Improving the Accuracy of Predicting Work Roll Wear in the Hot Strip Mill

Accurate prediction of work roll wear is a key component of high-quality hot strip rolling. Incorrectly calculated wear has different implications for the roughing and finishing stands. Comparative analysis of the measured and predicted roll wear in the roughing and finishing stands allowed for the identification of process variables that improve the accuracy of wear prediction.

Accurate prediction of work roll wear is one of the key components of the hot strip rolling process. Incorrectly calculated wear has different implications for the roughing and finishing stands. Inaccurate calculations of roll wear in the finishing stands leads to erroneous shape setup, as roll bending forces and shifting positions do not satisfy flatness criteria. In the roughing stands, the wear of the work rolls directly affects the transverse thickness distribution of the bar or the bar crown. The presence of excessive crown due to significant roll wear can cause bar width contraction instead of spread in a horizontal roughing pass or in the early finishing stands. In addition, severely worn work rolls on the last roughing stand can cause edge waves on the transfer bar.

Work Roll Wear Model

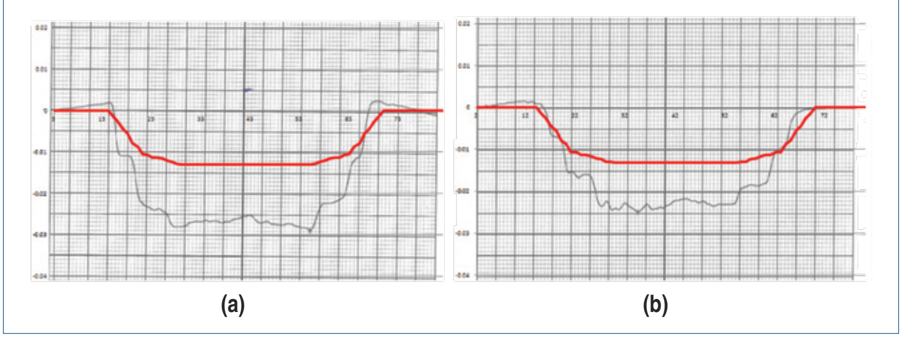
Deficiency of the Existing Model — During the operation of an 80-inch hot strip mill, on certain types of schedules, it was observed that the work roll wear model noticeably underpredicted the wear depth. The difference between the actual and calculated wear was on the order of 35–50%. An example comparing measured and predicted wear is shown in Fig. 1. The largest difference was observed after a rather long rolling schedule consisting of more than 250 bars of heavy-gauge product. Such discrepancy can lead to inadequate roll bending and shifting references, which cause deterioration of strip flatness and crown performance.

The existing wear model is presented by Exp. 1:

$$Wear = wear\_rate \cdot \frac{F}{W} \cdot \frac{h_{T-bar}}{h_{stand}} \cdot \frac{L_{T-bar}}{\pi \cdot D_{stand}} \left[1.0 + k\left(29.0 - D_{stand}\right)\right]$$

(Exp. 1)

Figure 1



Comparison of the measured (black) and predicted (red) work roll wear in stand F5: top roll (a) and bottom roll (b).

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where

F = roll force,
W = bar width,
$h_{T\text{-}bar}$ and h_{stand} = transfer bar thickness and exit thickness from the stand, respectively,
$L_{T\text{-}bar}$ = transfer bar length,
k = tuning coefficient and
D_{stand} = work roll diameter.

The model (Exp. 1) has been in service for a number of years. Nevertheless, due to the continuous endeavor to produce the highest quality hot bands and to maximize usable roll life, the aforementioned prediction deficiency had to be eliminated.

Improvement of the Existing Model — Process data from various mill schedules, which included different numbers of slabs of various steel grades, widths and hot band gauges, have been collected along with contours of the worn work rolls. The data was analyzed and simulated using an off-line shape and crown simulator (WinRollSim) developed at the U. S. Steel Research and Technology Center.[1] Besides the variables listed in Exp. 1, the following parameters were added to the analysis for each rolling stand: roll speed, draft, length of contact between the rolls and the bar, elongation, and strip temperature. As mentioned earlier, it was noticed that the highest degree of wear prediction error occurred on schedules of heavy-gauge products, which are rolled at a substantially lower speed compared to thin-gauge products. Lower rolling speed leads to longer contact time between a point on the roll surface and the surface of the hot bar in the roll bite, which, in turn, increases the roll surface temperature. As a consequence, it can be assumed that the hardness of the roll surface in contact with the hot bar will be reduced. As a result, wear of the roll will increase.

Contact time between a point on the roll surface and the surface of the hot bar in the roll bite was expressed as shown by Exp. 2:

$$\tau = \frac{l_{contact}}{v_{stand}}$$

(Exp. 2)

where
τ = contact time of a point on the roll surface while moving through the roll bite,
$l_{contact}$ = length of contact between the roll and the bar and
v_{stand} = circumferential speed of the roll.

