Z. S. ZHANG, X. L. ZHU, M. G. SHEN, G. W. AO

ISSN 0543-5846
METABK 59(4) 467-469 (2020)
UDC – UDK 669.18.002:66.065:621.56/59:518.1=111

SIMULATION STUDY ON EFFECT OF CHASSIS WATER COOLING ON SOLIDIFICATION OF ELEVEN TONS FLAT STEEL INGOT

Received – Primljeno: 2020-05-30
Accepted – Prihvaćeno: 2020-07-20
Original Scientific Paper – Izvorni znanstveni rad

In this paper, the solidification process of eleven tons flat steel ingot is simulated by the finite element analysis software PROCAST, and the solidification state of the ingot with and without chassis is analyzed and compared. The results show that the forced cooling chassis makes low temperature area of the bottom ingot enlarged. And it has little influence on the temperature field and the solidification speed of the upper ingot. For the small flat steel ingot, the forced cooling chassis will deteriorate the shrinkage.

Key words: flat steel ingot; solidification; forced cold chassis; temperature; numerical simulation

INTRODUCTION

The internal quality of flat steel ingot is a direct impact on the rolled thick plate products. And the internal quality of ingot often depends on its external cooling conditions. So the control of ingot cooling is particularly important in steel ingot production [1-3]. The water cooling method of the chassis can strengthen the bottom cooling intensity of the steel ingot, change the temperature field, make the isotherm move up and influence the angle of the solidification front, which is conducive to change the ingot segregation and looseness, and it can be applied to various casting processes [4-6]. In this paper, the effect of bottom forced cooling on the solidification process of eleven tons ingot is studied. The change of temperature field and the internal loose distribution of flat steel ingot is analyzed

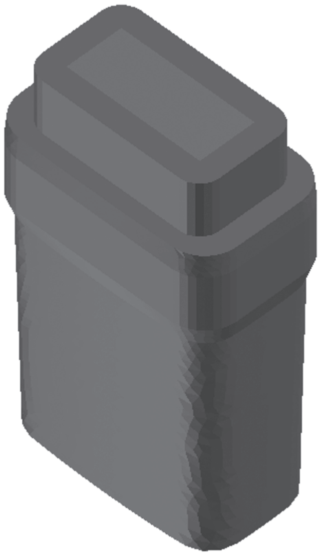


Figure 1 Geometric model

CALCULATION MODEL ESTABLISHMENT

Geometric model and grid partition

In this paper, the process of solidification of eleven tons flat steel ingot is simulated. The geometric model is shown in Figure 1.

The model grid partition is shown in Figure 2. The number of grid nodes is 84 842 and the number of tetrahedron elements is 401 458.

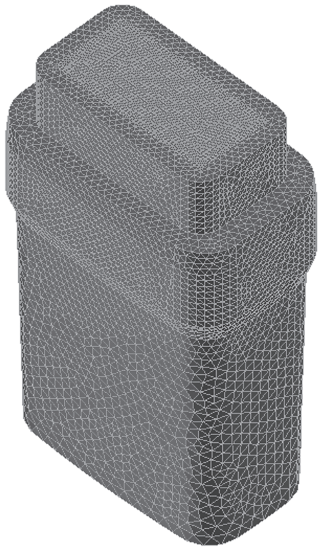


Figure 2 Model grid partition

Z. S. Zhang: lnaszzs@163.com, G.W. Ao, Applied Technology College, University of Science and Technology of Liaoning, Anshan City, China.
X. L. Zhu: State Key Laboratory of Metal Materials for Marine Equipment and Application of Iron & Steel Research Institutes of Ansteel Group Corporation, Anshan city, Liaoning, China
M. G. Shen,: College of Materials and Metallurgy, University of Science and Technology of Liaoning, Anshan City, China.

Governing equation and setting of simulation conditions

The heat transfer governing equation [6]:

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

Where T is temperature / °C, ρ is steel density / kg/m3, λ is thermal conductivity / W/m/°C, c is specific heat / J/kg/K.

Heat flux calculation is:

$$Q = h \times (Tm - Tc) \quad (2)$$

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

Initial conditions are:

Liquid steel: T = Tst0, mould: T = Tm0.

Composition of steel: C is 0,17 %, Si is 0,35 %, Mn is 1,4 %, S is 0,03 %, P is 0,03 %.

