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SIMULATION RESEARCH ON MOLTEN STEEL FLOWING BEHAVIOR IN WIDE SLAB CONTINUOUS CASTING MOLD

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Research on the flowing behavior of molten steel in the continuous casting mold is the key to promote the smooth process of continuous casting and improve the quality of casting blanks. In this article, a three-dimensional solid model of 230 mm × l 600 mm is created based on actual wide slab mold, and analyze the influence of the casting speed, nozzle angle and immersion depth on the flowing behavior of molten steel. It is concluded that the suitable nozzle angle and immersion depth at a certain casting speed can provide theoretical support for continuous casting efficiently and the process optimization.

Key words: steel, continuous casting mold, physical-mathematical model, casting speed, nozzle angle

INTRODUCTION

With the development of metallurgical technology, continuous casting has become a necessary process to improve the quality and output of steel billets. The impact depth and circulation strength of molten steel in the continuous casting mold are the important factors that influence on the quality of steel billets. The flowing state of molten steel in the mold is greatly affected by the casting speed, nozzle angle and immersion depth. Therefore, researching the effects of these three factors on molten steel, which has a great of significance to enhance the quality of continuous casting billets.The numerical simulation has been widely used because of its advantages of low cost, fast speed and capable of simulating various conditions. A lot of researchers have studied it. Thomas B G and other researchers used the high Reynolds numbers k-ε double equation model[1] to study the two-dimensional turbulent flowing behavior in the thick slab crystallizer. Leiviska K and Hintikka S[2] used the software of DIDAP and FLUENT to simulate the influence of nozzle structure parameters and casting speed on the fluctuation of meniscus. M R Aboutalebi[2]used the modified low Reynolds numbers turbulence model to build a two-dime nsional mathematical model of the slab, and studied the influence of process parameters on fluid flow and heat transfer. H L Yang and others developed a three-dimensional coupled model in continuous casting process based on the cartesian coordinate system[3], and they analyzed the flow, heat transfer and solidification coupled behavior of molten steel in the casting mold by using the finite difference method and SIMPLE algorithm.

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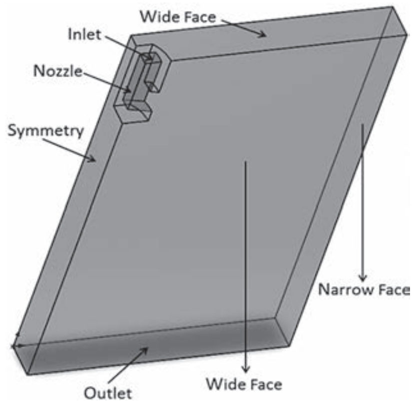


Figure 1 Physical model

PHYSICAL MODEL AND SIMULATION SCHEMES

Physical model of wide slab mold

This article uses practical wide slab continuous casting mold as the research object. Its section size is 230

