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Thermal Compensation of Work Roll Grinding in Hot Strip Mills

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In this paper, the influence of the residual work roll thermal crown after hot rolling on the work roll grinding process is investigated. A two-dimensional axisymmetric thermal model is employed to simulate the thermal behavior of the work roll during the rolling campaign and the post-rolling cooling process. The governing equation is solved based on an implicit finite volume method. The model parameters are identified based on the evolution of the work roll thermal crown measured in the mill during the cooling period. In order to increase the roll shop productivity, two work roll hot-grinding methods, "without contour compensation" and "with contour compensation", are proposed to eliminate the post-rolling cooling process. According to the on-site demand, experimental trials of the work roll hot-grinding with contour compensation are carried out in the roll shop. Based on the work roll temperature measured prior to the grinding process, the work roll can be ground immediately saving significant labor costs and time. The results indicate that the final profile of the work roll based on the proposed grinding procedure is in agreement with the target profile.

1. INTRODUCTION

In today's highly automated metalworking operations, demands for tighter strip dimensional tolerances increase. One of the major factors to affect the shape of the strip is the profile of the work roll. Since the work roll is worn and fatigued during the hot rolling process, a grinding operation is necessary to restore the required profile of the work roll periodically. However, when the rolling campaign is finished, the work roll surface in contact with the strip is hotter than that outside the width of the strip. The difference in radial expansion along the work roll axis due to the unevenly distributed temperature creates a thermal crown. If the temperature of the work roll is not uniform along the work roll axis during the grinding operation, the ground profile of the work roll will change as time elapses. The variation in the profile of the work roll makes the control of strip shape difficult and leads to an increase in the amount of rolled strip scrapped because of waviness, buckles, or other shape defects. If spacious area is available in the plant, work rolls can be cooled in air until a uniform temperature distribution along the work roll axis is achieved. Water sprays can be used to cool work rolls if a shorter cooling time is desired. However, both methods decrease the roll shop productivity.

In order to increase the efficiency of operations in the roll shop, the purpose of this study is to eliminate the work roll cooling process before the grinding operation. In this paper, a two-dimensional axisymmetric model is first established to simulate the work roll thermal behavior during the rolling campaign and the post-rolling cooling process. The governing equation is solved based on an implicit finite volume method. The model parameters are identified based on the evolution of the work roll thermal crown measured in the mill during the cooling period. Two work roll hot-grinding methods, "without contour compensation" and "with contour compensation", are proposed to improve the roll shop productivity. Finally, the experimental trials are carried out for different types of work roll materials to demonstrate the accuracy of the model.

2. THERMAL MODEL

2.1 Governing Equation

A two-dimensional axisymmetric thermal model was developed to predict the thermal profile of the work rolls during the rolling campaign and the post-rolling cooling process. A global heat transfer coefficient and corresponding temperature were formulated to represent the homogeneous surroundings in a circumferential direction.[1] Along the work roll axis, there are multiple zones to accommodate various strip widths and control cooling zones.[2] The global heat transfer coefficient and corresponding temperature in each axial section are different depending on the contact condition and the application of water sprays.

Due to the symmetry of the roll arrangement, only the top work roll was considered in the model. Assuming that the temperature distribution of the work roll is a function of the radial direction r, the axial direction z, and the time variable t, then the governing equation can be expressed as:

$$\frac{1}{\alpha}\frac{\partial T}{\partial t}=\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2} \quad \text{.................(1)}$$

Here, $\alpha=\dfrac{k}{\rho c}$ is the thermal diffusivity of the work roll, ρ is the density, c is the specific heat, and k is the thermal conductivity.

The temperature of the work roll is assumed to be identical with the ambient air temperature at the beginning of a rolling campaign. In order to solve Eq. (1), appropriate boundary conditions are assumed. The detailed boundary conditions can be found in.[2]

3. NUMERICAL METHOD

The two-dimensional heat transfer equation is solved based on an implicit finite volume method. The work roll is discretized into unit control volumes by computational grids as shown in Fig. 1.

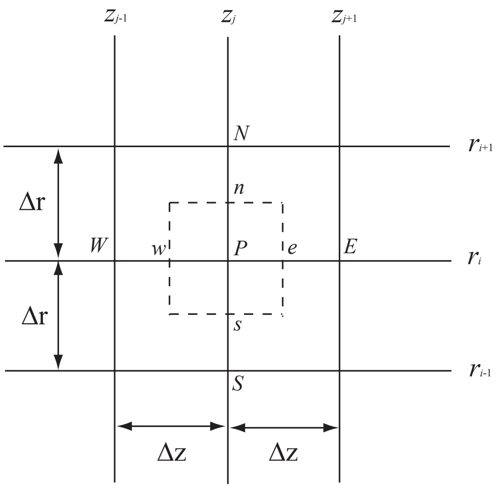

Fig. 1. A control volume element.

