2004.

[16] Z.Y. Jiang and A.K. Tieu, “Finite element method simulation of the roll bite for the cold rolling of thin strip with tensions,” *J. Mater. Proc. Technol.*, vol. 130-131, pp. 511-515, 2002

[17] Z.Y. Jiang and A.K. Tieu, “A 3-D finite element method analysis of cold rolling of thin strip with friction variation,” *Tribology Int.*, vol. 37, pp. 185-191, 2004.

[18] G.D. Wang and G.L. Wu, *Rolling Theory and Practice of Plate and Strip*, China Railway Press, Beijing: 1990.

[19] X.M. Zhang, Z.Y. Jiang, A.K. Tieu, X.H. Liu and G.D. Wang, “Numerical modelling of the thermo deformation of the CVC roll for hot strip mills,” *J. Mater. Proc. Technol.*, vol. 130-131, pp. 219-223, 2002.

[20] B. Paolo, B. Roberto and R. Massimo, “New mill stand with flexible crown control for rolling ultra-thin hot strip,” *Metallurgical Plant & Technol. Int.*, vol. 22, pp. 7, 1999.