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STUDY ON THE INFLUENCE OF GROOVE MOLD ON THE CHARACTER OF CASTING

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The thermal stress coupling calculation model of initial shell in groove mold is established for temperature field and stress field calculation. The calculated results show that groove mold can improve heat transfer of casting initial shell and form peaks and valleys of temperature and stress, and the whole curve corresponding to overall number of grooves. The surface temperature of initial shell increase with the width of grooves increase, the non-uniformity of initial shell surface temperature and stress also increases. The surface temperature of initial shell decrease with the space of grooves increase, the non-uniformity of surface temperature and surface stress of initial shell increases. Groove depth has a little influence on heat transfer of initial shell surface.

Key words: casting, groove mold, mathematical model, surface temperature, surface stress

INTRODUCTION

Uneven heat transfer of continuous casting shell brings about the non-uniformity of initial shell thickness, which leads to tensile stress on the initial shell surface, when the tensile stress exceeds critical strength then initial shell crack. Most cracks on the initial shell surface originated from the non-uniformity of initial shell thickness, if the heat transfer of initial shell and the uniformity of initial shell thickness can be improved then the production of surface crack on a continuous casting slab can be reduced [1-3].

The studies on the influence of the mold surface roughness to the solidification of molten steel from KoBan Hisao etc. show that the shell thickness formed in the rough inner surface mold is more uniform than that in smooth inner surface one, this can help to improve the surface quality of the shell [4]. The studies on the effect of thermal diffusion from the mold surface shape of liquid steel initial solidification from Masafumi Miyazaki etc. show that the heat diffusion of initial shell can be effected within 0,2 – 0,5 mm roughness to improve microstructure of shell and lead to more even close [5]. Nakai Ken, etc. has made longitudinal grooves on the mold inner surface, so as to improve the initial shell heat transfer to reduce the temperature gradient and generation of crack [6]. In the process of forming an initial shell, the solidification shrinkage lead to the air gap, it results in an uneven heat transfer and makes the shell thickness not uniform.

Scoring grooves in the surface of slab mold can change the large uneven air gap on the shell of plate mold within the whole section into smaller uneven air gap on the shell of groove mold within the one groove, so as to make the non-uniformity of the whole initial shell section reduce. The calculation of mathematical model and the experimental results show that: the groove mold can improve its initial shell heat transfer, compared with the plate mold, the non-uniformity of initial shell surface temperature reduce significantly, the shell surface stress and slab surface cracks also reduces.

In order to further study the influence on groove mold parameters for the character of slab surface, the thermal calculation model of initial shell in groove mold is established to study on the effects of groove width, space and depth of temperature field and stress field.

MATHEMATICAL MODEL

The heat transfer equation and assumptions

The basic equation for heat transfer used in the following calculation is:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) \tag{1}$$

Where T is the temperature / °C,and ρ is the density of the liquid steel / kg/m^3, and λ is the thermal conductivity / W / (m·°C), and c is the heat capacity / J/ (kg·K).

Stress control model is made from the elastoplastic model provided by procast database.

Interface heat transfer calculation equation and other heat transfer parameters :

The equation for heat flux between liquid steel and mold in the contact area without gap is:

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$$q_1 = h_1 \times (T_{st} - T_{cu}) \quad (2)$$

where q_1 is the heat flux between liquid steel and mold / W/m^2, and T st is the temperature of liquid steel /°C, T_{cu} is the temperature of the mold copper plate/°C, h_1 is described in the follow equation:

$$\frac{1}{h1} = \frac{1}{h_{st\text{-}slag}} \quad \frac{1}{h_{slag}} \quad \frac{1}{h_{slag\text{-}cu}} \quad (3)$$

Where h_1 is the integrated heat transfer coefficient between the molten steel and the copper plate of the mold / W/(m^2·°C), $h_{st\text{-}slag}$ is heat transfer coefficient of steel contact with casting powder / W/(m^2·°C),and h_{slag} is the quivalent of heat transfer coefficient for casting powder / W/(m^2·°C); $h_{slag\text{-}cu}$ is the heat transfer coefficient of casting powder contact with copper plate of the mold/ W/(m^2·°C);

