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SIMULATION STUDY ON THE EFFECT OF RISER HEATING MODE ON SOLIDIFICATION OF FLAT INGOT HEAD

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According to the production practice of 14 tons flat ingot, the influence of heat preservation measures on solidification state of ingot head is analyzed by the software ProCAST. The results show that the heating riser and electromagnetic heating riser delay the cooling of molten steel in the ingot head, but these heating risers have little effect on the temperature of the middle and lower parts of the ingot. Due to the different influence of corner heat transfer, the solidification time of molten steel in wide side is longer than that in narrow side. In comparison, the solidification time of the ingot head with electromagnetic heating riser is the longest.

Keywords: flat steel ingot, exothermic riser, numerical simulation, electromagnetic heating riser

INTRODUCTION

Die cast flat steel ingots are often used in the manufacture of shipbuilding, die steel and energy steel [1,2]. Its internal quality is very important for subsequent production. The research shows that in casting production, some castings will produce shrinkage cavity and shrinkage porosity after solidification [3-5]. The reason is that during the casting process, the cooling time of the casting is long, when the metal contracts during solidification, there is not enough liquid metal to fill the space caused by shrinkage. The volume of traditional riser is large and the utilization efficiency is low and the feeding effect is poor. In order to improve the yield of castings, it is the only way increasing the size of riser, and the molten metal in the riser will be increased which not only wastes resources, but also increases cost. How to improve the feeding efficiency of riser and prolong the solidification time of molten metal in riser has become the primary task of ingot casting technology research [6-8]. In this paper, the effect of heating mode of flat ingot riser on ingot solidification is studied, which provides theoretical basis for production practice.

CALCULATION MODEL ESTABLISHMENT

Geometric model and grid partition

In this paper, the process of solidification of eleven tons flat steel ingot is simulated. The geometric model and grid division diagram of flat ingot is shown in Figure 1. The mesh is tetrahedral element, and the number of elements is 364 051.

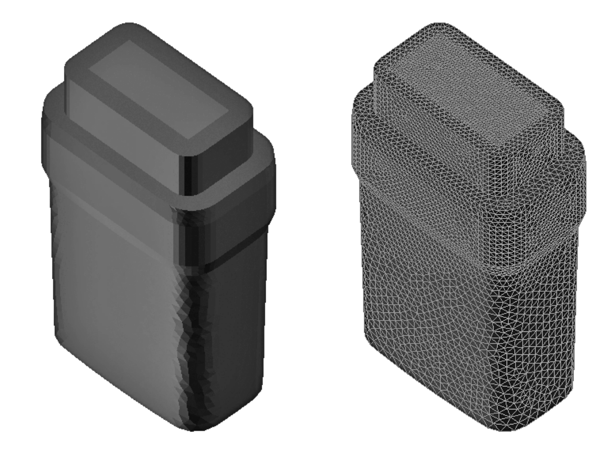

Figure 1 Geometric model and grid division diagram of flat ingot

Governing equation and setting of simulation conditions

The heat transfer governing equation [6]:

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

Where T is temperature / °C, ρ is steel density / kg/m^3, λ is thermal conductivity / W/m/°C, c is specific heat / J/kg/K.

Heat flux calculation is:

$$Q = h \times (Tm - Tc) \quad (2)$$

Where q is heat flux / W/m^2, Tm is mould surface temperature / °C, Tc is environmental temperature / °C, h is comprehensive heat transfer coefficient / W/m^2 /°C.

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Initial conditions are:

Liquid steel: T = Tst0, mould: T = Tm0.

In the simulation, the thermal conductivity is isotropic, the thermal physical parameters of molten steel is only a function of temperature. The casting temperature of molten steel is 1 550 / °C, and the initial temperature of the ingot mold and insulating board is 100 / °C. The ignition point of the exothermic riser is 700 / °C, the heating capacity is 1 000 / kJ / kg, and the heating time is one hour. The power of electromagnetic heating is 20 / kW.

