Numerical simulation of flow field of molten steel in the caster mould

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Abstract. In order to analyse the molten steel flow in the mould, a 2D model including the mould and the SEN was established. The fluctuation of molten steel on the meniscus of the mould and the steel flow velocity field in the mould and nozzle were analyzed. The calculation results show that: (1) the steel flow velocity field in the mould was the highest in the nozzle area. When liquid steel flows out of the SEN, its flow velocity decreases gradually. (2) There were three regions flow in the mould. There were two reflux areas outside the nozzle, the dividing line is the free surface, and the other reflux area is 0.2 m~0.9 m. The liquid steel within 0.9 m~1.5 m flows vertically downward. (3) The free surface near the nozzle is high, while the free surface away from the nozzle is low. The free surface is the lowest at 0.1 m and the highest at 0.06 m.

1. Introduction

At present, the continuous casting technology has made continuous progress, which has significantly improved the production speed. However, this also increased the disturbance of the meniscus of the mould, and then intensified the liquid level fluctuation of the mould, causing slag curling and molten steel entraining powdery inclusions into the mould, which will lead to surface defects [1, 2]. The mould is the key equipment in the continuous casting production process, also known as the "heart" of the continuous caster. At the same time, it is also the last process to remove inclusions and adjust the cleanliness of liquid steel. The flow state of liquid steel in the mould and the flow characteristics of liquid steel surface will directly affect the quality of slab. Therefore, the mould plays a vital role in the steelmaking process. In recent years, with the rapid development of computer science and technology, numerical simulation has been widely used in the field of continuous casting simulation.

Thomas investigated the turbulent flow of liquid steel in a continuous casting mould with time-averaged K–ε and transient LES computational models. The predictions were compared both qualitatively and quantitatively with velocities measured using PIV on a 0.4-scale water model and with MFC sensor measurements in an operating steel caster. The results compare the abilities of these four methods, in addition to providing new insights into flow phenomena in this process [3]. In the mould water model experiment, Mr. Shen used relevant professional technology to study the instability factors of liquid level fluctuation and fluid flow in the two hole submerged nozzle thin slab continuous casting mould, as well as the relationship between the swing of reflux center and the change of meniscus shape with time. The probabilities of fluctuated meniscus and swing circumference center position seem Poisson distributions with the highest frequency near the average position [4]. By simulating the coupled fluid flow and solidification in the cold zone of thin slab caster, Zarea concluded that there were two reflux zones from the lower part and two vorticity zones from the upper part when the flow field was stable, and predicted the temperature and solid fraction in the mould pool.
by solving the verified fluid flow profile energy program [5]. Calderón-ramos studied the liquid steel flow field of three kinds of SENs, and came to the conclusion that the orifice shape of the nozzle had a great influence on the liquid steel flow field in the nozzle [6]. Wang used CFD software to analyze fluctuation of meniscus in 150 ×1270mm slab mould, and found that the physical simulation results are in good agreement with the software simulation results [7, 8].

In this paper, the flow velocity field of molten steel in the mould was analyzed by the method of computational fluid dynamics. Through the calculation results, the liquid level fluctuation at the meniscus of the mould was described in detail, and the guidance for on-site production was given in order to produce high-quality special steel products.

2. Model and boundary conditions

2.1. Physical model

In order to investigate the flow velocity field of molten steel in the mould, a 2D model including the mould and the SEN was established, as shown in Fig. 1. The height of the mould is 780 mm, in order to make the calculation results more accurate, the height of calculation domain is extended to 1500 mm, and the size of billet is 250 mm ×250 mm.

![Figure 1. The physical model of mold used in the simulation.](image)

2.2. Boundary conditions

During the calculation, the boundary of the calculation was:

1. Steel throughput inlet: the steel throughput was calculated according to the production drawing speed and billet specification. The production drawing speed was 1.08 m/min and the billet specification was 250 mm × 250 mm.

2. Symmetry and meniscus: the velocity perpendicular to the surface and the normal gradient of the surface are zero.

3. Outlet speed: 1.08 m / min (casting speed).

The relevant parameters of molten steel pouring were shown in Table 1.

| Item       | Value       |
|------------|-------------|
| Density    | 7000 kg·m⁻³ |
| Viscosity  | 0.0063 Pa·s  |
3. Results and discussion

Figure 2 shows the contour of the liquid steel flow velocity in the mould. The figure shown that the velocity of liquid steel was the largest in the SEN area. When liquid steel flows out of the SEN, its flow velocity decreases gradually. In addition, it can be seen that the liquid steel flow speed is small on the side close to the copper plate of the mould.

![Figure 2. Velocity distribution of liquid steel in the mould.](image1)

Figure 3 shows the flow velocity vector of liquid steel in the mould. The figure shown that when the molten steel flows out from the nozzle to 0.9 m, there is always reflux in the mould. In addition, two backflows were formed outside the nozzle due to the existence of free liquid surface. In the area of 0.9 m~1.5 m, the flow direction of molten steel is basically consistent with the direction of casting speed.

![Figure 3. Velocity vector distribution of liquid steel in the mould.](image2)
Figure 4 shows the stream line of molten steel in the mould. It can be seen from the figure that there are three reflux areas of molten steel flow in the mould. There are two reflux areas outside the nozzle, the dividing line was the free surface, and the other reflux area is 0.2 m ~ 0.9 m. The liquid steel within 0.9 m ~ 1.5 m flows vertically downward.

Figure 4. Stream line of liquid steel in the mould.

Figure 5 shows the fluctuation of free surface of liquid steel in the mould. From the figure, it can be seen that the free surface near the nozzle is high, while the free surface away from the nozzle is low. The free surface was the lowest at 0.1 m and the highest at 0.06 m. It should be pointed out that the fluctuation of free surface is determined by the characteristics of molten steel flow in the mould.

Figure 5. Free surface fluctuation in the wide surface of mould.

4. Conclusions
In order to study the flow velocity field of molten steel in the mould, a 2D mould model including nozzle was established. The flow characteristics and meniscus fluctuation in the mould were analyzed. The results shown as follow:

(1) The velocity of molten steel is the highest in the SEN area. When liquid steel flows out of the nozzle, its flow velocity decreases gradually.
There are three regions of molten steel flow in the mould. There are two reflux areas outside the nozzle, the dividing line is the free surface, and the other reflux area is 0.2 m ~ 0.9 m. The liquid steel within 0.9 m ~ 1.5 m flows vertically downward.

The free surface near the nozzle is high, while the free surface away from the nozzle is low. The free surface is the lowest at 0.1 m and the highest at 0.06 m.

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