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MATHEMATICS SIMULATION AND EXPERIMENTS OF CONTINUOUS CASTING WITH STRIP FEEDING IN MOLD

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Steel strip feeding technology can reduce the degree of superheat of the molten steel, change the solidification order of the molten steel; raise the equiaxed crystal rate of the slab and improve the continuous casting quality. The paper establishes the mathematical model of heat transfer and temperature field of casting billet of steel strip feeding in continuous casting mold. Results show that if Plate Billet is 1 000 mm × 220 mm and the steel strip is 100 mm × 3 mm, feeding position of parallel is 250 mm from the narrow side. When the feeding speed is 3,6 m/min, the superheat degree can be reduced by 5 °C, and the solidification length can be reduced by 2,9 m. When the feeding speed is 6 m/min, the superheat degree can be reduced by about 9 °C, and the solidification length can be reduced by 3,7 m. The results of the test in a steel plant are in good agreement with the experimental results.

Key words: steel continuous casting, strip feeding, mathematical model, superheat temperature

INTRODUCTION

Continuous casting mold is an important component of the continuous casting machine; removal of molten steel heat in crystallizer is decisive to the improvement of the efficacy of continuous casting, forming of the inside and outside high-quality casting blank and the guarantee of the homogeneity of the initial solidified shell. Therefore, studying the solidification and heat transfer of casting blank in the crystallizer is of great significance[1-6]. In this paper, the mathematical model of heat transfer and temperature field of casting billet of steel strip feeding in continuous casting mold is established.

MATHEMATICAL MODEL ESTABLISHMENT

Basic condition setting

Composition of steel: C is 0,17 %, Si is 0,35 %, Mn is 1,4 %, S is 0,03 %, P is 0,03 %, The casting speed is 1,2 m/min. The casting temperature is 1 540 °C. The plans of strip feeding speed are 3,6 m/min, 6 m/min and 12 m/min, Steel strip cross section is 100 mm × 3 mm. Slab section is 1 000 mm × 220 mm. The feeding position is parallel to the narrow surface and 250 mm from the narrow edge. Sketch of slab model is showed by Figure 1.

The heat transfer control equation[6]:

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

(a) without strip feeding

(b) with strip feeding

Figure 1 Slab section model

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.

In this paper, the model is calculated and analyzed by using the method of 2D section traveling. Due to lateral (the wide and narrow faces of casting billet) heat transfer was much higher than that of the casting direction, the heat transfer of the casting direction is ignored. Molten steel flow is set as incompressible flow. The thermal conductivity is isotropic. The thermal physical properties of steel are only related to temperature. Considering the influence of continuous casting of molten steel flow on heat transfer, set the thermal conductivity of liquid steel as 5 times for absolute thermal conductivity[7]

Figure 2 Mesh generation of the slab without strip feeding

Figure 3 Mesh generation of the slab with strip feeding

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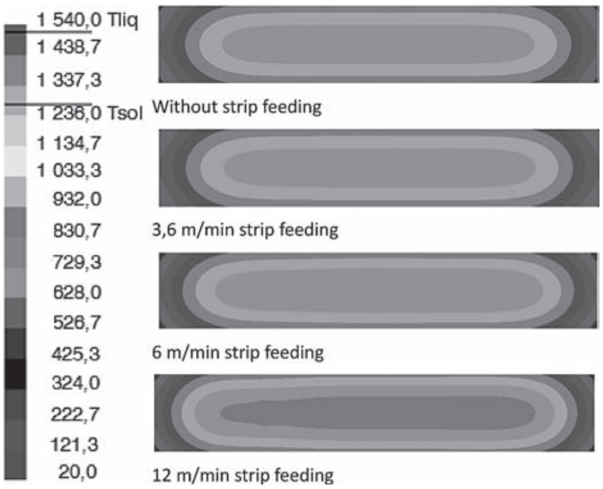


