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Abstract

Controlling cold strip profile is a difficult and significant problem has been found in industry during thin strip rolling. At present choosing the new type of strip rolling mill is the one of main methods to control the strip shape quality in cold rolling. The influences of rolling process parameters such as the work roll cross angle and work roll shifting on the strip shape and profile of thin strip are recognised throughout this study. The results show that the roll crossing and shifting is efficient way to control the strip shape. The increase of the work roll crossing angle would lead to improve the strip profile significantly by decreasing the exit strip crown and edge drop. The strip profile would be enhanced if the axial roll shifting was increased. Moreover, the total rolling force was analysed in detail by changing the roll cross angle and axial shifting roll. (2014) Trans Tech Publications, Switzerland.

Keywords

mill, rolling, thin, strip, shifting, profile, cold, control, capability, roll, crossing

Disciplines

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Thin strip profile control capability of roll crossing and shifting in cold rolling mill

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Abstract: Controlling cold strip profile is a difficult and significant problem has been found in industry during thin strip rolling. At present choosing the new type of strip rolling mill is the one of main methods to control the strip shape quality in cold rolling. The influences of rolling process parameters such as the work roll cross angle and work roll shifting on the strip shape and profile of thin strip are recognised throughout this study. The results show that the roll crossing and shifting is efficient way to control the strip shape. The increase of the work roll crossing angle would lead to improve the strip profile significantly by decreasing the exit strip crown and edge drop. The strip profile would be enhanced if the axial roll shifting was increased. Moreover, the total rolling force was analysed in detail by changing the roll cross angle and axial shifting roll.

Keywords: Work roll crossing; Work roll shifting; Strip shape and profile; thin strip

1. Introduction

The proportion of thin strip production has become very important to assess a country's steel manufacturing industry level. In that case an advanced strip shape control is necessary for strip quality that determined by the strip shape and the variation of the strip thickness. Although these geometric characteristics of the strip have been comprehensively studied by Ginzburg¹ and Robert², the market requirements for higher quality and increasingly thinner strip have recently motivated a growth of efforts for the development of new technology for predicting and controlling the thinner strip shape and profile. Indeed, the strip shape control naturally is to improve the strip profile using some advanced technologies, so it is very necessary to study the factors affecting the strip profile.

The introduction of new rolling mills, such as the continuous variable crown (CVC) and pair cross (PC)³ and the work rolls crossing and shifting (RCS)⁴ mills were developed to improve the strip shape and profile, as the mills have an ability to work as a shifting roll, crossing roll and bending roll. The PC mill was started in the world at Nippon Steel's Kimitsu Works in 1991³, which has been commonly used in hot rolling mills for plate and strip as finishing mill. In the development of high accuracy and high efficiency rolling technology, the PC mill not only significantly improve the capability of the shape, crowns control and reduce the edge drop, but also enhance the mechanical properties and productivity³. The crown control range of the PC mill equipped with bending roll was compared with 6-high mill equipped with roll shifting and a conventional 4-high mill equipped with roll bending only. It has been found that the crown control range of PC mill is approximately 10% greater than that of a 6-high mill and

nearly three times greater than the crown control of a 4-high mill⁵. Matsumoto et al⁶ and Omori et al⁷⁻⁸ carried out rolling experiments to verify the ability of PC mill on crown control and its effect on rolling force, torque and roll wear. Kitahama et al⁹ compared the cycle shifting, taper adjusting and taper oscillating methods with the conventional method.

