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ANALYSIS OF INFLUENCING FACTORS OF THE BLOCKING LAYER BASED ON ELECTROMAGNETIC INDUCTION-CONTROLLED AUTOMATED STEEL-TEEMING SYSTEM

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The steel-teeming time, directly affected by the output parameters of power supply, is one of the most important technical indicators for the electromagnetic steel-teeming system. The location and thickness of the blocking layer in the molten steel channel directly affect the steel-teeming time. This paper establishes numerical simulation model and uses high temperature off-line test to prove the accuracy of numerical simulation. Result shows: As the tonnage increase of ladle, the position and thickness of blocking layer are basically unchanged; As the length of molten steel channel extends, the position of blocking layer shift upper and thicker; As the diameter of molten steel channel extends, the blocking layer is lower and thinner slight; Comparing the molten steel channel in "horn" shape with cylindrical shape, the blocking layer of former is upper and thicker than the latter.

Key words: electromagnetic steel-teeming system; blocking layer; numerical simulation; high-temperature offline test

INTRODUCTION

The steel-teeming system is an important part to ensure the normal operation of continuous casting [1, 2]. However, there are several defects in traditional steel-teeming process [3, 4]. For example, the steel-teeming rate is relatively low which cannot achieve 100 % during traditional process. The stuffing sand filled in the brick nozzle which will cause pollution to the molten steel and so on [5, 6]. Based on these studies, He et al[7, 8]. began to study electromagnetic teeming system in order to solve these problems [9, 10]. Electromagnetic steel-teeming system uses electromagnetic induction heating technology in the following way, a certain amount of Fe-C alloy is added to the nozzle brick shortly before the ladle is filled with liquid steel. These links utilizes the heat of liquid steel to enable the Fe-C alloy to form a certain of thickness blocking layer. When the casting begins, electromagnetic induction heating technology will be applied to melt the edge of the blocking layer to complete the steel teeming process.

Steel-teeming time is one of the most important technical indicators in metallurgical industry. The location and thickness of blocking layer will affect the steel-teeming time directly. If the blocking layer is formed in the most effective induction heating area, the steel-teeming time will be reduced. Therefore, in order to shorten the steel-teeming time, we need to study the relevant factors which influence the position and thickness of the blocking layer (including molten steel channel's ladle tonnage, diameter, length and shape) and also obtain the rules of these factors.

NUMERICAL SIMULATION

Model

As Figure 1 shows, a three-dimensional finite element analytic model of the molten steel channel in the nozzle brick of a 110 / t steel ladle of a certain steel mill was developed. To clearly observe the position and thickness of the blocking layer, the meshes around the molten steel channel were refined. Previous works [11, 12] have given the heat conductivity (24,02 / W/m/k) and enthalpy (1 350 / J/kg/k) of an Fe-C alloy changing with temperature.

Basic assumption

In the simulation, the following basic assumptions are made according to the characteristics of the experiment.

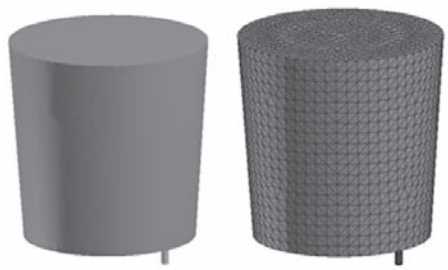

Figure 1 Three-dimensional model and mesh generation

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Neglect heat dissipation of the blocking layer. And neglect corrosion of the lining material of the nozzle brick, thus deeming its compositions constant.

Boundary condition

The molten steel temperature is taken as 1 600 / ℃, and that of the Fe-C alloy in the molten steel channel as 1 100 /℃. We note that in practical working conditions, the temperature of the blocking layer in the nozzle brick is about 1 100 /℃. Further, these temperatures remain unchanged.

In the actual production process, the heat transfer time of the molten steel and Fe-C alloy is about 90 /min for the entire process from steel teeming to casting. Therefore, the total time of the simulation is set as 90 / min. The physical parameters of the stacked granular Fe-C alloy, including heat conductivity, specific heat, and density, are modified according to the experimental data.

The length of the molten steel channel is 515 / mm, the diameter is 110 / mm.