Figure 4 Comparison of temperature field in the end of solidification simulation

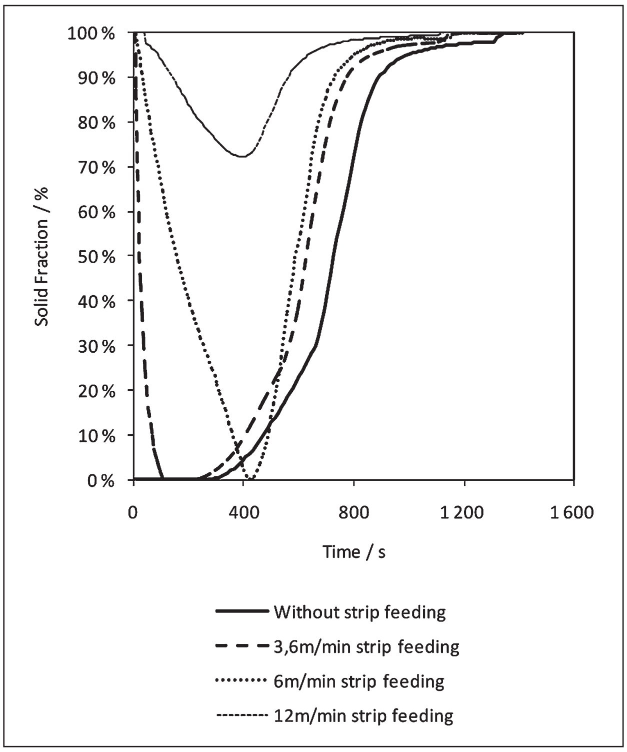


Figure 5 Comparison of the solid phase fraction curve

Mesh generation without strip feeding is shown by Figure 2, and the one with strip feeding is shown by Figure 3.

Initial conditions and boundary conditions

Initial conditions:

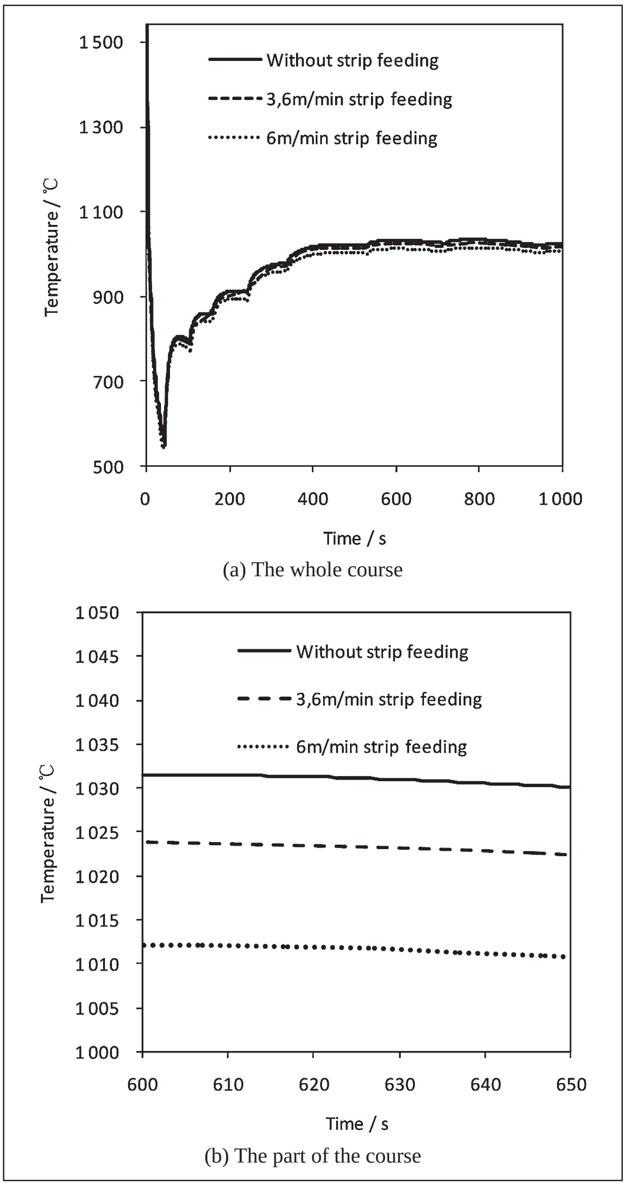
Liquid steel: $T = T_{st0}$, steel strip: $T = T_{cu0}$.