The energy balance should be maintained in the control volume:

$$\dot{q}_W+\dot{q}_E+\dot{q}_N+\dot{q}_S=\dot{E}_{ST} \quad \text{..........................(2)}$$

where $\dot{q}_W$, $\dot{q}_E$, $\dot{q}_N$ and $\dot{q}_S$ are the heat flow rates of the four sides of the control volume element, and $\dot{E}_{ST}$ is the energy variation rate stored in the element.

For each control volume, a discretized energy balance equation can be obtained. For the complete system, the discretized equations can be expressed in a matrix form as:

$$\boldsymbol{AX}=\boldsymbol{B} \quad \text{...(3)}$$

where $\boldsymbol{A}$ is the coefficient matrix, $\boldsymbol{X}$ is the current temperature distribution and $\boldsymbol{B}$ is dependent on the temperature distribution at the previous time step.

The current temperature distribution vector $\boldsymbol{X}$ is solved using the LU decomposition method where the coefficient matrix $\boldsymbol{A}$ is decomposed into the lower triangular matrix $\boldsymbol{L}$ and the upper triangular matrix $\boldsymbol{U}$. The detailed calculation procedure is described in.[2]

4. EXPERIMENTS

In order to increase the efficiency of the roll shop operations, two work roll hot-grinding methods, "without contour compensation" and "with contour compensation", were proposed to eliminate the post-rolling cooling process. Experiments were carried out to measure the temperature distributions and the profiles of work rolls as functions of time. A hand held thermometer was used to measure the temperature distributions of work rolls after they were extracted from the hot strip rolling mill. An equipment set, consisting of a movable cart, lever arms, a micrometer and a laser distance detector, was used to measure the profiles of work rolls.

For the work roll hot-grinding without contour compensation, the grinding procedures in the roll shop remain identical, as the work roll is completely cooled. The work roll crown can be predicted as a function of the elapsed time after it is ground. The predicted crown then can be used as the APFC (Automatic Profile and Flatness Control) set-up information. In the experiments, work rolls were ground with the original designed curves after they were extracted from the mill. A series of measurements was carried out to obtain the profile of the work roll until the temperature distribution was uniform along the work roll axis. The temperature measurements were also made along the barrel of the work roll at fixed intervals of 100 mm.

For the work roll hot-grinding with contour compensation, the grinding curve was modified based on the measured surface temperature of the work roll before the grinding operation. After the temperature of the ground work roll cools down to the uniform temperature along the work roll axis, the work roll crown can be achieved as the designed crown. In the experiments, the profiles and temperature distributions of work rolls were first measured before the grinding operation. After the uniform temperature distributions along the work roll axis were achieved, the measurements were carried out again to obtain the work roll profiles.

5. RESULTS

The results of the experiments were used to identify the model parameters. The model reads information from each coil and performs temperature calculations until the end of rolling campaign. The work roll temperature distributions are also calculated during the post-rolling cooling period until the time of thermal profile measurements.

Three types of work rolls are tested in the experiments: high strength steel (HSS) roll, high chromium (Hi Cr) roll, and ICDP roll. Figure 2 shows the prediction errors of thermal crown variations as a function of time for the different types of work roll. The results show that the prediction errors are in general within 10 μm. Note that the thermal crown variations of the HSS rolls and Hi Cr rolls are larger due to the higher work roll temperature for upstream stands, whereas the thermal crown variations of the ICDP rolls are less due to the lower work roll temperature for downstream stands.

For the work roll hot-grinding with contour compensation, the experimental results are summarized in Table 1. The comparison of profiles for the hot roll and cold roll (case HSS Roll 1-1) is also shown in Fig. 3 as an example. In the cold roll measurements, the work rolls were cooled as completely as possible such that the effect of the residual thermal crown can be neglected. In general, the temperature variations were within 2°C along the work roll axis when the measurements were taken. From the table, it can be seen that the crowns of the cold work roll are in general close to the target crowns. Note that during the grinding operation, the application of the grinding lubricant affects the work roll thermal crown. Due to the uncertainties of the work roll surface conditions, a message is recommended to warn the operators if the grinding time exceeds the normal conditions since the effects of the grinding lubricant can be significant.