The effect of contact time was accounted for by including the logarithm of the product of contact time and an empirical time constant into the wear model. A new wear model that is shown by Exp. 3 includes the Brinell hardness of the roll surface adjusted to the roll/strip interface temperature:

$$Wear = \begin{cases} \text{if } \ln(time\_constant \cdot \tau) > 1.0, \\ wear\_rate \cdot \dfrac{F}{W} \cdot \dfrac{h_{T-bar}}{h_{stand}} \cdot \dfrac{L_{T-bar}}{\pi \cdot D_{stand} \cdot HB_T} \cdot \ln(time\_constant \cdot \tau), \\ \text{if } \ln(time\_constant \cdot \tau) \le 1.0, \\ wear\_rate \cdot \dfrac{F}{W} \cdot \dfrac{h_{T-bar}}{h_{stand}} \cdot \dfrac{L_{T-bar}}{\pi \cdot D_{stand} \cdot HB_T}. \end{cases}$$

(Exp. 3)

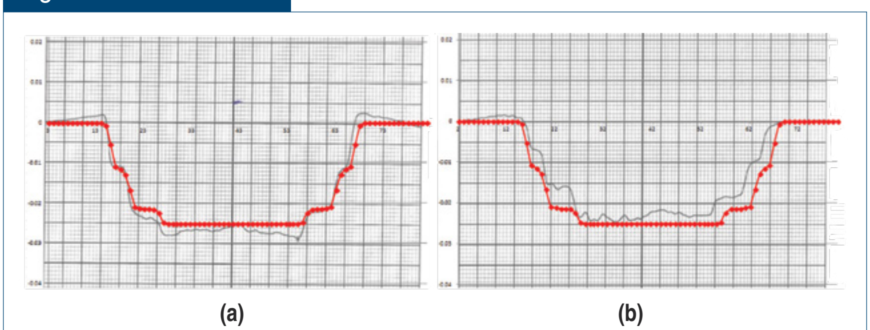
where HB_T is the Brinell hardness of the roll surface adjusted to the roll/strip interface temperature.

Exp. 3 accounts for an increase of roll wear when the logarithm of the product of contact time and the time constant exceeds unity. Practically, this is always the case, though the most significant effect is observed for heavy-gauge schedules. An example of improved agreement between the measured and predicted wear after using the new model (Exp. 3) is shown in Fig. 2.

Effect of the Bar Crown on the Width Change — The growth of bar crown is associated with roll wear developing during the rolling campaign. Results of an industrial study,[2] shown in Fig. 3, reveal the magnitude of the slab crown or roll wear impact upon slab width contraction. The total measured width reduction due to non-uniform deformation was 0.39 to 0.43 inch.

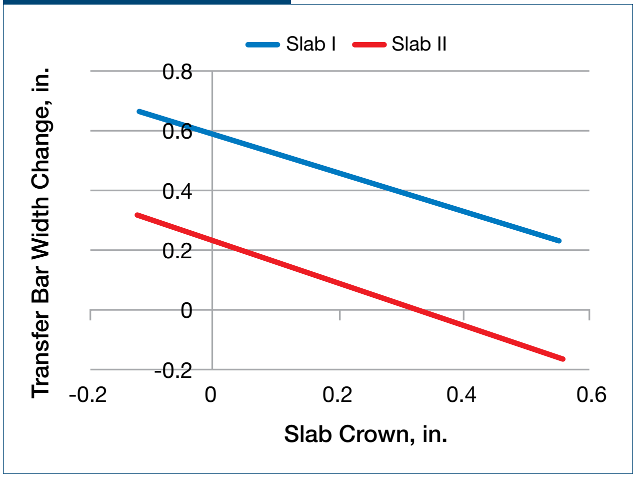
Similar results were reported[3] after studying the influence of work roll wear in the last roughing stand on the degree of width contraction in the first and second finishing stands of a 67-inch hot strip mill (Fig. 4).

Figure 2



Comparison of the measured (black) and predicted (red) work roll wear in stand F5, new model: top roll (a) and bottom roll (b).

Figure 3



Transfer bar width change due to initial slab crowning caused by roll wear (adapted from Reference 2).