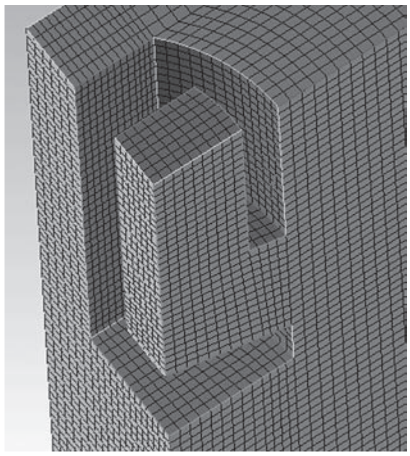


Figure 2 Grid model

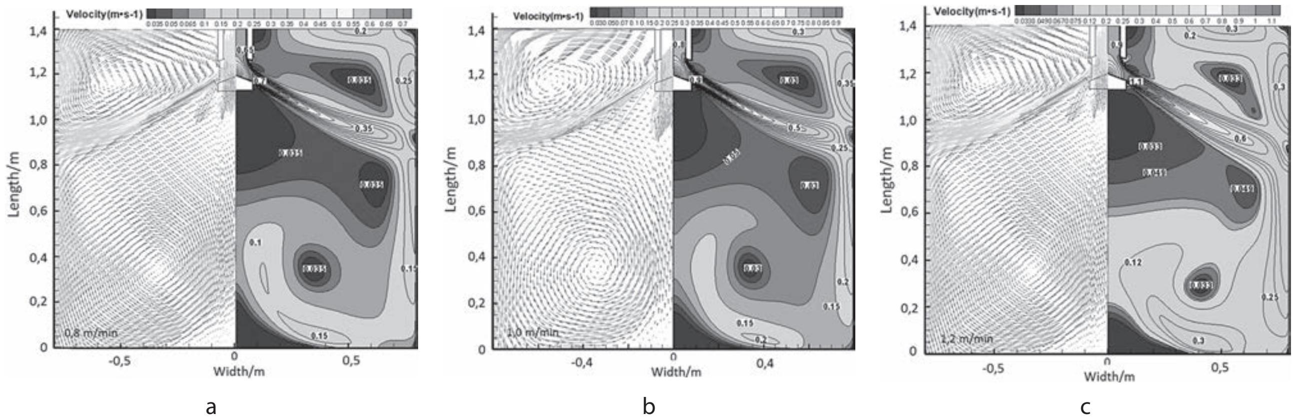


Figure 3 Velocity vector and contour map, a, b and c

mm×l 600 mm and its working length is 800 mm. In order to describe the flow field adequately, extend the calculation length to 1 400 mm. the calculation zone can be only a quarter of the original volume due to the symmetry of the slab mold.

Adopting ICEM CFD 17,0 to construct a hexahedral structured grid with a grid spacing of 5 mm, and the physical model and grid partitioning model are shown in Figures 1, 2,Table 1.

Simulation schemes

Table 1 Simulation schemes of flow field in the mold

Immersion depth/ mm	Casting speed/ ($m\cdot min^{-1}$)	Nozzle angle/ deg
110;140;170	1,0	-20
140	0,8;1,0;1,2	-20
140	1,0	-10;-15;-20

MATHEMATICAL MODEL AND CALCULATION METHOD

Basic conditional hypothesis

In order to simplify the equations and their boundary conditions, some assumptions are made as follow:

(1) It is assumed that the molten steel is Newton’s incompressible viscous fluid and its density is uniform.
(2) Supposing the flow state inside the mold is steady.
(3) The coupled effect between solidified shell and flow field is neglected.
(4) Ignoring the effect of meniscus fluctuation and slag layer on the flow field.

Governing equations

Based on the three laws of mass, momentum and energy conservation, using the three-dimensional turbulent Standard k-ε model to describe the flow state of molten steel in the mold[4]. Continuity equation and Momentum equation are used in the mathematical model. Model governing equations include turbulent kinetic energy equation and turbulence dissipation rate equation.

BOUNDARY CONDITIONS AND CALCULATION METHOD

All boundaries are shown in Figure 1. The inlet of nozzle is defined as the inlet boundary with the inlet boundary condition, and the inlet velocity is based on the principle that the mass flow is balanced. Defining the bottom of the mold as the outlet boundary and adopting the mass outflow boundary condition. The free surface is symmetry boundary condition[5]. The walls of the mold are no-slip boundary conditions.

SIMPLEC algorithm is used to solve the flow field. Also, this algorithm can also greatly accelerate the calculation speed[6].

ANALYSIS OF SIMULATION RESULTS

The simulation mainly analyzes three factors of immersion depth, nozzle angle and casting speed effects on the flow field.

Influence of casting speeds on flow field in the mold

Figure 3 is the velocity vector diagram and contour map. The casting speeds are 0,8 m/min, 1,0 m/min, and 1,2 m/min respectively. The molten steel flow field has similar characteristics under different casting speeds. The molten steel discharging from the nozzle approxi-