The combination of multiple shape control systems, such as the pair cross and work roll shifting (PCS)¹⁰ and the work rolls crossing and shifting (RCS)⁴ can provide more than one benefits of strip and profile control technology, for example, the roll crossing mill provides crown control while the roll shifting mill produces a more uniform roll wear along the roll surface. The relationship between the equivalent work roll crown and the roll shifting stroke was discussed among the work rolls crossing and shifting (RCS), CVC system and PC system. It has been discovered that the work roll crown adjustment range of RCS system is more efficient than of the CVC system. The RCS has greater efficiency of roll crown adjustment than that of the PC mill. These mills are appropriate to control the strip shape, profile and flatness when the rolling process is applied to the rolling of thick strip, and the control of the strip shape, profile and flatness no longer present a serious challenge to rolling mill operation for relatively thick products¹¹. However, for thinner gage strip such as the thickness less than 0.5 mm is still a challenge in rolling practice, this involves the control of the strip dimensional accuracy, the strip crown and surface finish. Therefore, it is necessary for researchers and manufacturers to comprehend the strip shape performance in cold rolling of thin strip.

In present paper, the effects of the rolling parameters on the strip shape and profile during cold rolling of thin strip with initial thickness of 0.55 mm was investigated. This can

2. Principle and configuration of roll crossing and shifting rolling mill

In the work roll crossed system, the axes of the upper and lower work rolls are crossed in the opposite direction, while the upper and lower backup rolls are kept exactly parallel as shown in Fig.1. Roll crossing mill purposes to adapt the roll gape profile causing the roll gap to increase with an increase in distance from the roll centre. This action leads to obtain large efficiency of shape and profile control¹². In the work roll shifting system, the work rolls are shifted cyclically by an amount S , to prevent step uneven wear on rolls and smooth thermal crowns. This method is very effective for improving schedule free rolling and strip profile accuracy¹³. Once both work rolls are in contact under a crossed state as shown in Fig. 2, the roll gap δ varies with the square of the distance z from the roll center to the edge of the roll as expressed by:

$$\delta \approx \frac{2z^2 \tan^2 \theta}{D_w} \approx \frac{2z^2 \theta^2}{D_w} \dots \dots \dots (1)$$

where D_w is the diameter of the work rolls. The equivalent amount of roll gap is adjustable using the cross angle θ . The change in the roll gap distribution caused by load variation can be minimised by controlling the cross angle if the degree of deformation in rolls can be approximated with quadratic curve. Therefore, this leads to the strip thickness distribution in the width direction be constant⁷.

3. Testing mill and experimental procedure

Extensive tests were carried out on a 4-high Hille 100 rolling mill revamped for the purpose of research as a work roll crossing and shifting system. The confirmatory tests were performed by modifying an ordinary cold rolling mill to work roll crossing and shifting system.

The specification for the test mill is given in Table 1. The cross angle can be changed by moving the roll nick with screw nuts. The roll shifting is done by using screw shafts that are respectively provided in upper and lower slide blocks to axially slide the upper work roll towards the operator side. Similarly, the lower screw shaft slides the lower work roll in opposite direction towards the drive side. Load cell set up on the backup roll to measure the rolling force. Whilst the torque was measured via a sensor cell

be a reference for building a thin strip shape control model and choosing the type of cold strip rolling mill.

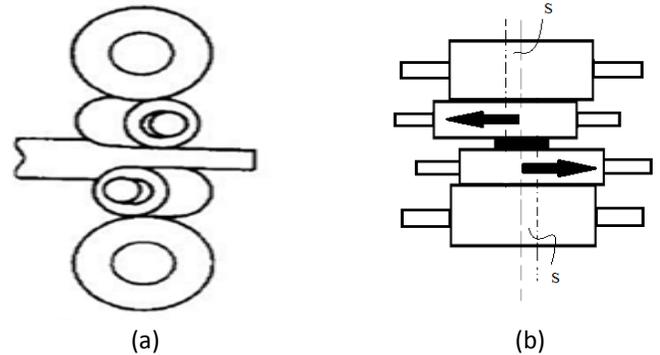


Fig. 1 Work rolls crossing (a) and shifting (b) system.