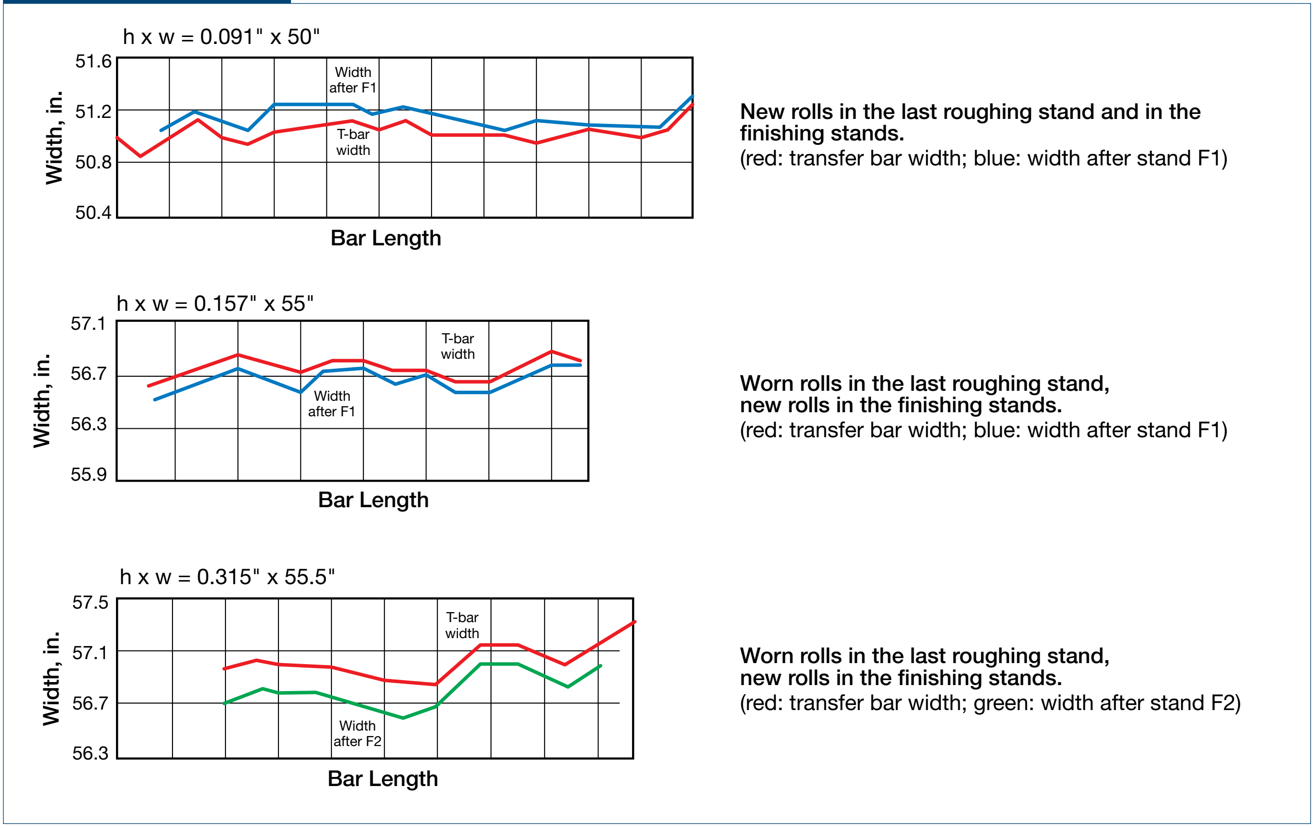
When freshly ground work rolls were used in the last roughing stand, a positive width change, or spread, occurred in the first and second finishing stands. Conversely, when these rolls developed considerable wear at the end of their campaign, an accumulated contraction of 0.12 to 0.24 inch was observed after rolling in finishing stands 1 and 2.

Besides the adverse impact on the width change, excessive transfer bar crown can result in unstable rolling under certain conditions. A piece of cobbled transfer bar with 1-inch thickness is shown in Fig. 5. The bar was partially rolled in stand F1 (left half of the picture) before the cobble occurred. Due to highly non-uniform elongation across the width, and particularly at the centerline, the transfer bar buckled in front of stand F1, resulting in the buckled shape, and was then rolled in. The cobble occurred because the transfer bar crown was excessively high, and this was a result of excessive wear on the roughing stand work rolls at the end of their campaign.

Furthermore, severely worn work rolls of the last roughing stand can cause edge waves on the transfer bar. In order to address the issue, a shape setup model can be enhanced by treating the last roughing stand, for example stand R5, as an "additional upstream finishing stand F0," as shown in Fig. 6.

This provides consistency in calculations of the roll stack deflection and wear of the work rolls in stands F0 to F7. It also allows for the increased accuracy of the transfer bar crown prediction.

Figure 4



Width contraction in the finishing stands of 67-inch hot strip mill (adapted from Reference 3).

