Laboratory Evaluation of New Type of Backup Roll for Strip Shape Control

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In this research work, a new back-up roll was developed, which could be used in any type of 4 high mills to reduce the strip shape defects. The developed back-up roll consists of a sleeve, an arbor and a phase angle adjusting system for the arbor. The circumference of arbor was specially machined to adapt the strip width when changing the product and control the shape during rolling. The developed \( \Phi 530 \text{mm} \times 498 \text{mm} \) backup roll was installed in a pilot mill and the rolling test was carried out to prove the effectiveness of the newly developed back-up roll. The rolling tests showed that the new back-up roll has better performance in reducing the shape defects than conventional back-up roll. It was also found that the new back-up roll provided higher shape stability. In addition, the arbor can be manufactured using scrapped conventional backup rolls, and it can be multi-times used because only sleeve surface needs to be reground and changed in most cases.

KEY WORDS: steel rolling; profile; flatness; strip shape control; backup roll.

1. Introduction

Strip shape is one of the most important parameters that evaluate the geometrical quality of rolled strip. To satisfy the ever-increasing demand for higher strip quality from end users, many new shape control technologies have been developed by mill suppliers and steel producers over the years. Special structured backup roll is one type of shape control technologies developed in recent years. Shape Control Roll of SMS,\(^1\) Variable Crown Roll of Sumitomo metals,\(^2\) and Dynamic Shape Roll of VAI Clecim\(^3\) are representative examples of special structured backup rolls. One common drawback of above special structured backup rolls is that high-pressure hydraulic units are used inside the rolls and complicated hydraulic control system is required for shape control. The other common drawback is that these rolls can be used as shape controller, but not shape stabilizer.

In this research work, a new type of special structured backup roll is developed, with which strip shape can be online fast controlled without high-pressure hydraulic control system. The shape stability is also increased with this new backup roll. Besides, the new backup roll has also many other advantages such as re-usable arbor, exchangeability with conventional backup rolls, and therefore, is suitable for retrofit of existing 4-high mills, etc.

The new type of backup roll consists of a sleeve, an arbor and a phase angle adjusting system for the arbor. The circumference of the arbor is specially machined into such a contour that the barrel length of the arbor can be changed when the phase angle of the arbor is adjusted. Therefore, shape can be controlled by adjusting the phase angle of the arbor. Shape stability can also be increased by setting the proper phase angle.

A \( \Phi 530 \text{mm} \times 498 \text{mm} \) backup roll of this new type was manufactured from scrapped backup roll as the arbor. The new backup roll was installed in a 4-high pilot cold rolling mill. A series of cold rolling experiments was carried out to test the new features of the new backup roll.

2. Profile and Flatness in Rolled Strip

2.1. Definition of Strip Profile and Flatness

Figure 1 shows the relationship between elastic deformation of work roll (WR) and plastic deformation of strip during rolling by 2-high mill. While the rolling load acts on the strip, the same force from strip reversely acts on a barrel of WR. The reaction force makes WR bend so that the thickness distribution across the strip width is not uniform after rolling.

Fig. 1. Elastic deformation of roll in strip rolling.
Because the strip is softer than the WR in general, the deformed strip profile will be resembled to WR, creating crown or edge drop in strip as shown in Fig. 2. The crown is representative strip profile and is defined as Eq. (1), which is thickness difference between the center and the edge part of the strip.

\[ C = h_c - h_e \] .................................(1)

where \( h_c \) and \( h_e \) are center and edge thickness respectively and \( W \) stands for strip width.

Another important strip profile is edge drop, which is abrupt thickness variation near the strip edge, is defined by the following equation.

\[ H_{ed} = h_x - h_e \] .................................(2)

where \( h_x \) is strip thickness at the pre-defined distance from strip edge.

In the mean time, if the reduction ratio varies across the strip width, a transverse variation in elongation will also vary, remaining non-uniform stress distribution on strip. Because a sufficient tension is applied to pull the strip flat, there may not be seen any problem on strip during rolling. But the transverse stress variation may result in a buckled strip when the tension applied is removed after rolling.

Figure 3 shows one of the examples of buckled strip in longitudinal direction. It is called edge wave because it is buckled at the strip edge. The magnitude of un-flatness generated in rolled strip is expressed by Eq. (3) introducing the flatness parameter called steepness \( \lambda \).

\[ \lambda = \frac{\delta}{l} \cdot 100 \text{ (%) } \] .................................(3)

where \( \delta \) and \( l \) are height and wavelength of the edge wave respectively.