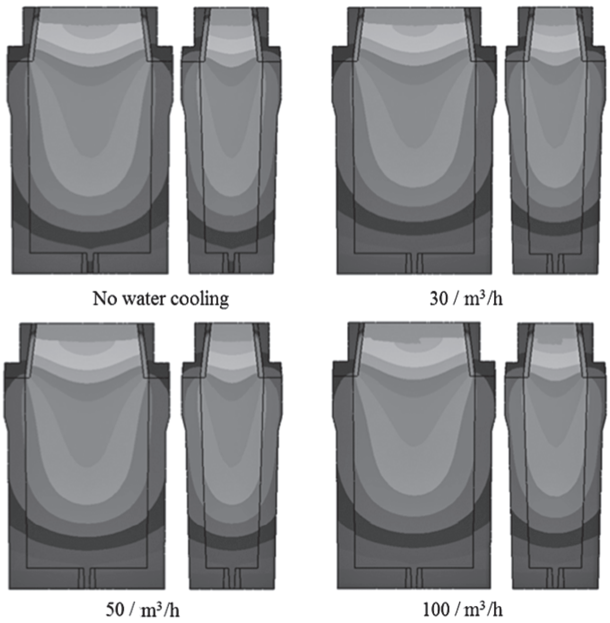
Composition of mould, C is 3,44 %, Si is 1,63 %, Mn is 0,8 %, S is 0,008 %, P is 0,017 %.

In the simulation, the thermal conductivity is isotropic, the thermal physical parameters of molten steel is only a function of temperature. The temperature of bottom cooling water is 20 / °C. The cooling water flow is set as three schemes, namely, 30 / m^3/h, 50 / m^3/h and 100 / m^3/h. The casting temperature of molten steel is 1 530 / °C, and the initial temperature of the ingot mold and insulating board is 100 / °C.

SIMULATION RESULTS AND ANALYSIS

Comparison of ingot temperature results of different chassis cooling schemes

Figure 3 shows the comparison of the calculated temperature field at the end of ingot for each chassis cooling scheme. It can be seen from the figure that the high temperature isotherm of the ingot moves up due to the water cooling measures of the chassis, and the greater the cooling strength is, the greater the range of the isotherm moves up. The cooling of the base plate has little effect on the shape of the isothermal surface of the upper part of the ingot. It also has little influence on the advance of the solidification front in the middle and later stage of solidification. This is because the heat transfer of the upper liquid steel in the direction of gravity needs to pass through the lower liquid steel or solid steel before it can be transmitted to the water-cooled chassis, and the limiting link of this heat transfer process is the lower metal of the ingot with low thermal conductivity, which results in the heat dissipation condition of the upper liquid steel similar to that of the ingot without water-cooled chassis.


No water cooling

30 / m³/h

50 / m³/h

100 / m³/h

Figure 3 Comparison of temperature field at the end of calculation for each chassis cooling scheme

Figure 4 is a comparison of the minimum distance between the isotherm of 328 / °C and the bottom of the mould under different chassis cooling schemes. The water-cooled chassis can obviously push up the high temperature isothermal surface and expand the low temperature area at the bottom of the steel ingot. The distance between the corresponding isothermal surface and the bottom surface of the mould is 26,73 / cm in no water cooling scheme, 38,51 / cm in 30 / m^3/h, 39,84 / cm for 50 / m^3/h and 42,47 / cm for 100 / m^3/h, respectively.

It can be seen from Figure 4 that in the early stage of ingot solidification, the temperature of the inner surface of the mould increases rapidly without forced cooling of the bottom part. However, the temperature of the middle and outer surface of the mould does not change at this time due to the thermal resistance of the mould. The two-dimensional cooling effect of the corner makes the corner of ingot radiate faster. In the early stage of solidification, the corner of ingot reaches a lower temperature, while the center is limited by the heat dissipa-