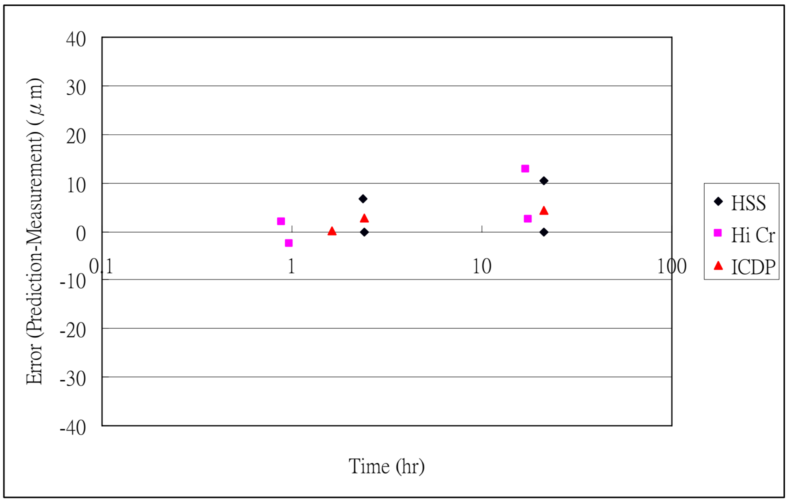

Fig. 2. The prediction errors of thermal crown variations as a function of time for different types of work rolls.

Table 1 The Experimental Results for the Work Roll Hot-Grinding with Contour Compensation

Work Roll Type	Crown (Hot Roll)	Crown (Cold Roll)	Target Crown
HSS Roll 1-1	-0.12 mm	-0.160 mm	-0.17 mm
HSS Roll 1-2	-0.12 mm	-0.165 mm	-0.17 mm
HSS Roll 2-1	0.00 mm	-0.035 mm	-0.06 mm
HSS Roll 2-2	-0.01 mm	-0.032 mm	-0.06 mm
HSS Roll 3-1	-0.04 mm	-0.044 mm	-0.06 mm
HSS Roll 3-2	-0.06 mm	-0.059 mm	-0.06 mm
ICDP Roll 1-1	0.02 mm	0.007 mm	0.00 mm
ICDP Roll 1-2	0.00 mm	-0.008 mm	0.00 mm

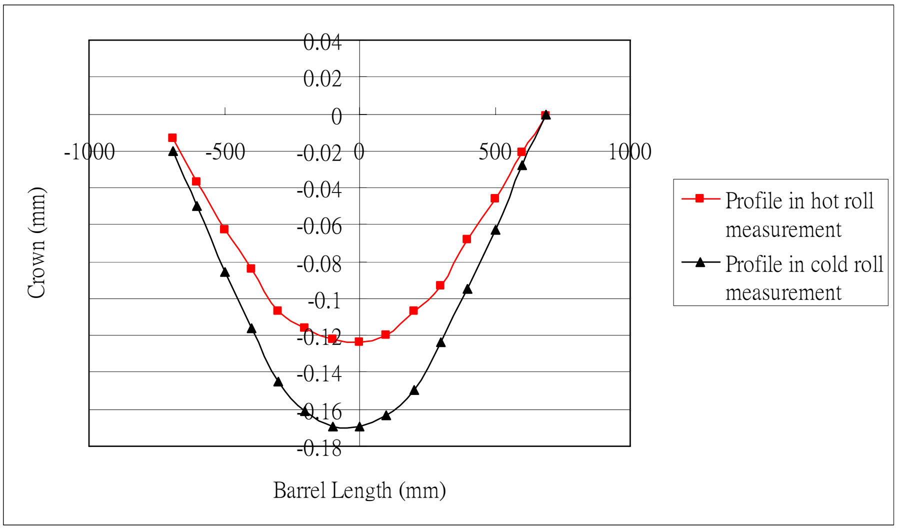

Fig. 3. The comparison of profiles for the hot roll and the cold roll.

6. CONCLUSION

In this paper, the influence of the residual work roll thermal crown after hot rolling on the work roll grinding process is investigated. A two-dimensional axisymmetric thermal model is developed to analyze the effects of the residual work roll thermal crown on the work roll grinding process. The governing equation is solved based on an implicit finite volume method. The accuracy of the model is validated by comparing thermal crowns of work rolls predicted by the model and those measured in the experiments. In order to increase the roll shop productivity, two work roll hot-grinding methods, "without contour compensation" and "with contour compensation", are proposed to eliminate the post-rolling cooling process. Comparisons between the profiles of the work rolls ground without the cooling process and the target profiles are in agreement. The results indicate that the model is reliable in evaluating the work roll thermal crown without significant errors. Based on the work roll temperature measured prior to the grinding process, the work roll can be ground immediately saving significant labor costs and time.

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