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THE SIMULATION STUDY ON CENTRAL POROSITY OF 450 MM DIAMETER STEEL ELECTRODE INGOT

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In this paper, cooling plan is optimized to solve the central porosity problem of 450 mm diameter steel electrode ingot. The central porosity of ingot in corresponding cooling plans is calculated by the finite element analysis software ProCAST. The results show that in the plan of independent riser and strengthened cooling in lower ingot part, the central porosity has been significantly reduced.

Key words: steel electrode ingot, heat flux, central porosity, numerical simulation

INTRODUCTION

There is high requirement for internal quality of electrode ingot. And the electrode ingot tends to be larger ratio of height to diameter due to the two parameters of the design of the filling ratio and the height to diameter ratio of the electro-slag remelting process[1]. In the large ratio of height to diameter electrode ingot production, there will be prone to central porosity or even concentrated shrinkage.

The internal quality of electrode ingot has great influence to electro-slag remelting production. The central porosity or even shrinkage will cause the fluctuation of current in the end of melting electrode, and that will affect the quality of the electro-slag remelting ingot [2].

The main influence factors of ingot internal quality is design parameters and heat flux control in solidification. And for the electrode ingot, the design parameters have been limited. So the only way to improve the internal quality of products is the heat flux control[3].

In this paper, the central porosity of the electrode ingot is calculated by ProCAST. And the plan of heat flux control in solidification process of the electrode ingot is optimized based on the comparisons of plans.

MATHEMATICAL MODEL ESTABLISHMENT

Basic condition setting

Geometric model and mesh of 450 mm diameter electrode ingot are showed by Figure 1.

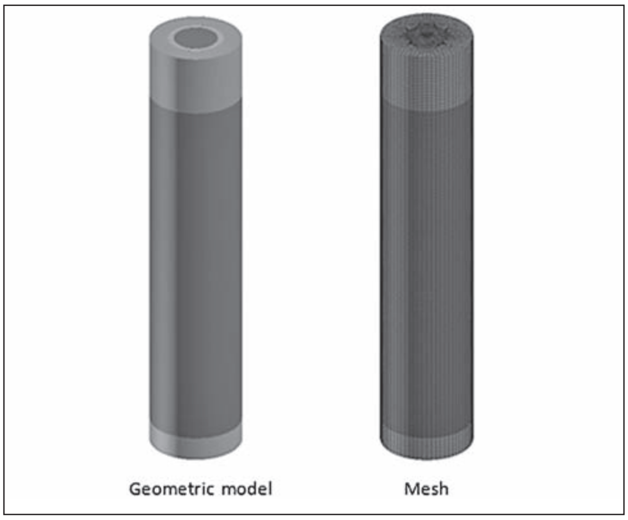

Figure 1 The ingot geometry model and mesh of electrode ingot

The heat transfer control equation[4]:

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

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.

The assumptions used for heat transfer simulation are the molten steel is viscous incompressible flow and the thermal conductivity is isotropic, the thermal physical parameters of molten steel is only a function of temperature, the boundary is no slip boundary.

The study plans are set as follow.

Plan 1 is set as air cooling at the outer wall.

Plan 2 is set as air cooling at the outer wall and exothermic at upper ingot.

Plan 3 is set as air cooling at the outer wall. The riser is designed separated from mould and the part contact with mould is refractory. It is set forced cool-

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ing to mould at the region of the 1 / 5 mould height from bottom.

Initial conditions and boundary conditions

Heat flux calculation is :

$$q=h\times(T_m - T_c) \qquad (2)$$

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

Initial conditions are:

Liquid steel: $T = T_{st0}$, mould: $T = T_{m0}$.

Composition of steel: C is 0,16 %, Si is 0,33 %, Mn is 1,5 %, S is 0,03 %, P is 0,03 %.

THE ANALYSIS OF CALCULATION RESULTS

Result of plan 1

The simulation results of solid phase rate and heat flux of ingot in plan 1 are shown in Figure 2.