Theoretical foundation

The heat transfer control equation:

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

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.

ANALYSIS AND DISCUSSION ON EXPERIMENT RESULT

Experiment process

As Figure 2 shows, the nozzle brick was enclosed in the heating chamber. First, stop heating and take out the sliding plate of nozzle brick so that the Fe-C alloy particles in the original layer can fall off by gravity. Second, the molten steel is poured out from the upper surface of the nozzle brick. Measure the height from the upper surface of the nozzle brick to the blocking layer and then pour out the blocking to measure its thickness. This experimental time is about 90 minutes according to the technological requirements of a steel mill. During the experiment, the combinations of physical parameters of Fe-C alloy are shown as follow: particle size is 2,0 / mm, shape is cylindrical. The output frequency of power supply is 35,3 / kHz, the output current is 152,9 / A, and the output power is 40,1 / kW. The simulation and experimental results are shown in Table 1.

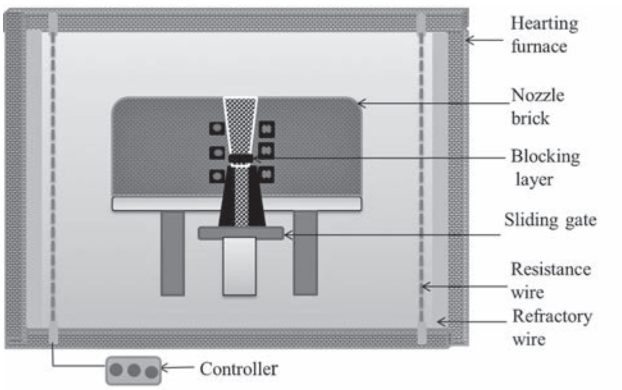

Figure 2 High temperature off-line device

Table 1 **Numerical simulation and experimental results**

	blocking layer	
	distance from the surface of nozzle block / mm	Thickness / mm
experiment	155,4	128,7
numerical simulation	156,3	128,5

As the Table 1 shows, numerical simulation and high-temperature offline test, for which the values are almost no difference, showing good conformity.

Simulation result

Influence of ladle tonnage on blocking layer

In order to investigate the influence of steel-teeming time with different tonnage of ladle which the corresponding blocking layer changes Select the tonnage of ladle from commonly used in steel mill: 90 / t, 110 / t, 260 / t and 300 / t as the research object. In this paper select the same Fe-C alloy's physical parameters (material is 10#steel, shape is cylindrical, granularity is 2,0 / mm), the rest of the boundary condition and the parameter values are the same with model above. According to the calculation results, the location and thickness of the 90 t steel blocking layer are shown in Figure 3. The position and thickness of the blocking layers of 90 / t, 110 / t, 260 / t and 300 / t ladle are obtained by the same

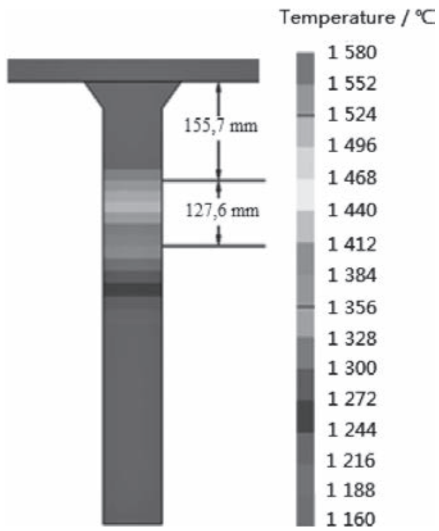

Figure 3 Temperature distributions of blocking layer for ladle (90 / t)

