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Analysis of Non-uniform Mechanical Behavior for a Continuous Casting Mold Based on Heat Flux from Inverse Problem

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Abstract: The distortion of mold plates plays an important role in the formation of surface cracks on continuously cast steel products. To investigate the non-uniform distortion of a mold, a full-scale stress model of the mold was developed. An inverse algorithm was applied to calculate the heat flux using the temperatures measured by the thermocouples buried inside the mold plates. Based on this, a full-scale, finite-element stress model, including four copper plates, a nickel layer and water slots in different depths, was built to determine the complex mechanical behavior of the continuous casting mold used to produce steel slabs. The heat flux calculated by the inverse algorithm was applied to the stress model to analyze the non-uniform mechanical behavior. The results showed that the stress and distortion distributions of the four copper plates were not symmetrical, which reflected the non-uniform distortion behaviors of copper plates, water slots, nickel layer and the corner region of the mold. The gap between the mold and the slab was increased because of the corner distortion, which was very important for the heat transfer of initial solidifying shell, and it may be a major reason for the slow cooling of the slab corner.

Key words: finite-element stress model; inverse algorithm; nickel layer; water slots; continuous casting mold

The heat transfer and mechanical behaviors inside a mold are very important factors for maintaining the stable operation of casting and slab quality. The distortion of the mold has a serious effect on slag infiltration, gap distribution and contact status between the slab and the mold. Many mathematical models describing the thermomechanical behavior of the strand and mold have been proposed and used in recent years. O′Conner and Dantzig[1] developed an elastic-plastic-creep finite-element model to predict temperature, distortion and stress in a funnel-shaped mold for producing thin slabs. Thomas[2] built two-dimensional (2D) and three-dimensional (3D) models to predict temperature, distortion and residual stress in a continuous casting mold used to produce steel slabs. Luo et al.[3,4] proposed a model for the design of water slots, which included calculations for the temperature, stress, and fatigue life of a mold. Park et al.[5] built a 3D finite-element model to investigate the stress, strain and distortion of the mold during thin slab casting. Janik et al.[6] used the finite-element method to investigate the thermomechanical behavior of steel billet in a continuous casting mold. Zhan et al.[7] analyzed the real heat flux of continuous casting billet and discussed the influence of various factors on the heat flux. Zhu et al.[8,9] developed a 3D finite-element model to predict the stress and distortion of the mold and shell under different conditions and they determined the effect of the copper plate parameters on distributions of temperature and distortion in detail. Yin et al.[10] calculated the mold distortion, shell thickness and gap size by inversely calculating the thermal resistance between the mold and the billet. Xie and Yin[11] focused mainly on the thermal stress analysis and conducted experiments to validate the model. Wang et al.[12] investigated the thermal and mechanical behavior of the solidifying shell using a finite-element model.

Until now, most of the models previously de-

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veloped were symmetrical, and the heat flux between the strand and the mold was obtained from an empirical equation that ignored the complex and non-uniform heat transfer in the mold, leading to the uniform distributions of temperature, solidification, distortion and other symmetrical results. However, the thermomechanical behavior of each copper plate is non-uniform and it plays an important role in the surface defects. Therefore, it is necessary to know the conditions of thermal and mechanical behaviors inside the mold in order to reveal the relationship between the non-uniform behaviors and the slab surface cracks. In this work, a full finite-element model of the mold, including the four copper plates, nickel layer and water slots in different depths, was developed to reflect the non-uniform thermal behavior in the mold. In the model, the inverse algorithm was applied to calculate the real heat flux and this was verified using experimental temperature data[13]. Based on this, a stress model was further devised to reveal the real mechanical behavior of the mold during continuous casting. In this way, a fresh insight has been gained into the non-uniform mechanical behavior of the mold.

1 Experimental

The experiment was conducted on a curved caster with radius of 10.75 m and metallurgical length of 28.8 m, which cast a slab with width varying from 1800 to 2700 mm and thickness of 320 mm at a casting speed of 0.65 m/min. The mold was oscillated in a non-sinusoidal mode with a stroke length varying from 2 to 6 mm and an oscillation frequency varying from 1 to 5 Hz. Further details of the caster are shown in Table 1. The main compositions of the steel used are shown in Table 2.

To obtain the mold temperatures, three rows of thermocouples were buried inside the mold wall at 210 mm, 325 mm and 445 mm from the top of the mold. The wide face contained six columns of thermocouples, and the narrow face contained one column of thermocouples. Therefore, a total of 42 thermocouples were symmetrically buried in the four mold plates, 18 for each wide face and 3 for each narrow face. The arrangements of the thermocouples were the same at the inside radius and outside radius, but the distances from the thermocouple tip to the hot surface were different, 24 mm for the outside radius and 14 mm for the inside radius.

Table 1 Main design details of the caster

Item	Value or type
Machine type	Curved, 10.75 m in radius
Metallurgical length/m	28.8
Mold oscillation	Non-sinusoidal
Oscillation stroke/mm	2—6
Oscillation frequency/Hz	1—5
Lubrication	Powder
Mold flux feeding	Manual
Mold level sensor	Radioactive sensor

Table 2 Compositions of the steel mass%

C	Mn	Si	P	S	Cr	Cu	Sn	Ni
0.145	1.2	0.25	0.018	0.0036	0.032	0.0578	0.01	0.0195

2 Mathematical Description

2.1 Finite-element heat transfer model

A finite element model was developed in this work by considering the water slots and nickel layer, as shown in Fig. 1. The width of all water slots is 5 mm, while the water slot depth of the inside radius face differs from those of the outside radius and narrow faces. The water slots begin at 25 mm below the mold top and extend to 25 mm above the mold bottom along the casting direction.

Following assumptions were made:

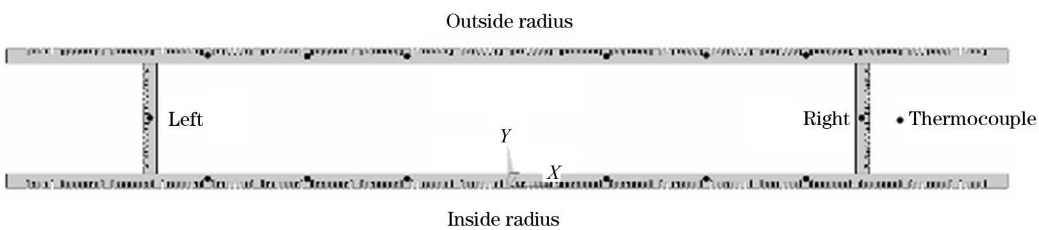

Fig. 1 Schematic diagram of model