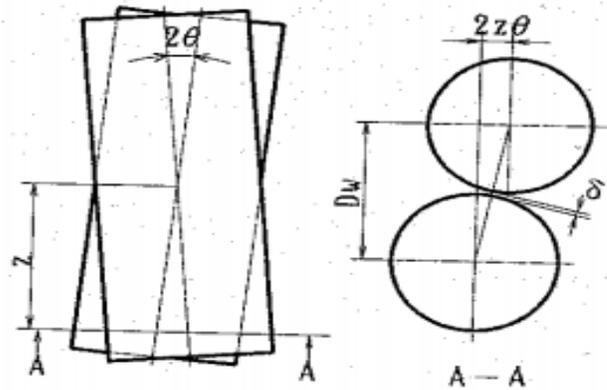


Fig. 2 Effect of roll cross angle on roll gap⁷

connected to the gearbox and backup roll. To simulate cold steel rolling, low carbon steel strips 0.5-0.55 mm thick, 80-120 mm wide and 400 mm long were mainly rolled under dry condition with roll speed 10 rpm. During implementation no bending force was applied to the rolls, nor was tension applied to the strip specimens.

Table 1 Specification for the 4-high Hille 100 rolling

Mill system	Work roll crossing and shifting
Cross angle	0-1.5°
Shifting value	0-16 mm
Work roll	Diameter = 63 mm, length = 250 mm
Backup roll	Diameter = 228mm, length = 250 mm
Rolling force	0-1500 kN
Rolling torque	0-13 kN m
Rolling speed	0-60 rpm

4. Experimental results

4.1 Shape control

Fig. 3 shows the rolled strip after rolling of flat strips under different roll cross angles by the test mill. When the cross angle is zero, an edge buckle is observed. However, the strip surface is roughly flat at cross angle 0.5° or 1.0° . Severe center buckle and some time the strip was damaged at a cross angle larger than 1° . Therefore, amendment of the cross angle would lead to control the thickness distribution of the strip along its width and the shape, resulting in a better control range.

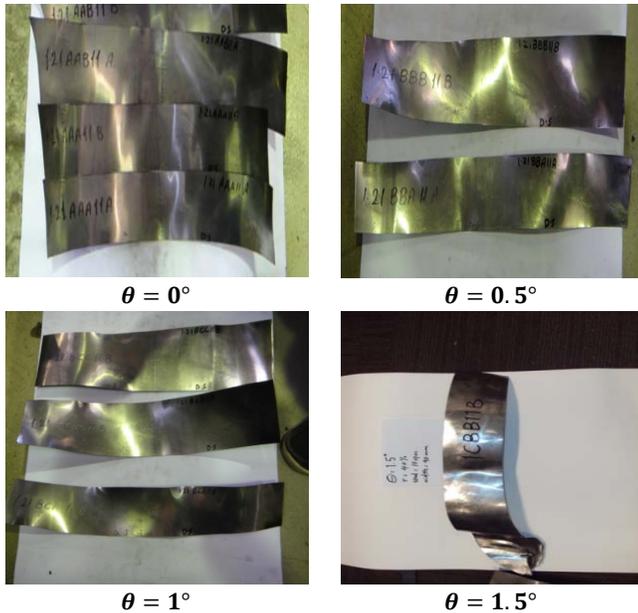


Fig.3 Shape of strips rolled by test mill

4.2 Wear of rolls

Fig. 4 shows the wear of work rolls after dry rolling process. It can be seen that the roll wear uniformly distributes as a result of the cyclic shifting method. Since the work roll shifting is mainly used to provide more evenly roll wear along the roll face and the influence of roll wear on strip profile control is greatly reduced.

