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Flow and Temperature Fields in Slab Continuous Casting Molds

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Abstract: In order to develop super-board and super-thick slabs, the flow and temperature fields were studied in slab continuous casting molds under different practical conditions, such as slab dimensions, with-drawing slab speed, design of nozzles, and superheat temperature. The results showed that it is preferred to incline nozzle bores downwards and the submerged depth of the nozzles is best kept between 250–300 mm. In addition, the solidified shell is thicker at the wide face than that at the narrow face, while the thin points along the wide face exist both in the center and in the some area toward each respective end.

Key words: slab continuous casting mold; flow field; temperature field; mathematical model

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The slab caster of Wuyang Steel Complex has the characteristics as follows. The width of slab is 1.3 to 1.9 m, the thickness is 210, 250, 300 mm respectively, and the length of the caster is only 28.2 m. Since the length of the caster is shorter than that of other factories, the casting speed has to be kept low, such as 0.8m/min.

In order to study the possibility of manufacturing the super board and thick slabs by continuous caster in Wuyang steel complex, the flow field and temperature field of the mould were investigated under the conditions of actual process.

There have been many achievements in the research on flow and temperature fields in the mould [1–4], mostly on the single flow flied or temperature flied. However, in the most cases, either the flowing feature has not been considered or the convection situations have not been modified by increasing the heat transfer coefficient. Therefore, a coupling method is used to solve the equations of flow flied and temperature flied in this paper.

1 Governing equations

The continuity equation

$$\frac{\partial(\rho u_i)}{\partial x_i}=0 \tag{1}$$

The momentum equation

$$\frac{\partial(\rho u_i u_j)}{\partial x_j}=\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu_e\left(\frac{\partial u_i}{\partial x_i}+\frac{\partial u_j}{\partial x_j}\right)\right]+(\rho-\rho_1)g \tag{2}$$

The effective viscosity μ_e is given by k–ε two-equation model [1].

The energy equation

$$\frac{\partial}{\partial x_j}(\rho c_p T u_j)=\frac{\partial}{\partial x_j}\left(\frac{\mu_e}{\sigma_T}\cdot\frac{\partial T}{\partial x_i}\right)+\dot{S} \tag{3}$$

where $\dot{S}$ is the source term generated by solidification.

$$\dot{S}=\rho H_f u_j\frac{\partial f}{\partial x_j},$$

where H_f is the latent heat of solidification and f is the solidification rate. From reference [2], the general formula can be dealt with as

$$f=\begin{cases}0 & T>T_l\\(T_l-T)/(T_l-T_s) & T_s\le T\le T_l\\1 & T<T_s\end{cases} \tag{4}$$

where T_l and T_s are the thermodynamic temperature of the liquidus and the solidus in phase diagrams respectively. These computer programs have been developed by the authors of this paper.

There are nine cases simulated in **table 1**. In calculation of the temperature field, the superheat degrees are mainly chosen at 12℃ besides a choice of 32℃ to the case 3.

2 Analysis and discussion

2.1 Basic explanations of flow field and temperature field in molds

Molten steel runs out from nozzles and flows linearly to the narrow face of the mold. While moving forward, the jet is expanding so that the speed of the flow slows down. After the flow arrives at the narrow face, the jet can be divided into two parts: the downward and the upward. The downward is the main part which goes

Table 1 Conditions for the simulation.

No.	Slab dimensions mm×mm	Submerged depth / m	Inclination angle of nozzles /(°)	Outlet area of nozzles mm²	Casting speed /m·min⁻¹
1	1 800×250	250	+15	83×65×2	0.8
2	1 800×250	350	0	83×65×2	0.8
3	1 800×250	250	−15	83×65×2	0.8
4	1 800×250	300	−15	83×65×2	0.6
5	1 800×250	300	−15	83×65×2	1.3
6	1 900×250	300	−15	83×65×2	0.8
7	1 800×250	250	−8	83×65×2	0.8
8	1 800×250	250	−15	65×65×2	0.8
9	1 800×250	300	+15	83×65×2	0.8

down along the narrow face of the mold until a certain depth (normally about 2–3 m), called penetration depth, then forms an inverse flow upward in the center of the mold. This flow pattern has an effect on dendrites growth because the concentration barrier, generated by selective crystallization, is removed off by the downward movement of fresh molten steel. Moreover, here exists a greater temperature gradient. Heat is lost through the mold walls because of cooling water. The upward flow also forms an inverse flow in the upper part of the mold. This flow will affect the melted thickness of shielding slag above the steel in molds.

The distribution of isothermal contour also agrees with the flow pattern. The conditions in **figures 1 and 2** are: case 3; 20# steel made in China; the teeming temperature, 1540℃; and the overheat temperature, 32℃. It shows that the temperature of the jet is dropped rapidly after molten steel flows out of nozzles (figure 2, this is an enlargement of the area around the nozzle). This is because the lower temperature liquid of the inverse flow surrounding the jet path has been absorbed into the jet.