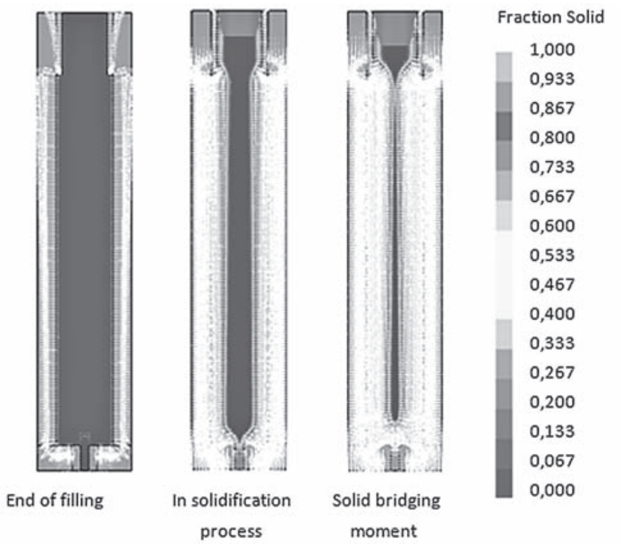

Figure 2 The solid phase rate and heat flux of ingot in plan 1

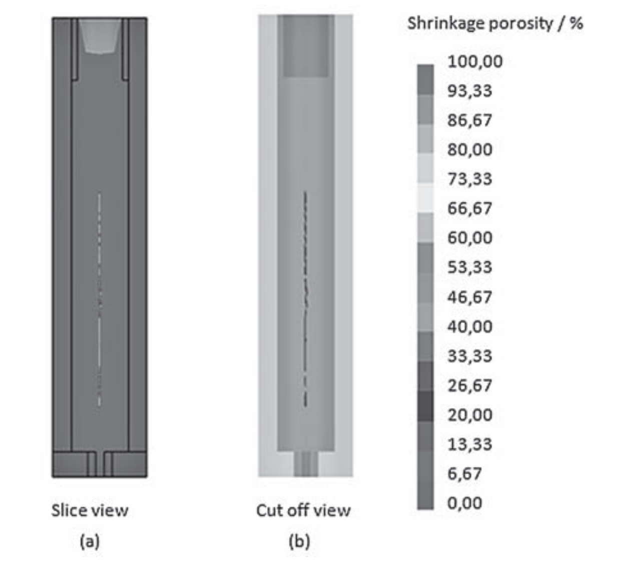

Figure 3 The ingot shrinkage solidification simulation result in plan1

Figure 2 shows that the heat flow in the upper part of the ingot is large because of the heat absorption by iron mould. And in addition to the heat transfer to the horizontal direction, there is lots of heat absorbed by the upper part of iron mould. In the upper area of ingot, the temperature of molten steel decreases rapidly. And thus, a solid bridge is formed at 1 843 s from end of filling. Then, the steel feeding channel disappeared, eventually led to the formation of the ingot central porosity.

The simulation results are shown in Figure 3. In the Figure 3, it can be seen that the central shrinkage porosity is very serious. And as being shown in (b), the area of shrinkage porosity above 30 % level is very large. The main reason is that the “solid bridge” hinders the upper molten steel feeding.

Result of plan 2

The simulation results of solid phase rate and heat flux of ingot in plan 2 are shown in Figure 4. And the ingot shrinkage simulation result is shown in Figure 5.