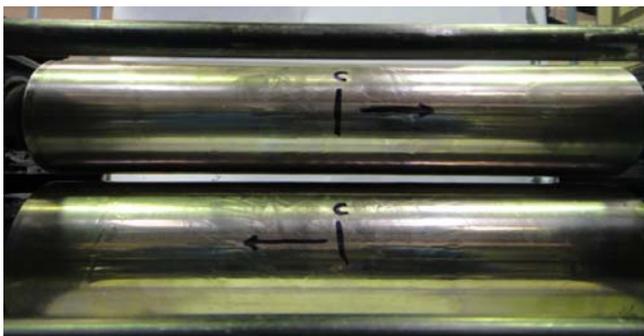


Fig.4 Work roll surface of test mill

4.3 Effect of cross angle on the strip profile

Figs. 5-7 show the exit strip profiles and the rolling force under different work roll cross angles and no work roll shifting with same strip width of 80 mm. As shown in Fig.5 the strip thickness did not differ significantly, but when the cross angle was zero, it decreased dramatically towards the edge which resulting in increase of the strip crown. The great variation of thickness near the strip edges was attributed to the fact that the resistance of transverse flow in the area near the strip edges was relatively low, and this reflects the character of the general strip profile produced with conventional rolling mill. Whilst with an increase of the roll cross angle, the strip profiles were more flat, which prove that the work roll crossing system has an ability to adapt the roll gape profile causing the roll gap distribution to be uniformed. This action leads to obtain large efficiency of the shape and profile control. In order to illustrate that more clearly, the metric of crown and edge drop were used to estimate the strip profile. Here, the strip crown C_5 was defined as the variation value between the thickness at the strip center and the thickness at a 5mm distance from the edge, and the edge drop C_e was defined as the variation value between the thickness at the 35mm distance from the strip edge and the thickness at the 10mm distance from the strip edge. Fig.6 shows the effect of the roll cross angle on C_5 and C_e when the strip width and the total rolling force were not changed. Both C_5 and C_e decreased with an increase of the roll cross angle, which was attributed to the fact that the transverse flow of the metal was controlled with crossing angle.

Fig. 7 illustrates the total rolling force under different work roll crossing angles. The work roll crossing was observed to influence the rolling force with no shifting value. The slopes of the trendlines for different strip widths indicate that the rolling force did decrease as the cross angle increased. This may be as a result of decreasing the contact area between the work roll and the backup roll.