The solidified shell is usually a little thinner at the wide face than that at the narrow one. In these results, the difference is 1 mm only. The average thickness of the solidification shell is larger than 21 mm when it goes out of the mold according to the cooling intensity. The variation of the shell thickness at the wide face of

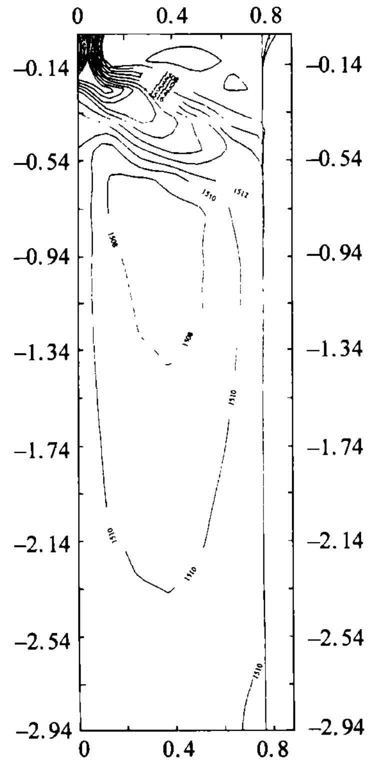

Figure 1 Temperature contour at the section of the center in the mold.

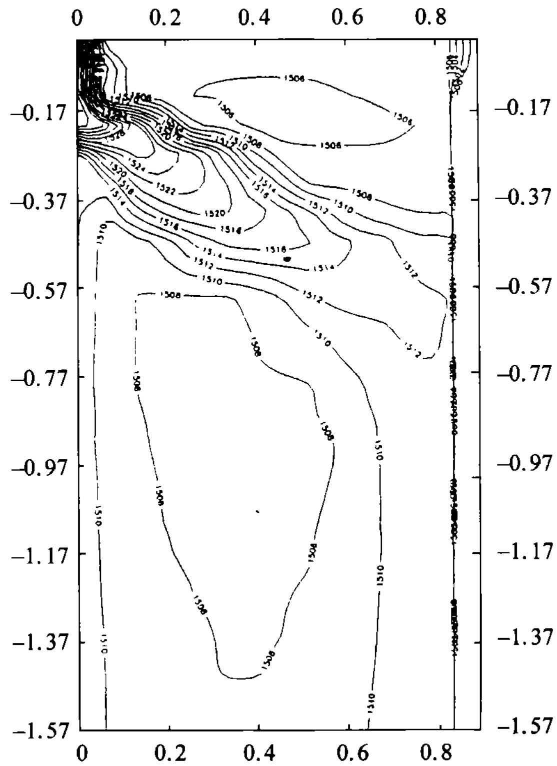

Figure 2 Enlargement of the temperature of the temperature contour in area around the nozzle.

the mold is different from that at the narrow one (**figure 3**). With the wide, the variation of thickness of shells from the center to the corner of the mold is a curve-like distribution. Therė are two thin places in the shell. They are in the center and in the quarter near the corner of the mold. In other words, these two positions are the most possible ones to experience the breaking-out during the practical process of steel production. This result has not surprised to us because this variation of the shell thickness can be compared with the flow patterns. However, the variation of the shell thickness in the narrow face is different. It increases gradually from the center to the corner of the mold.

2.2 Effects of the nozzle design

The inclination of the nozzle bores is often downward. The upward inclination of the nozzle has been studied in order to increase the flow rate at the upper part of the mold (**figure 4** (a), case 1). However, the upper inverse flow can suppress the upward jet out of the nozzles into a horizontal flow. Since the space at the upper part of the mold is not large enough to develop well the upper inverse flow, the flow speed at the surface of the mold rises only a little.

The flow pattern is almost the same and the surface speed is no different when the downward inclination angle of nozzles changes from −15 to −8°.