Boundary conditions:

1) Heat flux between molten steel and mold:

$$q_1=h_1\times(T_{st} - T_{cu}) \tag{2}$$

Where q_1 is heat flux between molten steel and mold / W/m^2, T_{st} is steel temperature / °C, T_{cu} is mold temperature / °C, h_1 is comprehensive heat transfer coefficient between molten steel and mold / W/m^2 /°C.



(a) The whole course

(b) The part of the course

Figure 6 The comparison of temperature curves of different schemes in middle of narrow face

$$\frac{1}{h1} = \frac{1}{h_{st-slag}} + \frac{1}{h_{slag}} + \frac{1}{h_{slag-cu}} \tag{3}$$

Where $h_{st\text{-}slag}$ is contact heat transfer coefficient between steel and slag / W/m^2 /°C, h_{slag} is equivalent heat transfer coefficient of slag / W/m^2/°C, $h_{slag\text{-}cu}$ is contact heat transfer coefficient of mold and slag / W/m^2 /°C.

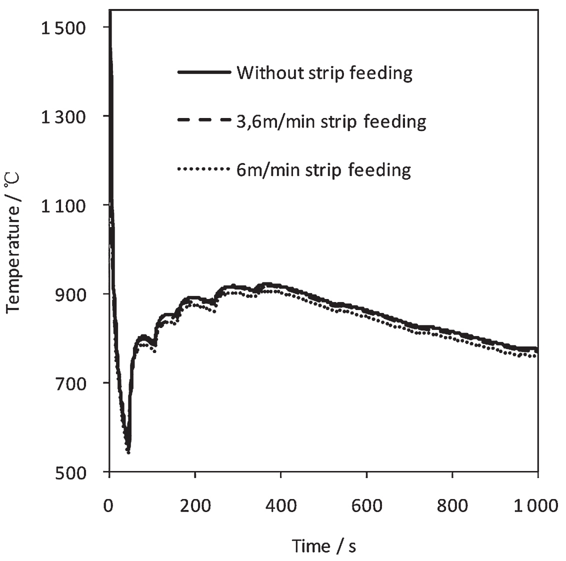
2) Heat flux in secondary cooling zone:

$$q_2==h_2\times(T_{st} - T_{wa}) \tag{4}$$

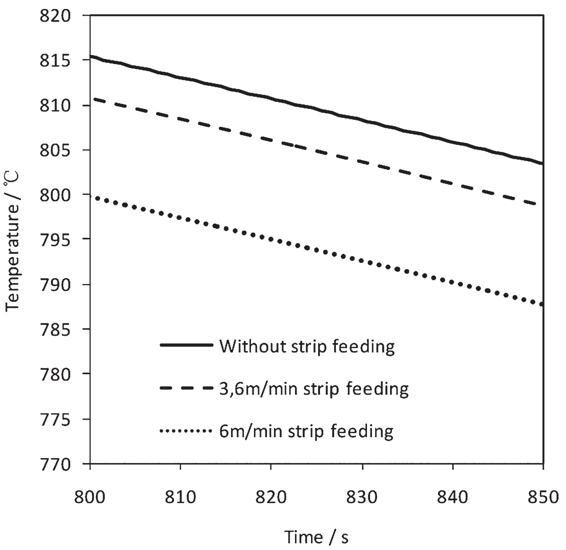
Where q_2 is heat flux in secondary cooling zone / W/m^2, T_{st} is steel temperature / °C, T_{cu} is cooling water temperature / °C, h_2 is equivalent heat transfer coefficient of cooling water / W/ m^2/°C.

The results and analysis

Figure 4 is comparison of temperature field in the end of solidification simulation with maximum temperature 1 200 °C.