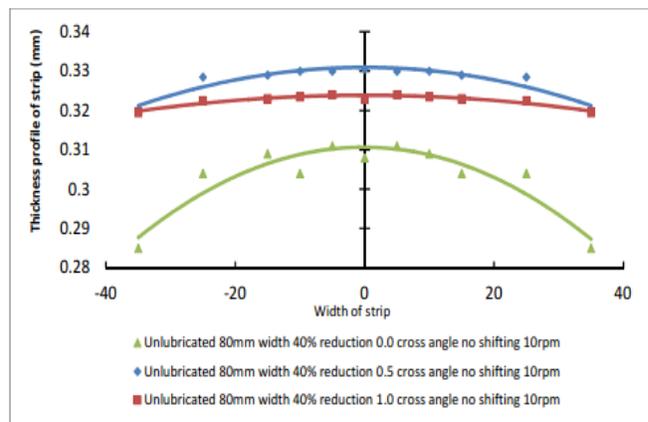


Fig.5 Effect of cross angle on the strip profile and total rolling force

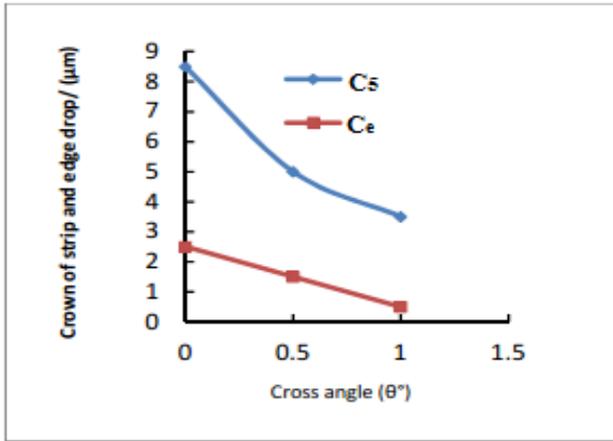


Fig.6 Effect of cross angle on the strip crown and edge drop

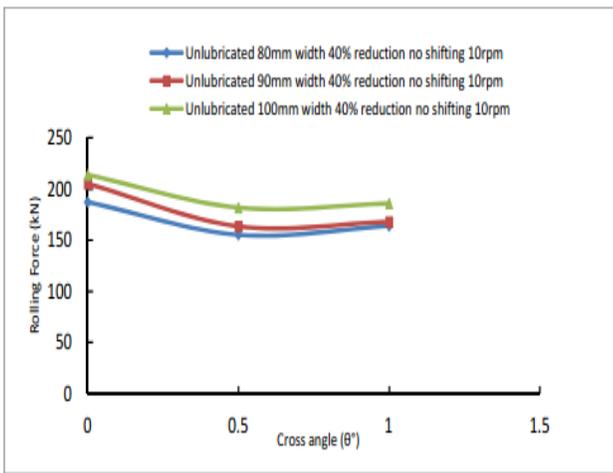


Fig.7 Effect of cross angle on total rolling force

4.4 Effect of the work roll shifting on strip profile

Figs. 8-10 show the exit strip profiles and the rolling force under different work roll shifting values and no cross angle with the same strip width of 80 mm. It is obvious that the shape control ability of roll shifting is much less than that of rolls crosses. However, the strip profile improves obviously when the shifting value increases as shown in Fig.8. This indicates that when the top work roll shifts to the left and the bottom work roll shifts the same amount to the right, the force distribution between rolls changes. This reaction affects the forces over the strip and makes them more uniform, which lead to increase the strip crown control range as shown in Fig.9 and to avoid asymmetrical roll wear.

Fig. 10 shows the effects of roll shifting on the total rolling force. It is obvious that the influence of axial roll shifting on the total rolling force is complicated and small. As mentioned before the efficiency of roll shifting can be obtained by the application of axial side shifting of the

work rolls, which leads to the roll wear becomes more evenly distributed until a smooth roll crown can be achieved.