The equation for heat flux of air gap formed from shell's shrinkage is:

$$q_2 = \frac{\lambda_1}{\delta_1} \times (T_{st} - T_{cu}) + \varepsilon \times Cb \times \left[\left(\frac{T_{st}}{100} \right)^4 - \left(\frac{T_{cu}}{100} \right)^4 \right] \quad (4)$$

Where q_2 is the heat flux of air gap formed from shell's shrinkage / W/m^2, and $\lambda_1$is the air thermal conductivity / W/(m·°C), δ_1 is the air gap thickness / m, C_b is the blackbody radiation coefficient / 5,68W/(m^2·K^4), ε is the exterior blackness.

The equation for the heat transfer flux density of cooling water outside copper plate of the mold is:

$$q_3 = h_2 \times (T_{cu} - T_{wa}) \quad (5)$$

where q_3 is the heat transfer flux density of cooling water outside copper plate of the mold / W/m^2,and T wa is the cooling water temperature / °C, h_2 is the equivalent heat transfer coefficient of water cooling is:

$$h_2 = 0{,}023 \times \frac{\lambda_2}{D} \times \left(\frac{\rho_1 v D}{\mu} \right)^{0,8} \times \left(\frac{C\mu}{\lambda} \right)^{0,4} \quad (6)$$

Where λ_2 is the thermal conductivity of water / W/(m·°C), and D is the equivalent diameter of water seam, m, ρ_1 is the density of water, kg/m^3; v is the flow rate of cooling water, m/s, μ is the dynamic viscosity of water / Pa·s; C is the specific heat of water, J/ (kg · K).

The heat flow, density of heat transfer processes in groove is:

It is assumed that only heat transfer and radiation heat transfer exist inside the fine groove, the equation for the heat flow inside the groove should be:

$$q_c = \frac{\lambda_1}{\delta_2} \times (T_{st} - T_{cu}) + \varepsilon \times Cb \times \left[\left(\frac{T_{st}}{100} \right)^4 - \left(\frac{T_{cu}}{100} \right)^4 \right] \quad (7)$$

Where q_c is the heat transfer flux of water cooling outside copper plate of the mold/W/m^2;and δ_2 is the depth of the groove/ m.

In this simulation, two-dimensional slices and travelling pattern are adopted, in addition, based on symmetry of this model and a quarter of the slab mold to calculate.

Considering the effect of continuous casting molten steel flow on heat transfer, it is assumed that the thermal conductivity for liquid thermal is 5 times than that of conductivity for absolute.

Groove parameters

The liquidus temperature of simulated low carbon steel is 1 514 °C and solidus temperature is 1 274 °C.

It is based on a match on the results experimented and calculated for the initial shell of groove mold, that the temperature field and stress field of the initial shell of 120 mm × 1 000 mm slab has been calculated. Calculation conditions: Casting speed is 1,2 m / min, the grave space is 0,2 mm, the depth of the groove is 0,5 mm, the width of the groove is from 0,1 mm to 0,9 mm; the width of the groove is 0,5 mm, the depth of the groove is 0,5 mm, the grave space is from 0,6 mm to 1,0 mm; the groove space is 0,7 mm, the width of the groove is 0,5 mm, the depth of the groove is respectively to 0,5 mm, 2,0 mm.

THE ANALYSIS OF CALCULATION RESULTS

The influence of groove width

The proportion of mold surface air gaps increase with the groove width wider, and the heat transfer flux reduce, and forming initial shell is later, the initial shell surface temperature of wider groove width is higher at the same time. At the beginning of 7s the temperature distribution of the initial shell surface with different groove width is shown in Figure 1, referring to Figure 1, the initial shell surface temperature of 0,1 mm groove width is 44 °C lower than that of the 0,3 mm width, etc. The non-uniformity of the initial shell surface temperature increase with the groove width wider, 0,1 mm groove width of the initial shell surface temperature is an approximation to a straight line, the wave of temperature curve almost can't be seen. When the groove width is over 0,3 mm, the initial shell surface temperature is in wave shape, and the temperature peaks are corresponding to the groove cent-