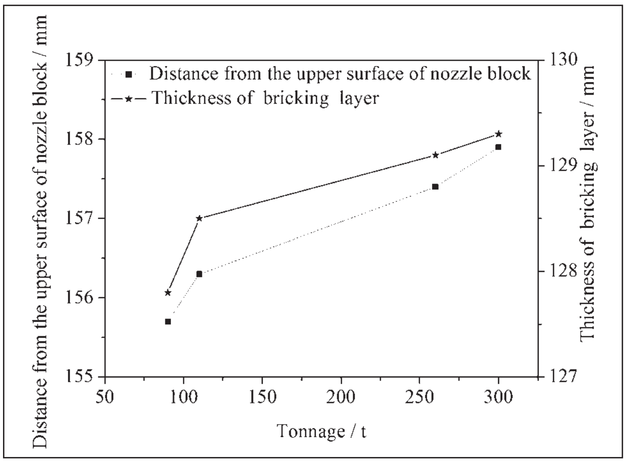

Figure 4 The location and thickness of blocking layer under different molten steel channel's tonnage

method as shown in Figure 4. (The calculation of other schemes is similar to that of this scheme, so it will not be explained in detail.)

As Figure 4 shows that the position and thickness of the blocking layer are basically unchanged as the tonnage of the steel package increases.

The main reason for this phenomenon is the heat-transfer rate between objects is mainly influenced by the temperature gradient between objects and the coefficient of heat transfer between objects. And the initial temperature of different tonnage ladles is the same, which is basically the same as that of Fe-C alloy in the molten steel channel. Second, the cross-sectional area of the molten steel channel is a constant. The material between the molten steel and the upper surface of the blocking layer is unchanged, so that the coefficient of heat transfer remains unchanged. Therefore, the position and thickness of the blocking layer is basically unchanged.

Influence of molten steel channel's diameter on blocking layer

Select 70 / mm, 90 / mm and 110 / mm are selected as study objects. Finally, the location and thickness of blocking layer is obtained as Figure 5 shows.

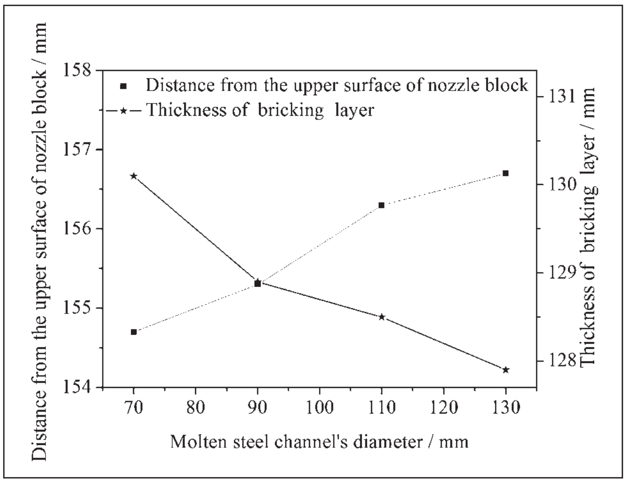

Figure 5 The location and thickness of blocking layer under different molten steel channel's diameter

As Figure 5 shows, with the increase of molten steel channel's diameter, the blocking layer becomes lower and thinner slightly.

The main reason for the phenomenon is that with the increase of molten steel channel's diameter, heat-transfer rate which is above blocking layer has increased. This will make the blocking layer absorb more quantity of heat and tends to be lower and thinner. However, due to the increase the molten steel channel's diameter, the amount of Fe-C alloy added in the molten steel channel is also increased. And more heat is needed, which leads to the blocking layer become upper and thicker. But the heat-transfer rate is a little faster than that of Fe-C alloy absorbs heat. And the effect of both on blocking layer is opposite, with the increase of the molten steel channel's diameter, the blocking layer moves lower and thinner slightly.

Influence of molten steel channel's length on blocking layer

Select 420 / mm, 520 / mm, 620 / mm as study objects. Finally, the location and thickness of blocking layer is obtained as Figure 6 shows.

As Figure 6 shows, with the increase of molten steel channel's lengths, the blocking layer becomes upper and thicker slightly.

The main reason for the phenomenon is that with the increase of molten steel channel's diameter, heat-transfer rate which is above blocking layer has increased. This will make the blocking layer absorb more quantity of heat and tends to be lower and thinner. Due to the effect of heat-transfer, the high temperature region will transfer heat to the low temperature continually. The longer molten steel channel, the more Fe-C alloy filled into the molten steel channel. So the lower surface of blocking layer will absorb more heat than shorter one. These will make the temperature of Fe-C alloy in whole molten steel channel decrease. As a result, the blocking layer will move upper and thicker comparing with short molten steel channel.