2.2. Relationship between Mill Stiffness and Strip Profile

As described in the previous section, strip profile or flatness is closely related to the elastic deformation of WR. Therefore, to minimize the strip shape defects, elastic deformation of WR should be reduced by increasing the stiffness of rolling mill. Maybe, the simplest method of increasing mill stiffness is to use large diameter WR. But it is not simple because it needs to augment the mill housing to receive larger WR.

The introduction of multi roll mills is another way of increasing mill stiffness. For example, the 4-high mill, which consists of WR and backup roll (BUR), has not only higher stiffness but also better strip profile controllability than the 2-high mill under the same rolling conditions.

From this point of view, the 2-high mill has disappeared in steel rolling process except light reduction rolling, for instance, temper rolling or skin pass rolling process. Meanwhile, the 6-high mill has been adopted as a main facility in tandem cold mill, in which the strip flatness is treated as the most important quality criterion. In addition, the 20-high mill has been introduced to the high strength steel rolling process like stainless steel or electrical steel rolling mill.

3. Strip Shape Control by BUR

3.1. Effects of BUR on Strip Shape

Though the 6-high and 20-high mill have lots of technical advantages in strip shape control over the 4-high mill, they also have weak points that they are very expensive and are not easy in maintenance. For this reason, the 4-high mill has been widely used in the field of hot rolling as well as cold rolling process.

Many measures have been suggested to reduce the strip shape irregularities in steel strip, for example, cambering the roll barrels, thermal cambering, and applying bending moments to the roll ends since the 4-high mill was introduced. But all such methods have however suffered from various objections under the complex or varying rolling conditions.

In the meantime, some research works have been tried to develop new countermeasures for reducing the strip shape defects by modifying conventional 4-high mill. Figure 4 explains the basic concept of new method for strip shape control by modification of BUR.

In general, the barrel length of BUR used in conventional 4-high mill is almost equal to that of WR. Therefore, the applied rolling forces exerted on BUR chocks would be transmitted to strip through the whole face of WR making WR as well as BUR deflect. Those roll bending deformations make rolling pressure distribution on strip non-uniform and finally lead to unwanted irregular strip profile.

If the barrel length of BUR is shorter than WR, the bend-
ing deformation of WR could be decreased by the load concentration effect. Figure 4(b) shows the path of applied rolling load via rolls and pressure distribution on strip in modified BUR. The optimum barrel length of BUR, which is maximum contact length with WR, would be equal to the width of strip that should be rolled in a mill. By concentrating the applied rolling force on the WR center, the bending deflection of WR could be reduced. By maintaining the pressure distribution uniform, strip profile as well as flatness could be improved.

3.2. Structure of the New Backup Roll

In this research, new BUR that not only can control the strip shape but also can accommodate the strip width change is developed. Of course, it has simple structure that is manufactured cheaply and very easy in maintaining for service life. Figure 5 shows the conceptual drawing of the proposed new type of backup roll, which consists of a sleeve, an arbor and a phase angle adjusting system for the arbor. The circumference of arbor is specially machined into such a contour that the barrel length of the arbor can be changed when the phase angle of the arbor is adjusted.

Figure 6 shows the structure of the new backup roll. Ball bearings are used between the sleeve and the arbor to allow the rotation of the sleeve. The existing backup roll chock is reused to accommodate the new backup roll, which shows that the new backup roll is exchangeable with the existing conventional backup roll. The new backup roll can only be used in 4-high mills that are work roll driven. The sleeve of the new backup roll rotate with the work rolls, while the arbor is stationary when it is not adjusted by the phase angle adjusting system. The optimal arbor phase angle \( \phi \), in case of strip width \( W \), can be calculated by the following equation.

\[
\phi = \cos^{-1}\left(1 - \frac{2(W - W_2)}{(W_1 - W_2)}\right)
\]

where \( W_1 \) and \( W_2 \) are the maximum and minimum available backup roll barrel lengths as shown in Fig. 5, which are also equivalent to the maximum and minimum strip widths respectively.

4. Experimental Investigation

4.1. Pilot Mill and Rolling Conditions

Figure 7 is the picture of the pilot mill, in which the new backup roll is installed. The arbor phase angle adjusting system and the lubrication pipelines of the new backup roll can also be seen in the picture. Motor driven worm-gear system is used to adjust the arbor phase angle under rolling load. The pilot rolling mill is fully computer-controlled so that all experimental data can be acquired automatically during rolling. The specification of pilot rolling mill and basic rolling conditions are summarized as shown in Table 1. Because sheet was used as rolling specimen, no tensions were exerted on steel strip. Meanwhile, the basic specifica-
tion of new backup roll can be found in Table 2.