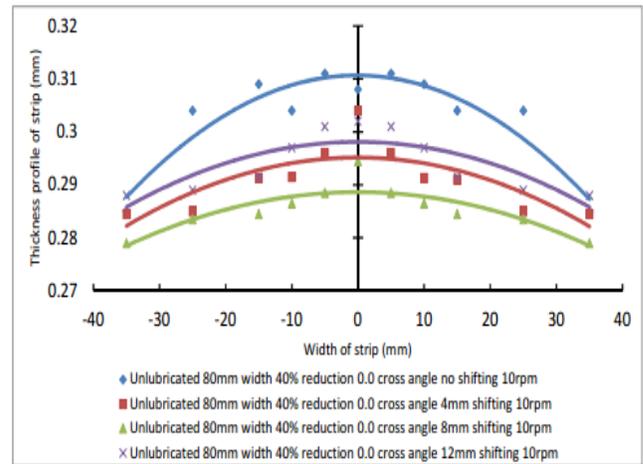


Fig. 8 Effect of the work roll shifting on the strip profile

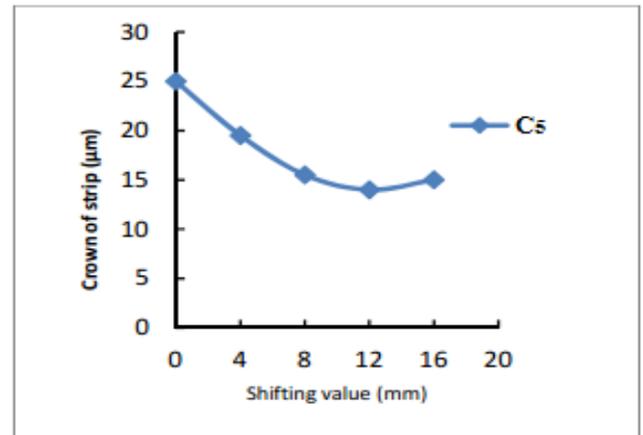


Fig.9 Effect of the work roll shifting on strip edge

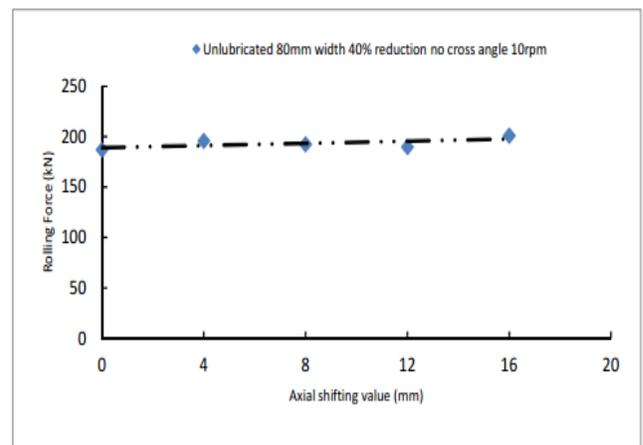


Fig.10 Effect of the work roll shifting on total rolling force

4.5 Effect of the combination of the work rolls crossing and shifting on strip profile

Since the work roll crossing and shifting rolling mill used as a multiple shape control systems provide an easy and relatively inexpensive way to make high efficiency profile control devices, which avoid or minimise the formation of wear caused by worn rolls, by axial shifting of the work rolls, and reduces the strip crown and edge drop by implanting work roll crossing rolling system. The influences of the work rolls crossing and shifting on strip profiles were analysed and the result was illustrated in Fig.11. The strip profile clearly changed when changing the work roll axial shifting value at a cross angle of 0.5° . This could be a result of modifying the roll gap profile by crossing angle and simultaneously the local roll wear decrease as the shift amount of roll stroke increases. However, although the roll shifting of 16 mm is the maximum possible given the restricted condition of revamping modification, it is sufficient to achieve the target strip crown of $C_{15}=10 \mu\text{m}$.

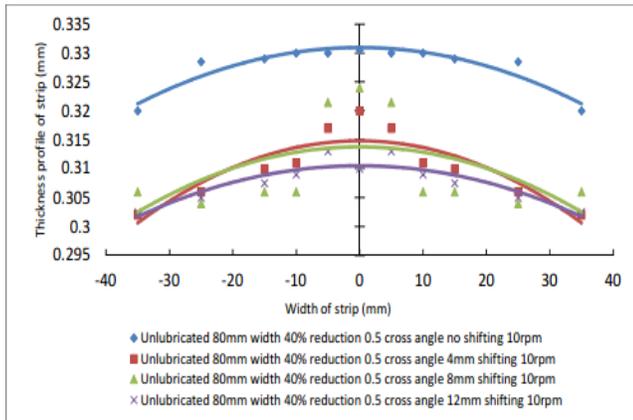


Fig.11 Effect of the combination of the work rolls crossing and shifting on strip profile

5. Conclusions

The exit strip profile for thin strip in cold rolling process was systematically estimated considering the work roll crossing, axial work roll shifting and the combination of the work rolls and shifting using the Hille 100 mill located at the Manufacturing Research Laboratory, University of Wollongong. The following conclusions can be drawn from the results of this study.

1. The influence of the cross angle on strip profile was evident. The strip profile is improved as the cross angle increased but not more than 1.0° .
2. Under the same condition, the exit strip crown and/or edge drop decreased as the roll cross angle increased.
3. The axial roll shifting changed both the strip profile distribution over the strip width and the strip edge shape.

This may be as a result of the redistribution of roll wear along the strip width.

4. The work roll crossing was observed to influence the rolling force, the rolling force decreases as the cross angle increased.
5. The practical application of the work roll crossing and shifting mill has demonstrated that the combination of the work rolls crossing and shifting can effectively improve the strip profile.
6. The result of strip profile control capabilities of this rolling mill will serve as a useful reference for building a thin strip shape control model and choosing other types of cold strip rolling mills.

Acknowledgments

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