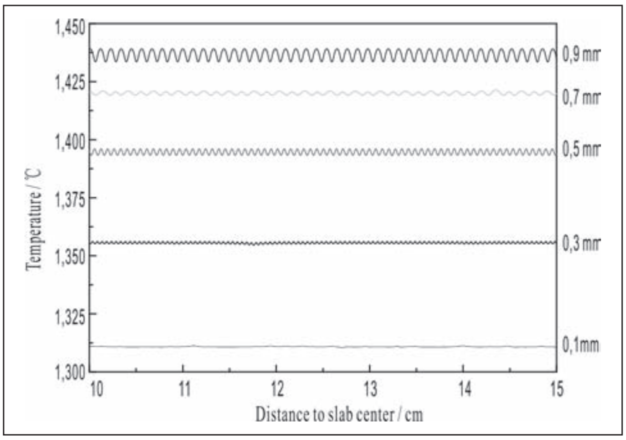

Figure 1 The temperature distribution of the initial shell surface at 7 s with different groove width

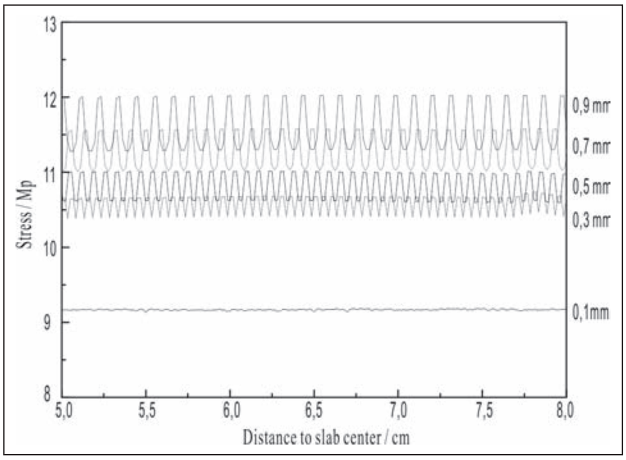

Figure 2 The stress distribution of the initial shell surface at the thickness of 0,1mm with different groove width

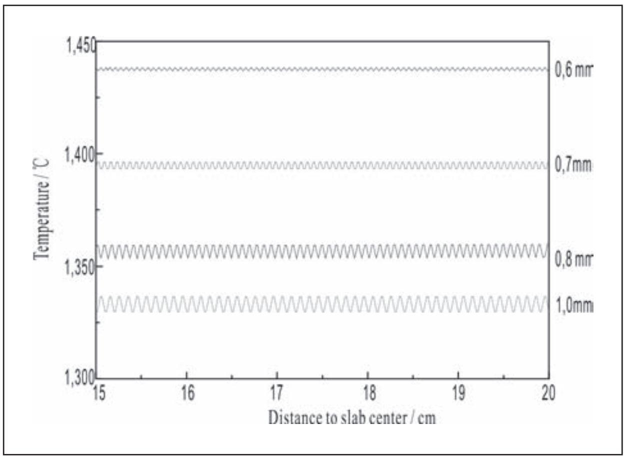

Figure 3 The temperature distribution of the initial shell surface at 7 s with different groove space

ers, the temperature troughs are corresponding to the convex platform centers between the adjacent grooves. The range of the initial shell surface temperature for 0,3 mm groove width is 1,62 °C. The range of oher width is from 2,91 °C to 5,79 °C.

Similar to the temperature distribution, the stress of initial shell surface increase with the increase of groove width. At the initial shell thickness of 0,1 mm, the stress distribution of the initial shell surface with different groove width is shown in Figure 2, referring to Figure 2, the initial shell surface stress of 0,1 mm groove width is 1,4 Mp lower than that of the 0,3 mm width, etc. The non-uniformity of the initial shell surface stress increase with the groove width wider. The range of the initial shell surface streets for 0,1 mm width groove is so smaller that is only 0,02 Mp. When the width of the groove is over 0,3 mm, the initial shell surface stress is also in wave shape, and the stress troughs are corresponding to the groove centers, the stress peaks are corresponding to the convex platform centers between the adjacent grooves. The range of the initial shell surface stress for 0,3 mm groove width is 0,26 Mp. The other kind of groove width is from 0,39 Mp to 0,73 Mp.

