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3차원 유한요소법을 이용한 열연중 판 및 롤의 열적/기계적 거동 해석

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Precise Prediction of 3D Thermo-mechanical Behavior of Roll - Strip System in Hot Strip Rolling by Finite Element Method

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Abstract

A finite element-based, integrated process model is presented for a three dimensional, coupled analysis of the thermo-mechanical behavior of the strip and work roll in the continuous hot strip rolling. The validity of the proposed model is examined through comparison with measurements. The effect of Edge-Heater on the finishing delivery temperatures is examined by using the present model. The models capability of revealing the effect of diverse process parameters is demonstrated through a series of process simulation.

Key words : Finite Element, Integrated Process Model, Three Dimensional, Thermo-Mechanical Behavior, Hot Strip Rolling

1. Introduction

In hot strip rolling, a hot slab is passed through the roll gap several times, with its thickness being progressively reduced to achieve the final dimensions. The primary goals to be met by process design and control may vary depending upon the need of manufacturers and customers, however, unprecedented considerations are being given to precise control of the product quality as well as enhancing the production economy in most modern rolling practices. Product quality and production economy greatly depend on the thermo-mechanical behaviors of roll-strip systems during rolling, and, therefore, in order to achieve successful process design and control, it is highly desired to be capable of predicting the detailed aspects of these behaviors through sound process modeling.

Modeling for the precise prediction of such behaviors, however, is a difficult task, due to strong interaction among the thermal and mechanical

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behavior, and also due to the three dimensional nature of the problem. As a result, most of the modeling efforts were concentrated either on revealing only

metal flow in the roll gap [1,2], or on assessing the coupled behavior but in two dimensional analysis [3,4]. Recently, some researches began to conduct three dimensional behavior, but related works [5] were mostly limited to one single mill stand. As it is well known, in industry hot finishing rolling, the strip is continuously passing through at least seven stands, therefore, deformation behavior of strip is much dependent on the temperature history.

Described in this paper is a full three dimensional, coupled, Eulerian FE model for the precise prediction of thermo-mechanical behavior of roll-strip system in continues hot strip rolling. Validity of the proposed model is examined through comparison with measurements. Then, a series of process simulation is conducted to demonstrate the models capability of reflecting the effect of Edge-Heater (residing before first rolling stand to reduce the temperature drop in the strip edge zone) on FDT (finishing delivery temperatures).

2. Finite Element Models

An integrated FE process model employed for the present investigation consists of three basic FE models a model for the analysis of 3-D thermo-viscoplastic deformation of the strip (Model A), a model for the analysis of 3-D steady state thermal behavior of the strip (Model B), and a model for the analysis of 3-D steady state thermal behavior of the work roll (Model C). As shown in Fig. 1, interaction between the thermal behavior of the work roll and that of the strip due to roll-strip contact as well as the interaction between the thermal behavior and the mechanical behavior of the strip were taken into account by an iterative solution scheme.

The heat transfer coefficient at the roll-strip interface used in conjunction with the present FE process model was an empirical equation derived by Hlady et al [6]:

$$h_{\text{lub}} = \frac{k}{C}\left(\frac{P_r}{\bar{\sigma}_s}\right)^{1.7} \tag{1}$$

$$k = \frac{k_r k_s}{k_r + k_s} \tag{2}$$

where $C = 35 \times 10^{-3}\, mm$, k_r and k_s are the thermal conductivity of the roll and that of the strip, respectively, P_r is the mean roll pressure, and $\bar{\sigma}_s$ is the mean flow stress in the skin of the strip at the bite region. Due to the dependency of the interface heat transfer coefficient on the thermo-mechanical behavior, an additional iteration loop was required, as shown in Fig. 1.

Details regarding Model A may be found in the reference[4]. Model B and Model C were developed based on the models for the analysis of the steady-state thermal behavior, which were also described in the reference[4]

3. Results and Discussions

Investigated was the thermal and mechanical behavior of the strip and work roll during rolling in the finishing mill in POSCO no. 2 hot strip mill, Pohang works. The finishing mill consists of seven mill stands (from F1 to F7) in straight line with a 5.8m space between the two consecutive stands, the distance between the exit of last finishing stand (F7) and the position measuring FDT is 4.2 m, and Edge-Heater is located about 18.0 m before entering first finishing stand.