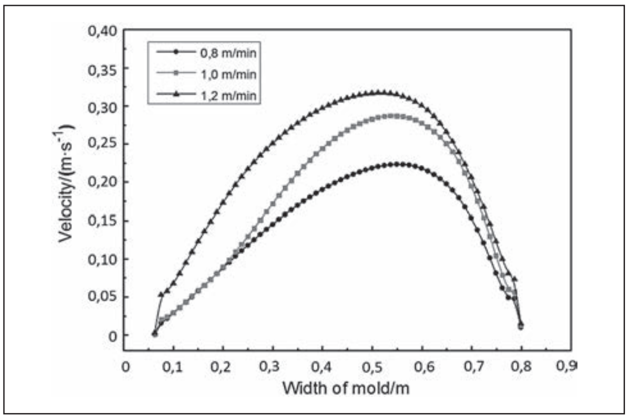
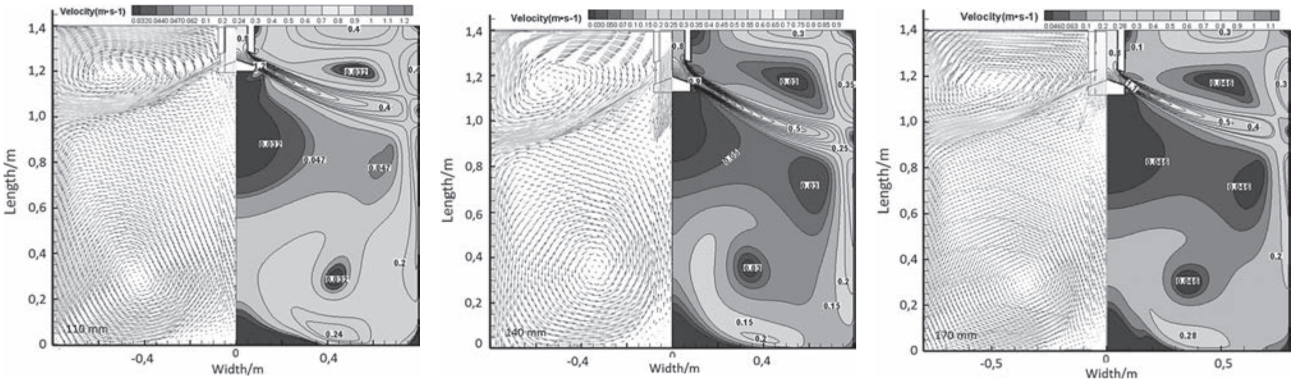


Figure 4 Free surface centerline velocity distribution



a b c

Figure 5 Velocity vector and contour map, a, b and c

mates a linear jet flow when the casting speed is low. When the casting speed increases, the jet flow gradually deflects upward, and the velocity changes obviously. The surface of molten pool become more volatile, which is easy to cause the involvement of the protecting slag and molten steel bareness.

Figure 4 is the velocity distribution of free surface centerline under three kinds of casting speeds. As the casting speed increases, the velocity near free surface also increases, the maximum velocity increases from 0,22 m/s, 0,283 m/s to 0,3 m/s, and the velocity of free surface is quite different. It is known that the velocity of free surface is greatly influenced by the changes of casting speeds. Therefore, the casting speed of wide slabs should be controlled between 0,8 m/min and 1,0 m/min in the actual continuous casting process.

Influence of immersion depths on flow field in the mold

Figure 5 is the velocity vector diagram and contour map. The immersion depth are 110 mm, 140 mm, and 170 mm respectively. From the Figure 5a, it can be seen that the jet flow deflects close to the top of the mold because of small immersion depth of the nozzle, of the molten steel in the lower region. With the increase of the immersion depth, the backflow area of the upward movement near the surface of molten pool becomes more and more large, and the agitation of the slag interface gradually decreases. The slag cover is well covered and the possibility of slag reel is reduced.