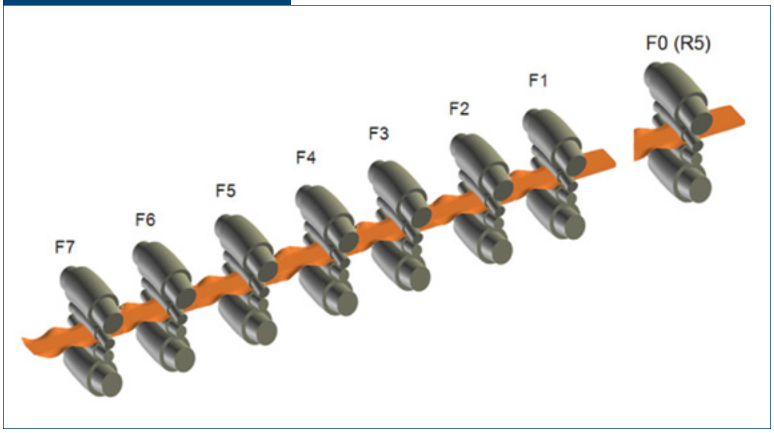
Figure 5

Cobbled transfer bar in the first finishing stand.

In order to prove the concept, simulations were conducted to evaluate how work roll wear at the last roughing stand affects the crown of the transfer bars of various widths. The last roughing stand was included in a shape setup model as stand F0. Wear of the work rolls in stand F0 was simulated for one week of service time in the mill. The work rolls had an initial ground crown of +0.005 inch. Fig. 7 provides an illustration of the effect of the roll wear for the two bar widths, i.e., 40 inches and 70 inches.

Simulation results confirmed the significant impact of roll wear on the transfer bar crown. They also provide insight into the cause of unexpected shrinkage of bar width in the finishing stands, especially for the wider product. The narrow bar has positive crown after passing between both fresh and worn rolls, although of a noticeably different magnitude, as shown in Fig. 7a. The crown of the wider bar changes considerably from being concave (negative) for fresh rolls as compared to becoming high positive with worn rolls, as shown in Fig. 7b. According to Figs. 3 and 4, one can expect a measurable difference in width change between negatively and positively crowned bars after passing through the stands F1 and F2. A spread model in the finishing stands must be enhanced by allowing for the transfer bar crown effect.

Figure 6



Schematic of the roughing stand treated as an upstream finishing stand.

Conclusions

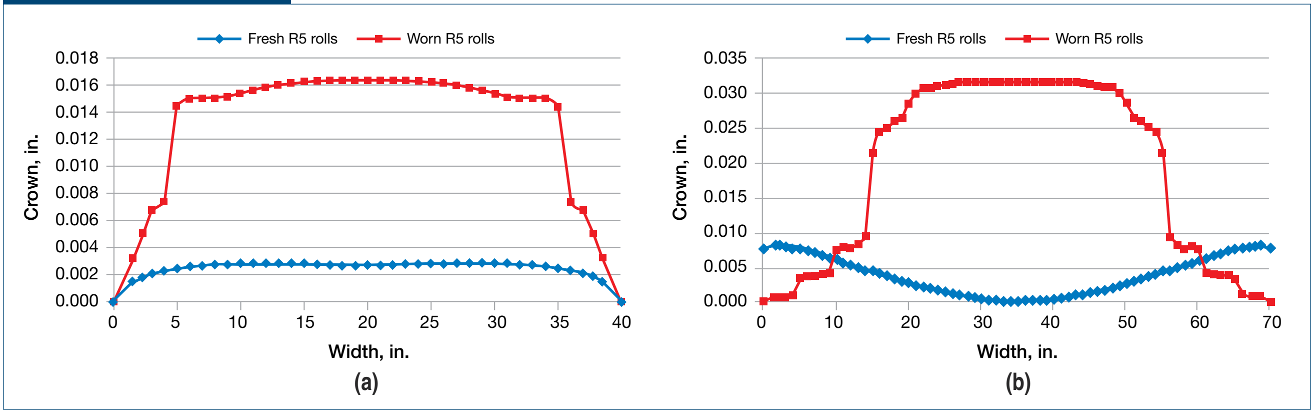
Comparative analysis of the measured and predicted roll wear in the roughing and finishing stands allowed for the identification of a process variable that improved the accuracy of wear prediction.

The work roll wear model accuracy was improved by accounting for the time of the contact between a point of the roll surface and the surface of the hot bar in the roll bite.

Accuracy was improved by 35–50% for the rolling of more than 250 slabs of heavy-gauge product.

In order to improve the prediction of crown on transfer bars, the last roughing

Figure 7



Transfer bar crown simulations for various degree of roll wear: 40-inch-wide transfer bar crown (a) and 70-inch-wide transfer bar crown (b).

stand was added to the shape setup model as an upstream stand F0.

Simulations of the effect of roll wear on transfer bar crown provided insight into the reason for unexpected bar width shrinkage in the finishing stands, especially for wide products.

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