SIMULATION RESULTS AND ANALYSIS

Comparison of ingot temperature results of different chassis cooling schemes

Figure 2 shows the temperature distribution at 12 959 / s under three schemes. According to the calculation results, due to different heat preservation methods, the end time of the temperature is obviously different. The exothermic riser is 1 799 / s longer than the ordinary one, and the electromagnetic heating riser is 1 805 / s longer than the exothermic riser. At the end point, the temperature distribution on the ingot surface is obviously different due to the different total heat dissipation time. The longer the solidification time is, the more the high temperature isotherm will advance toward the riser. This is because of the better heat preservation effect, which makes the upper riser molten steel in a high temperature state for a long time, while the bottom heat dissipation conditions are the same in each scheme at the same time.

The temperature distribution of the ordinary riser and the exothermic riser is similar at the end time, while the high temperature region of the electromagnetic heating riser is concentrated in the upper part. The reason is that the temperature distribution of molten steel is always in the bottom-up state due to the continuous heating effect of electromagnetic heating riser. On the other hand, due to the same heat dissipation conditions, the temperature change in the middle and lower parts of ingot is not affected by the heating riser under the three schemes.

Analysis of heat flow results

Figure 3 shows the comparison of heat flow changes in the wide side center of the ingot head. It can be seen from the figure that in the early stage of solidification, the heat flux density of each scheme is at a high level due to the large temperature gradient. As time goes on, the chilling effect of ingot mold and insulation board disappears, the temperature increases, the temperature gradient decreases, and the heat flux decreases rapidly.

As shown in Figure 4, at about 563 seconds, the heat flow density under each scheme starts to be different. The heat flow of the exothermic riser and the electromagnetic heating riser are smaller than that of the ordinary riser for a long time. And the heat flux of the exothermic riser is obviously smaller than that of the electromagnetic heating riser in the combustion time because it releases a lot of heat after reaching the ignition point. At the end of combustion (about 3 260 / s), the heat flux increased obviously. The electromagnetic heating riser has the function of heating for a long time, keep the low heat flow longer, and turn point appears at 8 963 / s. With the air cooling effect on the outside of the mould, the temperature of the ingot mold and insulation board decreases, and the heat flux density increases again. In the later stage of solidification, the surface temperature of ingot head is not strongly supported by heat due to the loss of sensible heat of molten steel, so the heat flow of common riser is reduced, and the sensible heat accumulated in the other two schemes in the early stage makes the heat flow of molten steel rise greatly.

Figure 5 shows the comparison of the heat flow changes of the central node with the center of the narrow side under the conditions of each scheme. It can be seen from the figure that the heat flow in the center of the narrow side is generally higher than that in the center of the wide side at the same time. This is due to the large heat flux density of two-dimensional heat transfer at the corners of both sides of the narrow side, which has a significant influence on the center of the narrow side. Compared with the three schemes, the heat flux of the ordi-

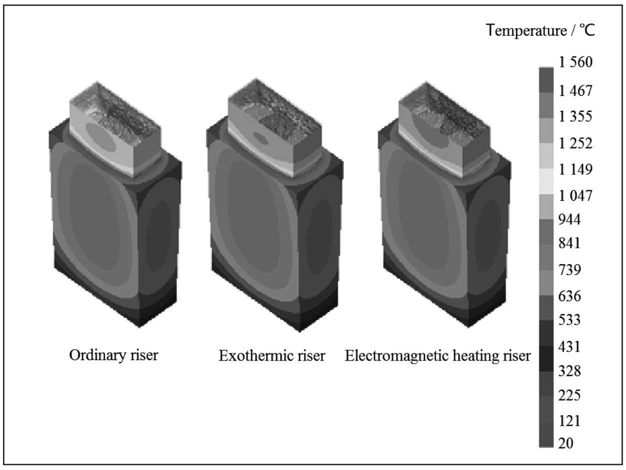

Figure 2 Comparison of temperature field at 12 959 / s under different schemes

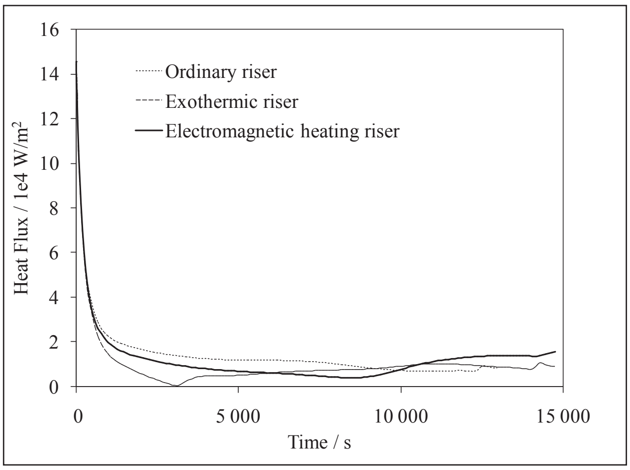

Figure 3 The comparison of heat flow changes in the wide side center of the ingot head