It was assumed that air cooling was the main factor in all zones except the stage when strip passing through roll gap. Computation procedure may start with the steady state thermal behavior of strip before entering F1 stand, then subsequent interchange between the thermo-mechanical analysis of roll-strip system in roll gap and thermal behavior of strip in the inter stands, and thermal behavior of strip between the exit of F7 stand and the position measuring FDT. The present strategy of successive computation has a definitive advantage of substantially reducing the computation time required compared to employing the entire finishing zone as the analysis domain.

(a) *Strip temperatures during rolling*

Fig. [2] shows the finite element meshes for the roll and strip selected for the three dimensional analysis of the steady state thermo-mechanical behavior of the roll-strip system. Note that the mesh density distributions adopted for the roll were non-uniform, to take into account the occurrence of relatively large temperature gradients at the bite region and higher mesh density was adopted for the strip edge to examine the Edge-Heater effect. The surface temperature of strip before entering Edge-Heater was measured and shown in Fig. [3]. Because strip undergoes edge rolling during roughing stands, as a result, the high plastic deformation would occur at some distance from the strip edge, implying a temperature up at the distance about 100 mm from the strip edge. For comparison, simulation was conducted to verify the accuracy of the present model. Fig. [4] described the surface temperatures of strip at the moment entering and leaving the F1 stand. During rolling, the hot strip undergoes the contact with chill work roll, inevitably resulting much drop of strip surface temperature. Shown in Fig. [5] was the comparison of FDT surface temperature between the prediction and measurement and a good agreement was observed.

(b) *Effect of Edge-Heater on FDT*

Strip temperature is one of most important factors in hot strip rolling, not only because flow stress is strongly dependent on temperature, but also because the metallurgical behavior of the strip is highly affected by the history of temperature. As a result, precise evaluation and control of strip temperature are of great interest to researcher and engineer. Recently, Edge-Heater was used in such purpose to reduce the edge drop of strip temperature by heating strip edge. It looks like an inverse C in the cross section, focusing on covering about 50 mm in width from strip edge. It was assumed that uniform heat flux was conducted to the covering space in the present simulation.

Described in Fig. [6] was the effect of Edge-Heater on FET (finishing entering temperature). The surface temperature at the position about 25 mm from strip edge was the target temperature for the examination of the effect of Edge-Heater. Considering the target temperature was normally increased for 50 ~ 60 oC in the field when comparing to ignoring use of Edge-Heater, the heat flux for the normal case was approximately estimated as 4.0 W/mm2oC. It was found that the target temperatures were increased as the increase of heat flux. It should be mentioned that though the strip surface temperature may show edge up after passing through Edge-Heater, since the inner temperature was almost less heated in the strip edge, strip surface temperature consequently still showed the edge drop after the subsequent air cooling before entering F1 stand. Fig. [7] showed the effect of Edge-Heater on FDT. For the normal case, the target temperature was increased as about 16 oC when comparing to no use of Edge-Heater.

As far as FDT target temperature and Edge-Heater are concerned, a quantitative relationship would be obtained, as illustrated in Fig. [8]. Case 2 in the figure is the application in hot rolling for a larger final delivery thickness. A linear relation was observed for both the two cases. It should be noted that thermal resistance for strip with smaller thickness is lower than for that with larger thickness, which means heat recovery for strip with smaller thickness is faster than for that with larger thickness. Consequently, the effect of Edge-Heater is less for strip with smaller thickness. Such relationship would be a great help for the guide in the proper use of Edge-Heater.

4. Concluding Remarks

An integrated finite element-based model was developed for the precise prediction of the three dimensional thermo-mechanical behavior of roll-strip system in hot strip rolling. Capability of the model to reveal the detailed aspects of the three dimensional strip temperatures was demonstrated through the present investigation. Consequently, from a series of process simulation, a simple relationship was derived for the effect of Edge-Heater on strip temperatures.