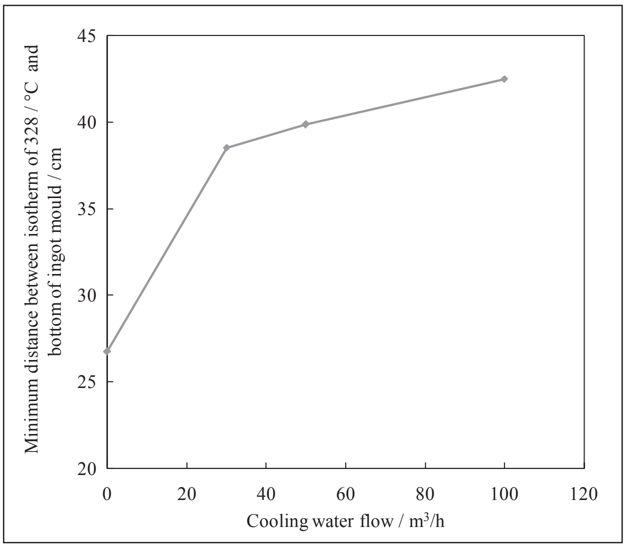
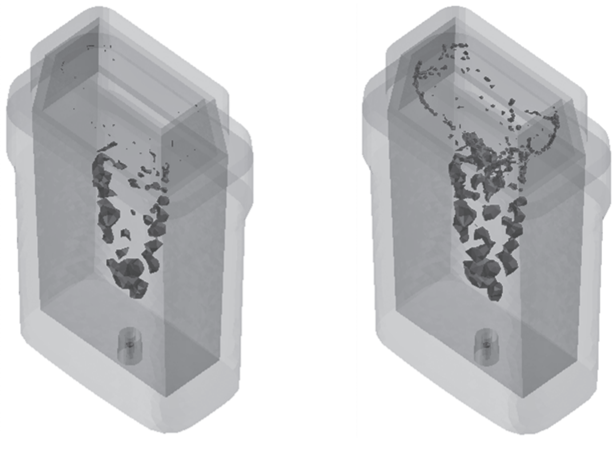
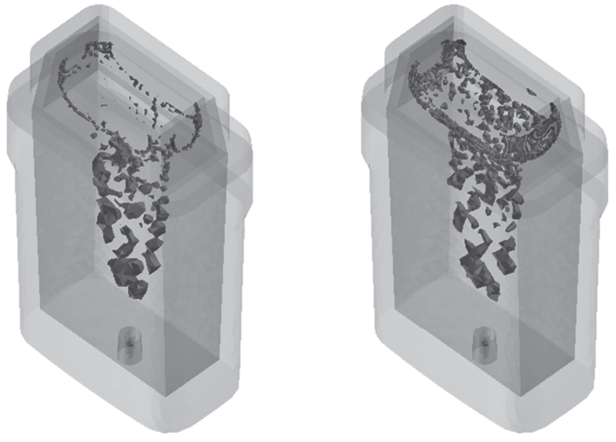


Figure 4 Comparison of the minimum distance between the isotherm of 328 / °C and the bottom of the mould under different chassis cooling schemes



No water cooling 30 / m^3/h



50 / m^3/h 100 / m^3/h

Figure 5 Shrinkage and porosity of the steel ingot under different chassis cooling schemes

tion unable to synchronize with it, a clearly inclined isotherm (relative to the horizontal plane) is formed.

Comparison of shrinkage porosity results of steel ingots with different cooling schemes

Figure 5 shows the comparison of shrinkage and porosity results of steel ingots with different chassis cooling schemes.

It can be seen from the figure that the shrinkage of the steel ingot is not improved but more serious after the water cooling measures of chassis are added. With the increase of water cooling intensity, the severity of shrinkage porosity also increases. The reason is that for the flat steel ingot simulated in this paper, the narrow section of the steel feeding channel is an important way of ingot feeding, while the water-cooling of the chassis strengthens the cooling of the middle and lower parts of the ingot, increases the solidification speed of the middle and lower parts, so that the upper part of the steel can not be effectively fed in time.

CONCLUSIONS

Compared with the ingot without water-cooling chassis, the low temperature area at the bottom of the end ingot is enlarged under the action of water-cooling chassis, and the isothermal surface moves up at 328 °C, and with the increase of cooling strength, the isothermal surface moves up, and the low temperature area at the bottom is further expanded.

Due to the limitation of heat transfer of liquid (solid) metal in the middle and lower part of the steel ingot, the water cooling has little effect on the temperature field in the upper part and the solidification front.

For the flat steel ingot mould mentioned in this paper, the water cooling of the chassis cannot improve the internal shrinkage of the ingot, and the internal quality of the ingot will get worse. The reason is that the space in the narrow direction of the ingot in this paper is too narrow, and the water cooling at the bottom leads to the poor feeding of the liquid steel, which leads to the serious internal shrinkage.

Acknowledgements

This work has been supported by The Metallurgical Engineering Laboratory.

REFERENCES

[1] G. W. Ao, M. G. Shen, Z. S. Zhang, X. D. Li. Study on Influence of Water-Cooled Stool During the Process of Unidirectional Solidification[J].The Open Materials Science Journal (2015) 9, 158-161.

[2] W. S. Li, H. F. Shen, X. Zhang. Modeling of species transport and macrosegregation in heavy steel ingots[J]. Metallurgy and Materials Transactions (2014) 45B, 464-471.

[3] L. Xiang, M. S. Geng. Design and evaluation of steel ingot shape of large flat steel ingot [J]. China Metallurgy (2016) 5, 8-14.

[4] L. Hu, C. F. Li, X. L. Meng. Development of 35t giant flat steel ingot for thick plate [J]. Steel Rolling (2003)6, 1-4.

[5] Q. Zhang. Z. H. Gao, Y. Yang. Research and development of Q345e-Z35 extra heavy plate[J]. Journal of iron and steel research (2015) 27, 73-76.

[6] W. S. Li, H. F. Shen, B. C. Liu. Numerical simulation of macrosegregation in steel ingots using a two phase model[J]. International Journal of Minerals, Metallurgy and Materials (2012) 9, 787-794.

Note: The responsible translator for English is Yan Wu, University of Science and Technology Liaoning, Anshan, China