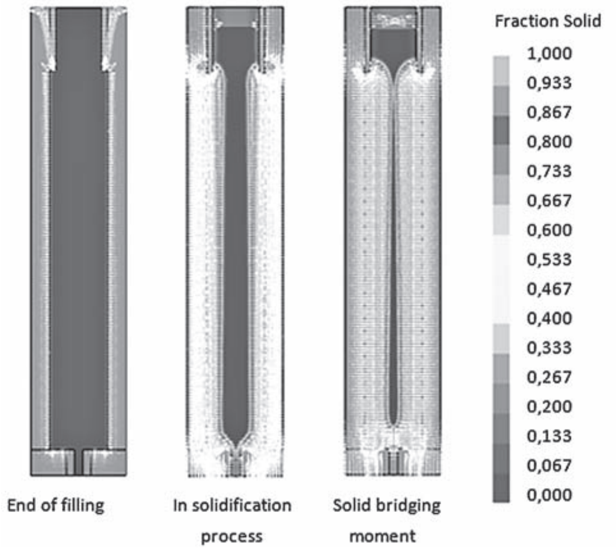

Figure 4 The solid phase rate and heat flux of ingot in plan 2

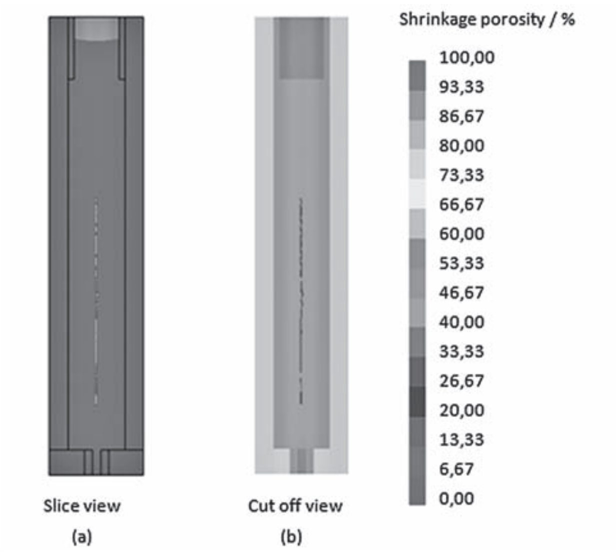

Figure 5 The ingot shrinkage simulation result of plan 2

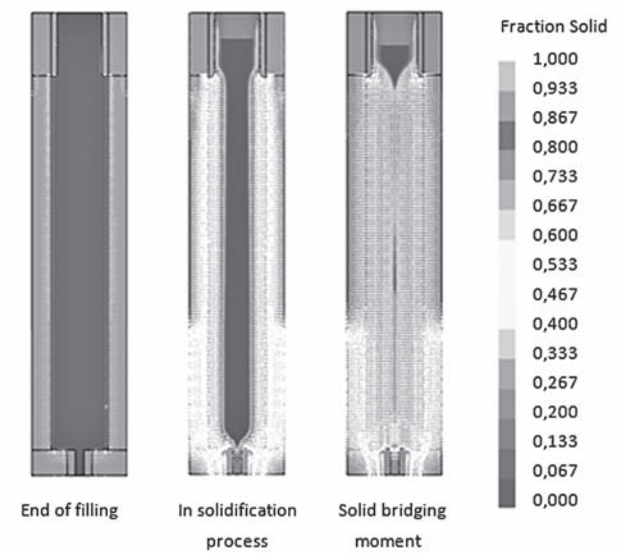

Figure 6 The solid phase rate and heat flux of ingot in plan 3

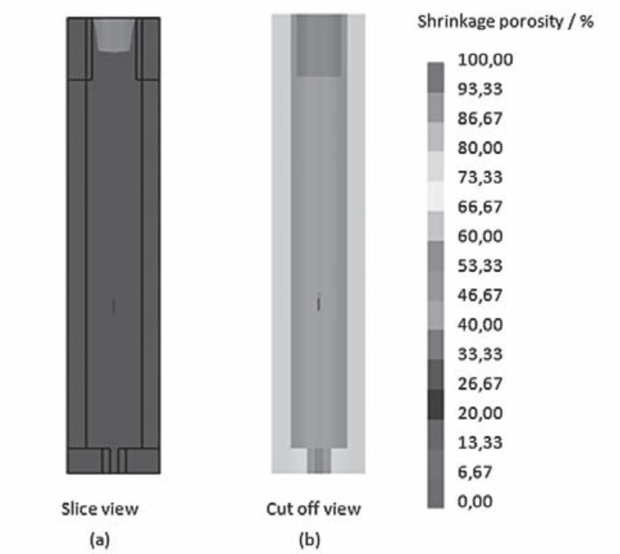

Figure 7 The ingot shrinkage simulation result of plan 3

The simulation results show that the exothermic keep the molten steel temperature in riser at a high level, move the solid bridging position down slightly. But it do not disease large heat flux in upper ingot, and delay the solid bridging time to 1 847 s from end of filling. This is because a lot of heat of the molten steel is mainly absorbed by the iron mould, exothermic cannot change this situation.

Result of plan 3

The simulation results of solid phase rate and heat flux of ingot in plan 2 are shown in Figure 6. And the ingot shrinkage simulation result is shown in Figure 7.

The simulation results show, in plan 3, the heat flux in upper ingot is significantly limited due to the independent riser. The solid bridging moment is delayed to 1 947 s. And the solidification rate of molten steel in the lower ingot part is higher because of the enhancement cooling.

CONCLUSION

The solid bridge in upper part of traditional 450 mm steel electrode ingot is formed because the heat flux in upper part of ingot is large. The reason is in addition to the horizontal heat flux, there are a lot of heat flow to the riser part.

In the small diameter electrode ingot cooling process, heat flux of the upper ingot cannot be decreased significantly in traditional electrode ingot mould because of the strong endothermic effect of iron mould. And thus solid bridging is formed quickly which will leads to a wide range of central porosity in ingot.

Heat flux in upper ingot is significantly limited by independent riser. The solid bridging formation is delayed. And enhance cooling in lower ingot part accelerates the solidification of molten steel. The central porosity of electrode ingot can be significantly diseased due to the comprehensive effect in plan 3.

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