(a) The whole course



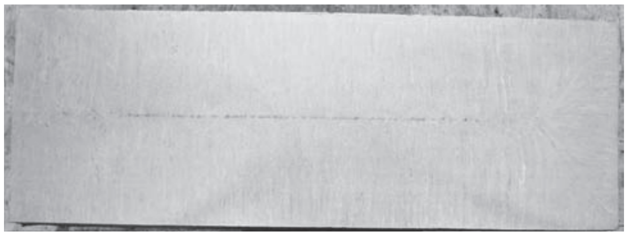
(b) The part of the course

Figure 7 The comparison of temperature curves of different schemes in middle of width face

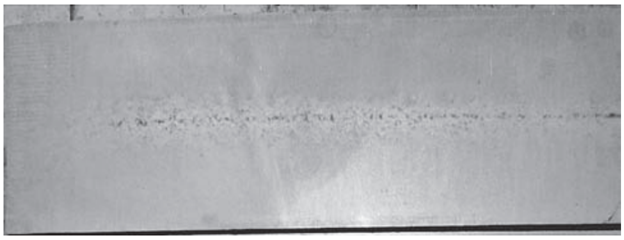
The results show that the temperature field of the slab with strip feeding is changed due to the cooling effect of the strip, especially in the vicinity of the steel strip.

Figure 5 is the comparison of the solid phase fraction curve under different schemes.

According to the curve data, the solid phase fraction of slab without strip feeding gets to 1 at 1 345 s and the length of the liquid core length is 26,9 m. When the feeding speed is 3,6 m / min, the steel strip is completely melted after about 100 s, and then gradually solidified, the center of the slab is completely solidified at about 1 200 s, and the liquid core length is 24 m. When the feeding speed is 6 m / min, the steel strip is completely melted by about 430 s, and the center of the slab is completely solidified at about 1 160 s. Its liquid core length is 23.2 m. And when the feeding speed is 12 m / min, the solid phase fraction of steel strip is the smallest at about 400 s, but it is not completely melted at this time, the solid phase rate is about 0,72, so this parameter is not desirable in the production practice.



(a) Without strip feeding



(b) 3,6 m/min strip feeding

(c) 6 m/min strip feeding

Figure 8 The pictures of macrostructure of the test slabs

Figure 6 and Figure 7 are comparison of temperature curves of different schemes in middle of narrow face and the width face.

The results show that under the condition of faster strip feeding speed, the surface temperature of slab is lower because of the cooling effect of the steel strip. According to the calculated data, compared with the slab without strip feeding, when the feeding speed is 3,6 m/min, the superheat degree is reduced by 5 °C, and the superheat degree is reduced by 9 °C when the feeding speed is 6 m/min.

Industrial test

The test parameters were the same as the simulation parameters, and the feeding speed 3,6 m/min and 6 m/min test were carried out. The Figure 8 shows picture of macrostructure of the test slabs.

The pictures show that the middle equiaxed dendrite is almost invisible in slab without strip feeding. And the dendrite is very developed, almost to the center of the slab. The central segregation is concentrated. And under the condition of 3,6 m/min feeding speed, the central segregation appeared to be scattered trend, but the effect is not ideal. Measurement shows the equiaxed crystal width is about 40 mm. The dispersion of central segregation is better under the condition of 6 m / min. Measurement shows the equiaxed crystal width is about 85 mm. And the macro structure of the slab is changed with the middle equiaxed crystal and the central segregation is decentralized, and then the internal quality of the slab is improved.

CONCLUSION

The results show that the liquid core length can be shortened. Compared with the slab without strip feeding, the liquid core length is reduced by 2,9 m when the strip feeding speed is 3,6 m/min and 3,7 m is reduced when the strip feeding speed is 6 m/min.

When the steel strip feeding speed increases, the cooling effect of steel strip is enhanced. Compared with the slab without strip feeding, the superheat is decreased by 5 °C with 3,6 m/min strip feeding and the superheat is decreased by 9 °C with 6 m/min strip feeding.

When the feeding speed is too fast, the steel strip cannot melt completely in the molten steel. In the actual production of this situation is undesirable.

The industrial tests show that internal quality of the slab with strip feeding is better than the one without strip feeding. Compared with the slab with 3,6 m/min strip feeding, the slab with 6 m/min strip feeding equiaxed crystal rate has been improved, and central segregation is more decentralized.

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