Both the new backup roll and a conventional backup roll were used in the rolling experiments for comparison purpose. After rolling, the data were analyzed and the results are discussed in the following sections.

4.2. Effect of the New Backup Roll on Strip Flatness

Figure 8 shows the picture of two rolling experiment samples. The sample on right is the strip rolled by conventional backup roll and the sample on left is the one rolled by the new backup roll when the arbor barrel length is set equal to the strip width, while all other rolling conditions are the same. The comparison shows that, by setting the arbor barrel length equal to strip width, flat strip can be obtained with the new backup roll under the condition that large edge wave would occur if the strip were rolled with conventional backup rolls. The better shape control performance of the new backup roll is proven by this comparison.

The relationship between the steepness of the rolled strip and the reduction ratio of the new backup roll is also compared with that of the conventional backup roll as shown in Fig. 9.

The flatness in the strip rolled by the new backup roll, when the arbor barrel length is set equal to the strip width, is considerably improved from the one rolled by the conventional backup roll. In case of low reduction ratio, which is 10–20%, the steepness of the strip rolled by the new backup roll shows negative (−) value meaning that the strip has center wave. This phenomenon is originated from maintaining the same rolling conditions as in the conventional backup roll. The initial work roll bending force is so high that it brings out center wave when rolled with the new backup roll.

In the meantime, some edge waves are remained for high reduction ratio around 30–40% even though the new backup roll is used. The reason why the strip was not perfectly flat even though the new BUR was used is that the new BUR was only used for the upper side of mill. If the new BUR was used for the upper as well as the lower side, the perfectly flat strip might be gotten.

With the conventional backup roll, the steepness increases rapidly as the reduction ratio increases. While, it increases slowly when the strip is rolled with the new backup roll. This experimental result shows that the new backup roll has higher shape stability, which means there is less shape variation when the rolling load varies.

4.3. Effect of New Backup Roll on Strip Crown

The measuring position of strip crown is, in general, 25.4 mm from strip edge. However, the experimental specimen, which is 300 mm in width, was too narrow to follow the standard rule. In exchange, strip edge thickness was measured in 2 mm intervals from strip edge to strip center to get strip crown values in multi-positions. Figure 10 shows the comparison of strip crown variations between new backup roll and conventional backup roll. As expected, the strip crowns rolled by the new backup roll are 30–50% less than those rolled by conventional backup roll.

4.4. Effect of New Backup Roll on Edge Drop

The edge drop is abrupt thickness variation near strip edge and it should be minimized to raise the yield. If the thickness variation at strip edge exceeds its limit, the edges have to be slit off causing yield loss, or in some cases,
width shortage products. The edge thickness is measured in far most edge part and the edge drop is defined as the thickness difference between the edge thickness and the thickness at predefined location from edge.

Figure 11 shows the variation of edge drop in accordance with the distance from strip edge for the case of 30% reduction ratio. The new backup roll has also good performance in reducing edge drop. However, the effect of new backup roll on reducing the edge drop is less than that of crown or flatness adjustment.

4.5. Shape Control Capability of the New Backup Roll

The shape control capability of the new backup roll was also examined by rolling the strips under various arbor phase angles. Figure 12 shows the measured results of strip shape variation by changing the arbor phase angle. It is found that the steepness varies with the arbor phase angle. By adjusting the arbor phase angle from 180°, at which the new backup roll is equivalent to the conventional backup roll, to 78°, at which the barrel length of the new backup roll is equal to the strip width, the strip steepness is decreased linearly from 5.6 to 0.42%. This confirms the effective shape control capability of the new backup roll.

5. Conclusions

(1) A new BUR, which can increase the rolling mill transverse stiffness, is proposed and developed. The structure of new BUR is simple to manufacture and easy to maintain.

(2) Experimental rolling results show that the new BUR has greater capability in shape control than the conventional BUR, for instance, reducing the steepness, crown, and edge drop in accordance with the strip width. In addition, the new BUR can be used as an on-line strip shape control equipment by adjusting the arbor angle.

(3) Because the sleeve of the new BUR is changeable and the arbor can be used semi-permanently, the cost for purchasing BUR will be saved.

REFERENCES