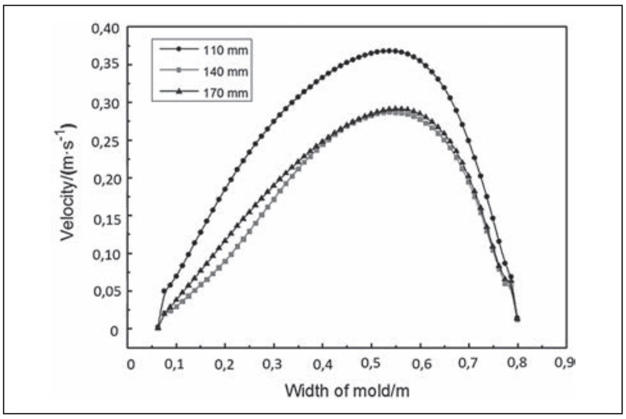
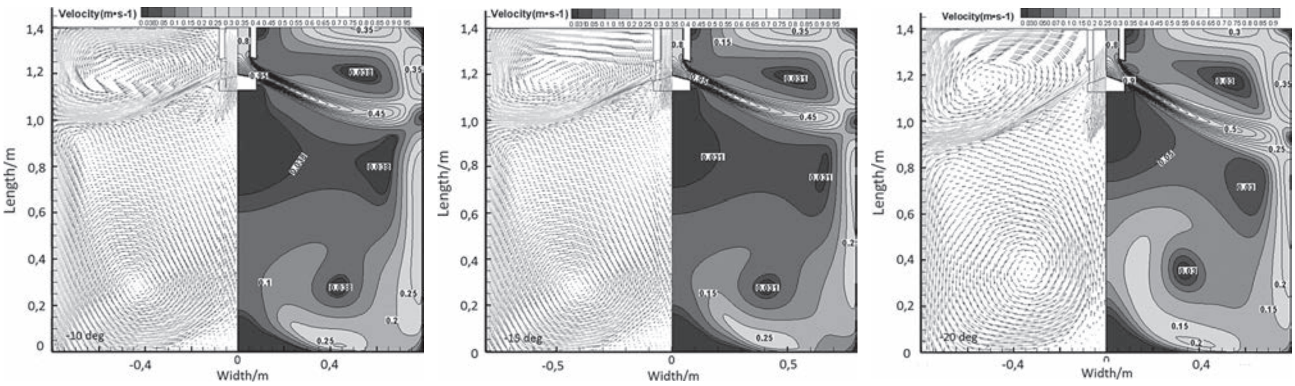


Figure 6 Free surface centerline velocity distribution

Figure 6 is the velocity distribution of the centerline of free surface at different immersion depths. The maximum velocity decreases from 0,36 m/s, 0,283 m/s to 0,28 m/s. The velocity of slag interface decreases, which can effectively reduce the fluctuation of liquid level and the involvement of slag, thereby avoiding the occurrence of new inclusions.

Influence of nozzle angles on flow field in the mold

Figure 7 is the velocity vector diagram and contour map. The nozzle angles are -10 deg, -15 deg, and -20



a b c

Figure 7 Velocity vector and contour map, a, b and c

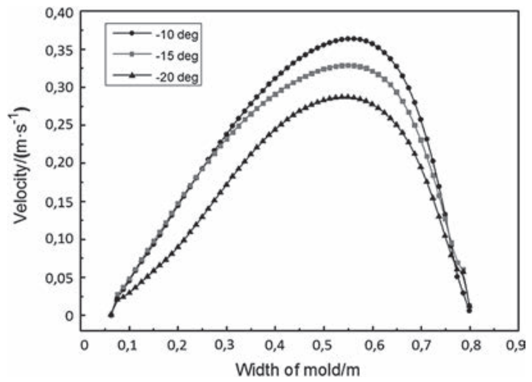


Figure 8 Free surface centerline velocity distribution

deg respectively. It can be seen from the figure that the influence of nozzle angles on the flow field is significant. When the nozzle angle is -10 deg, the trend of upper molten steel flowing upwards becomes more intense. It is easier to cause the phenomenon of slag entrapment and secondary oxidation. When the nozzle angle becomes larger, the obstructing effect of the nozzle decreases and the jet flow flows smoothly. But the outlet velocity of jet flow changes slightly, which varies from 0,9 m/s to 0,95 m/s.

Figure 8 is the velocity distribution of free surface centerline at different nozzle angles. The angle changes from -10 deg to -20 deg, the maximum velocity decreases from 0,34 m/s to 0,283 m/s. Because of the small angle, the ejection angle of jet flow gradually tends to horizontal, and the impact position of right narrow surface is higher.

CONCLUSIONS

(1) The basic characteristics of wide slab mold show that the velocity of the flow strand reaches its peak near the nozzle after the strand is ejected from the nozzle. But with the increase of distance from the nozzle, the central flow velocity decreases gradually, which shows the essential characteristics of jet flow.

(2) Casting speed is an important factor affecting the flow field. Nozzle angle also has some influence on the flow field. When the angle changes from -20 deg to -10 deg, resulting in the bareness of molten steel on the right narrow surface.

(3) In terms of the wide slab mold with a section size of 230 mm×1 600 mm, the simulation results can provide a theoretical basis for the practical continuous casting process.

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Note: X. Huang is the master degree candidate and responsible for English language.