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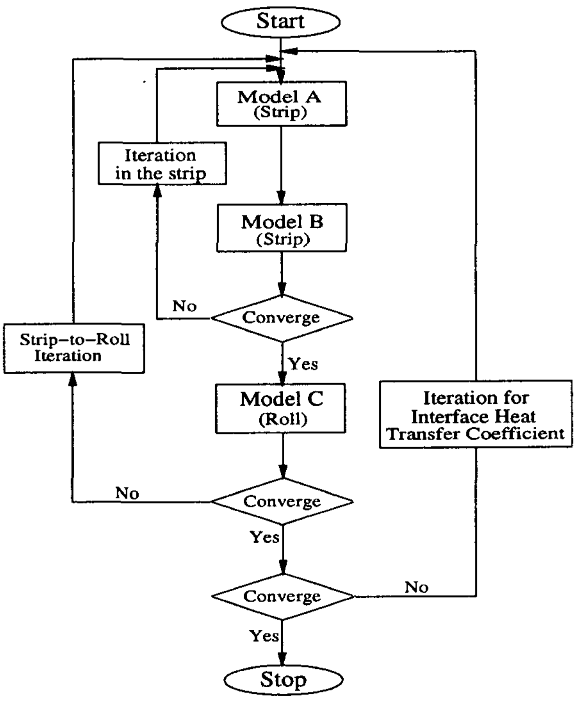

Model A : Analysis of plastic deformation of the strip
Model B : Analysis of steady state thermal behavior in the strip
Model C : Analysis of steady state thermal behavior in the roll

Fig. 1 An integrated FE process model

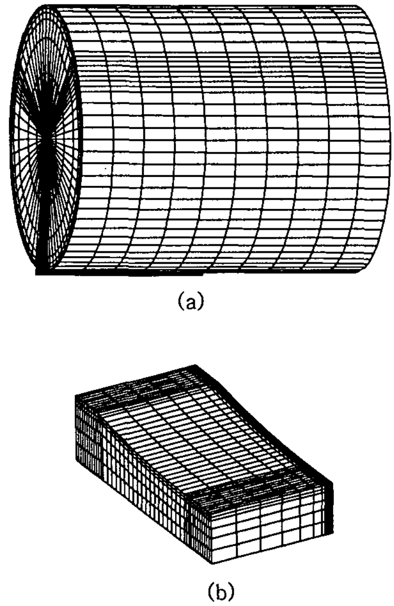

Fig. 2 Finite element meshes (a) for the work roll, (b) Finite element mesh for the strip