The influence of groove space

The proportion of mold surface air gaps increase with the grave space, reduce that is same as the groove width wider, so the heat transfer flux reduce, and forming initial shell is also later, the surface temperature of initial shell is higher at the same time. At the beginning of 7s the temperature distribution of the initial shell surface with different groove space is shown in Figure 3, referring to Figure 3, the surface temperature of the initial shell of 0,6 mm groove space is 43 °C higher than that of the 0,7 mm space ,etc. The non-uniformity of initial shell surface temperature increases with groove space wide. The range of the initial shell surface temperature for different space is from 1,19 °C to 6,9 °C.

The initial shell surface stress increase with groove space wider. At the initial shell thickness of 0,1 mm, the

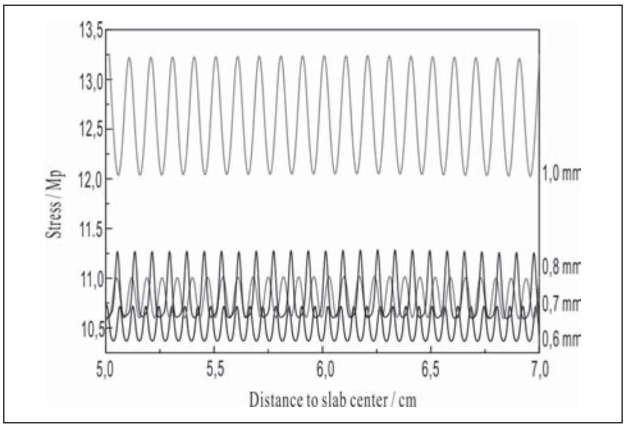

Figure 4 The stress distribution of the initial shell surface at the thickness of 0,1mm with different groove space

stress distribution of the initial shell surface with different groove space is shown in Figure 4, referring to Figure 4, the initial shell surface stress of 0,6 mm groove space is 0,23 Mp lower than that of the 0,7 mm space, etc. The initial shell surface stress is in wave shape, and the stress troughs are corresponding to the groove centers, the stress peaks are corresponding to the convex platform centers between the adjacent grooves. The non-uniformity of the initial shell surface stress increase with the groove space wider. The range of the initial shell surface stress for different groove space is from 0,18 Mp to 1,03 Mp.

The influence of groove depth

Changing groove depth does not affect the proportion of mold surface air gaps, the chamber volume of grooves increase with the increase of groove depth, so does the heat transfer flux of mold, but compared with the width and space of groove, the groove depth has less effect on the heat transfer flux. Calculation results show that compared to a depth of 0,5 mm and 2,0 mm, the temperature curves are not obviously different. The initial shell surface temperature at 7 s with two kinds of groove depth is differ with 1,14 °C. The initial shell is formed at almost the same time. The temperature range of two kinds of groove is respectively to 2,85 °C and 2,86 °C.

The difference of two kind stress curves is also not obviously. The initial shell surface stress of 2,0 mm groove depth is 0,4 Mp lower than that of the 0,5 mm depth. The range for 2,0 mm depth is 0,46 Mp. The range for 0,5 mm groove is 0,49 Mp.

CONCLUSIONS

Through establishing the thermal stress coupling calculation model of initial shell in the groove mold for continuous casting, and the calculation of the initial shell temperature field and stress field, we can draw the conclusion from the calculation results:

The non-uniformity of the initial shell surface temperature is bigger with groove width wider, the initial shell surface temperature is increasing in the same time, so does the initial shell stress increase with same shell thickness.

The non-uniformity of the initial shell surface temperature is bigger with groove space wider, the initial shell surface temperature is decreased in the same time, and the initial shell stress increase with same shell thickness.

Groove depth has little effect on the temperature and stress of the initial shell surface.

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