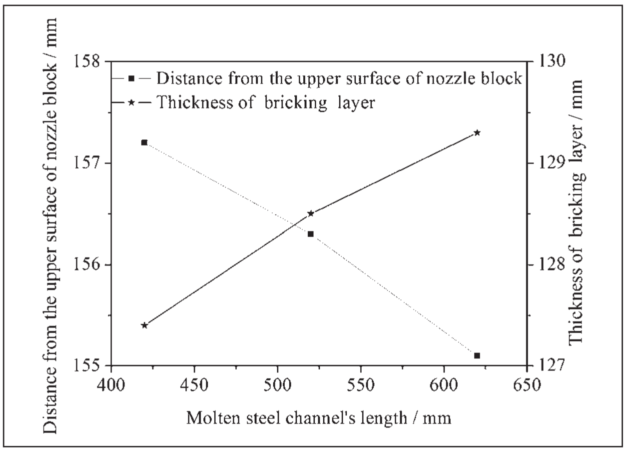

Figure 6 The temperature distribution of the location and thickness for blocking layer under different molten steel channel length

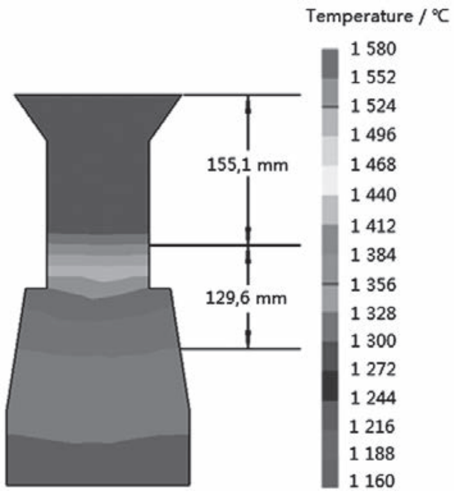

Figure 7 Temperature distributions of the blocking layer with "horn" shape

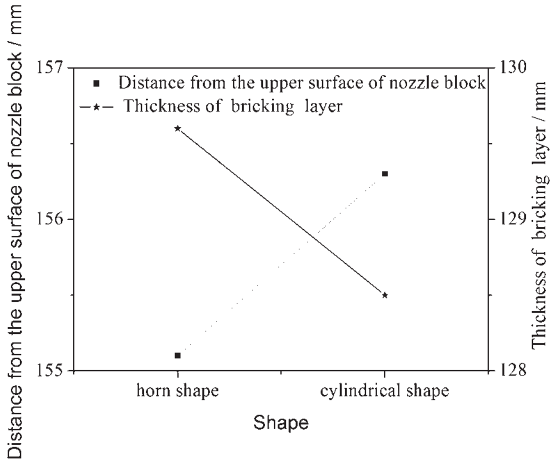

Figure 8 The location and thickness for blocking layer under different molten steel channel's shapes

Influence of molten steel channel's shape on blocking layer

Select cylindrical shape and horn shape are as study objects. Temperature distributions of the blocking layer with "horn" shape as Figure 7 shows. The location and thickness of blocking layer is obtained as Figure 8 shows.

As Figure 8 shows, the "horn" shape of the blocking layer has a slight upward trend and thicker compared with that of the cylindrical shape. The main reason for this phenomenon is that comparing with cylindrical shape, the "horn" shape of molten steel channel needs to add more Fe-C alloy, and absorbs more heat from the molten steel channel. The lower surface of blocking layer will absorb more heat than that of cylindrical shape. These will make the temperature of Fe-C alloy in whole molten steel channel decrease. As a result, the blocking layer will move upper and thicker comparing with cylindrical shape of molten steel channel.

CONCLUSION

As the tonnage increase of ladle, the position and thickness of blocking layer are basically unchanged.

As the length of molten steel channel extends the position of blocking layer shift upward a slight; and a slight increase in thickness.

As the diameter of molten steel channel extends, the blocking layer is slightly has an upward trend and increases slightly.

Compare the molten steel channel in "horn" shape with cylindrical shape. The blocking layer of former is upper and thicker than the latter.

Acknowledgments

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