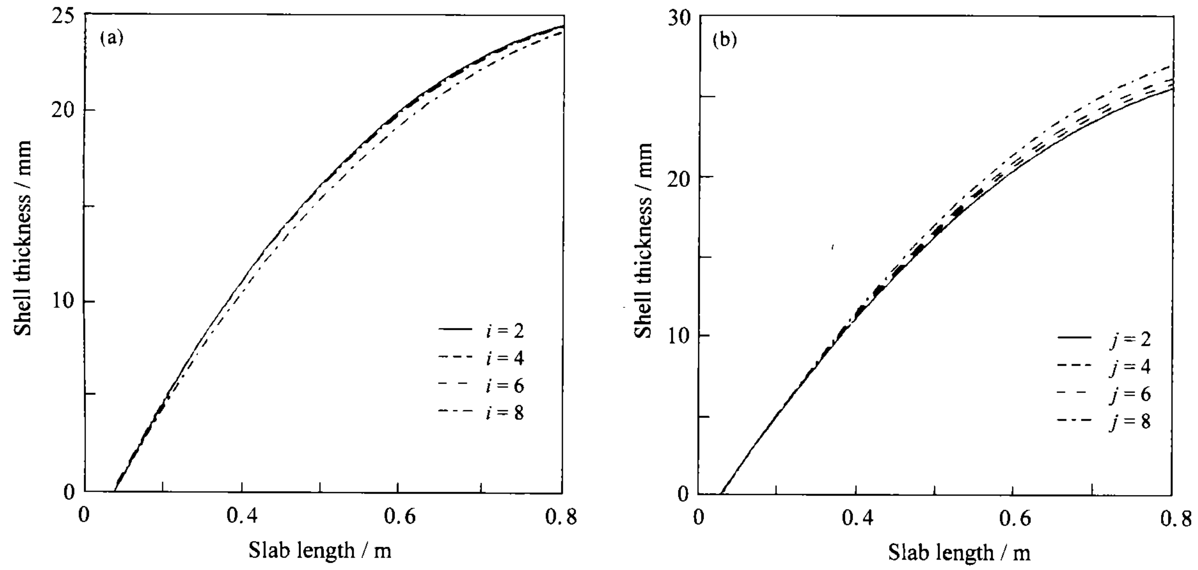

Figure 3 Variation of the shell thickness at the wide face of the mold (a) and at the narrow face of the mold (b).

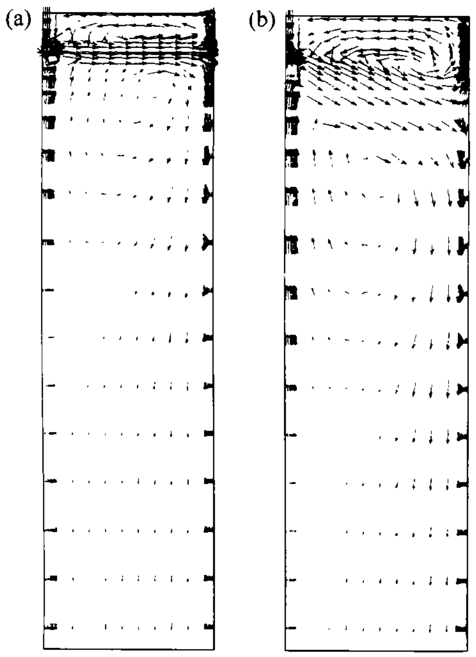

Figure 4 Flow patterns at the section of the center in the mold (a) when the inclination of the nozzle bores is +15° and (b) while the size of the slab is 1 900 mm × 300 mm, respectively.

When the outlet area of the nozzles is reduced, the outlet speed of the liquid rises. It is somehow similar to the effect of the withdrawing slab speed. If the area of the nozzles is too large, the inverse flow can flow into the nozzle bores, since the flow has to cover the total outlet area. In that case, the surface speed of the mold is decreased greatly.

2.3 Effects of withdrawing slab speed

The flow patterns have no change when the withdrawing slab speed is varied from 0.8 to 1.3 m/min. However the absolute values of speed at the flow fields rise if the withdrawing speed is increased.

2.4 Effects of slab dimensions

Slab dimensions do not alter the flow patterns again, although in the larger slab dimensions more space will be supplied. The flow speed is proportionally reduced at each point. To the thickness of the shell, it keeps the same thickness as it leaves the mold, while the size of the slab is enlarged from 1800 mm×250 mm to 1900 mm×300 mm (figure 4(b)).

3 Conclusions

(1) It is preferred to incline nozzle bores downwards.

(2) The submerged depth of the nozzles is best kept between 250–300 mm.

(3) The solidified shell is thicker at the wide face than that at the narrow face, while the thin points along the wide face exist both in the center and in the some area toward each respective end.

References

[1] Y. He, Y. Sahai: *Acta Metallurgica Sinica* (English Edition), Series B, 2(1989), No.5, p.301.
[2] Y. Zhang, L. Ding, B. Li, *et al.*: *Industrial Heating* (in Chinese), 1996, No.3, p.6.
[3] Q. Liu, N. Tian, Y. Wang, *et al.*: *Steelmaking*, 1996, No.6, p. 7.
[4] M. Zhu. *The Chinese Journal of Nonferrous Metals* (in Chinese), 7(1997), Suppl.1, p.64.
[5] B. Li, Y. Zhang, J. He: *J. of Univ. of Sci. and Tech. Beijing* (in Chinese), 17(1995), Suppl., p.22.