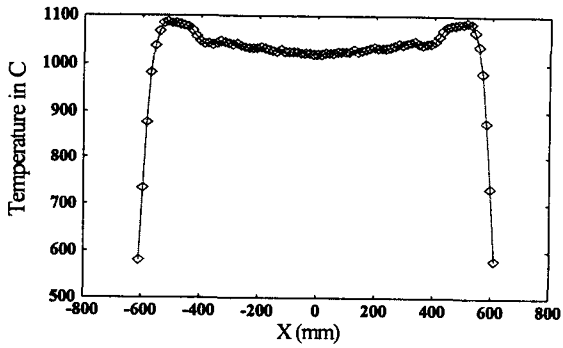

Fig. 3 Measured strip surface temperature before entering Edge-Heater

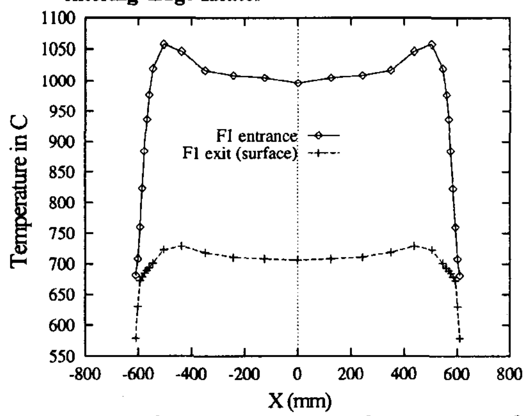

Fig. 4 Strip surface temperatures at the entrance and exit of F1 stand

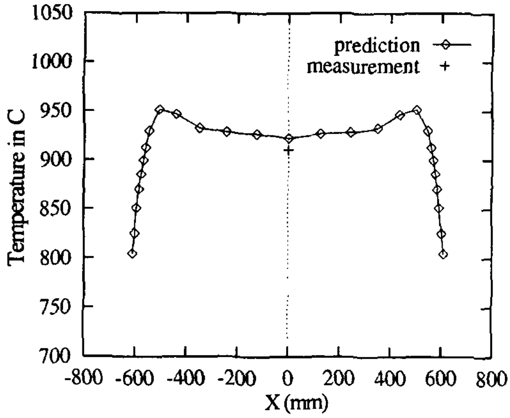

Fig. 5 Comparison of FDT between prediction and measurement

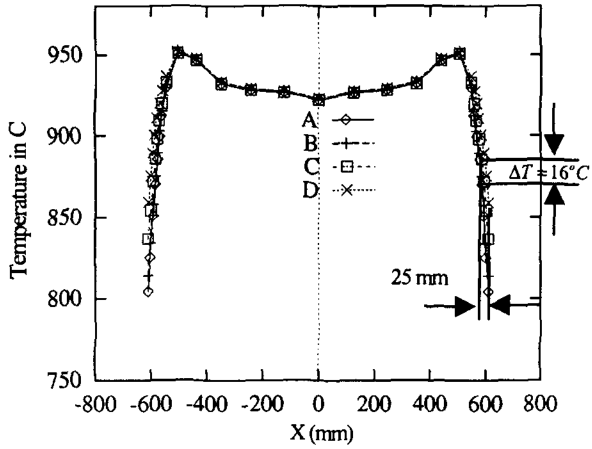

Fig. 7 Effect of Edge-Heater on FDT

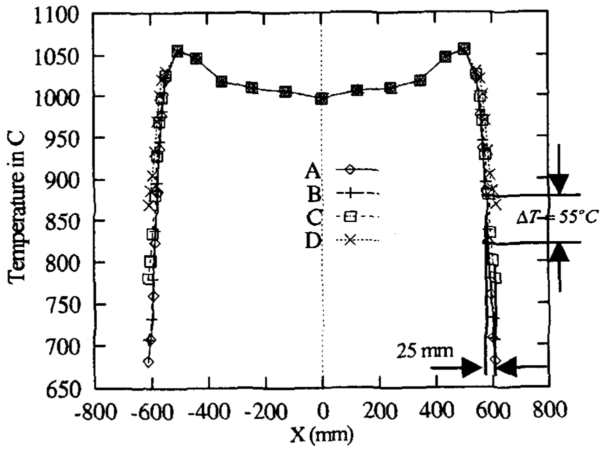

Fig. 6 Effect of Edge-Heater on FET

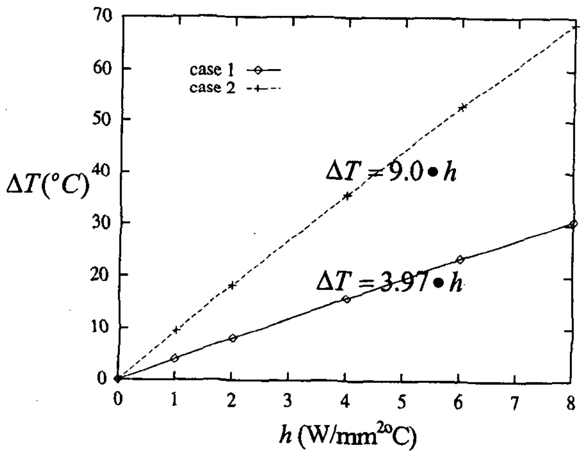

Fig. 8 Effect of heat flux on FDT target temperature