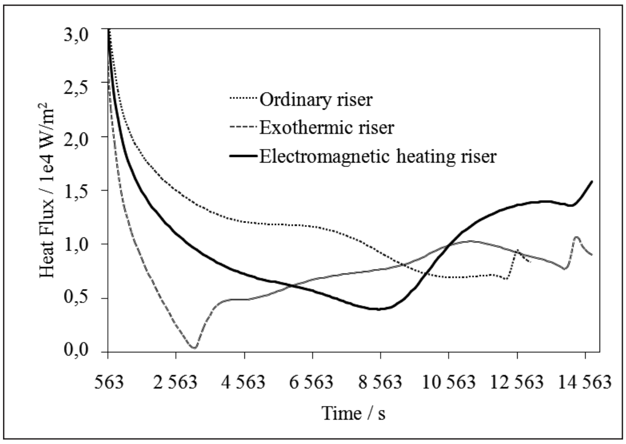

Figure 4 The comparison of heat flow changes in the wide side center of the ingot head (part)

nary riser is the largest, the electromagnetic heating riser is the second, and the exothermic riser is the smallest before about 6 800 / s. After that, the exothermic riser lost the support of the accumulated heat of combustion, and the heat flow increased sharply. The sensible heat disappeared and the temperature gradient decreased, and the heat flux density of the common riser was significantly lower than that of the other two schemes due to the rapid solidification of liquid steel. The electromagnetic heating riser can still maintain a relatively low heat flux density because of its continuous heating function.

Analysis of heat flow results

Figure 5 shows the solidification time of ingot head. It can be seen from the figure that at the ingot head position, the solidification sequence of the ordinary riser and the exothermic riser is similar, and the final solidification area is in the central of the surface. However, due to the function of combustion to supplement heat, the solidification time is longer than that of ordinary riser. The electromagnetic heating riser still has heating effect at the later stage of solidification, so the final solidification area is the upper part. On the other hand, the solidification time of wide side is significantly longer than that of narrow side. According to the calculation results, the maximum solidification time of ordinary riser is 12 472 / s, that of exothermic riser is 14 242 / s, and that of electromagnetic heating riser is 16 243 / s. The electromagnetic heating riser can significantly prolong the solidification time of riser molten steel, which provides favorable conditions for feeding riser molten steel.

CONCLUSIONS

Exothermic risers and electromagnetic heating risers delay the cooling of molten steel in the ingot head, but they have little effect on the cooling of molten steel in the middle and lower parts of ingots.

The results show that the heat flux of molten steel in riser can be significantly inhibited by a large amount of heat released by the exothermic riser after combustion, but the duration of the inhibition is shorter than that of the electromagnetic heating riser.

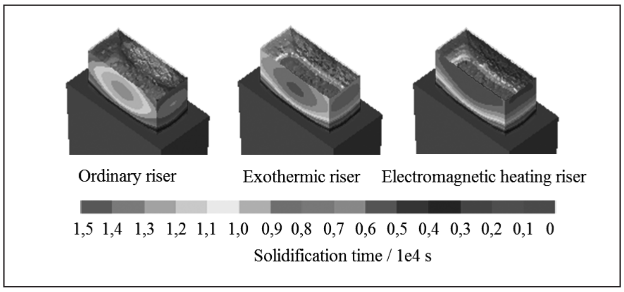

Figure 5 Comparison of solidification time of ingot head

Due to the different influence of corner heat transfer, the overall solidification time of molten steel in ingot riser is longer than that in narrow surface. The solidification time of the ingot head with electromagnetic heating riser is the longest.

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Note: The responsible translator for English is Yan Wu, University of Science and Technology Liaoning, Anshan, China