L.W. ZHANG, C. LEI, N.N. LIU, J.P. WANG, C.J. XU

ISSN 0543-5846
METABK 63(3-4) 347-349 (2024)
UDC – UDK 669.15.26.28:621.74.04-658.281:621.775.002.3:536.45.42=111

INFLUENCE OF PROCESS PARAMETERS ON GRAIN STRUCTURE OF ROUND BILLET IN VERTICAL CONTINUOUS CASTING

Received – Primljeno: 2023-12-14
Accepted – Prihvaćeno: 2024-02-25
Original Scientific Paper – Izvorni znanstveni rad

The Zhong Yuan Special Steel (ZYSS) installed a vertical caster for the production of special steel. This vertical caster differs from the vertically curved caster, exhibiting unique inclusion behavior, stress distribution, and solidification process. Based on ZYSS's continuous casting process parameters and CAFE nucleation parameters, the chip-moving boundary method was adopted to conduct a numerical simulation of the round billet. The superheat and cooling intensity are key process parameters of continuous casting. A gradual coarsening of the macrostructure can be observed with an increase in the superheat of the liquid steel. When the superheat increases from 30°C to 50°C, the center equiaxed crystal region decreases from 63,56 % to 42,25 %. A lower cooling intensity is beneficial for improving equiaxed crystallization.

Keywords: 42CrMo steel; continuous casting; round billet; temperature field; grain structure

INTRODUCTION

With the rapid development of various projects, the market is demanding a large number of large-scale, low-cost, and high-end special steels [1]. High-alloy steel is characterized by high strength, low plasticity, and high temperature stress. In 2015, ZYSS of Henan, China installed a vertical continuous casting machine. The primary purpose of this installation was to replace a significant amount of conventional ingot casting, thereby enhancing productivity and product yield while maintaining the quality of the casting billet. The continuous casting equipment comprises a tundish, mold, secondary cooling system, and vertical roll layout, etc [2]. The temperature field and solidification organization of the round billet are simulated based on ZYSS's continuous casting process parameters. The nucleation and crystal growth that occur during the solidification of molten steel significantly affect the grain structure of the billet. This grain structure forms the basis for the internal quality of the billet and influences its composition uniformity and hardening capacity.

THE FEATURES OF VERTICAL CASTER

The structures of the vertical caster and the vertically curved caster are different, and they exhibit different inclusion behaviors, as shown in Figure 1. The inclusions will converge on the internal arc of the vertically curved caster. The structure of the vertical caster is symmetrical, and inclusions are evenly distributed [3].

Unlike the vertically curved caster, the vertical caster does not require a bending or straightening process, which significantly reduces crack defects on round billet surfaces. The ZYSS vertical caster adopts advanced three-roll clamping technology. Figure 2a shows high tensile stresses over the whole cross-section of two-roll clamping technology. Figure 2b shows that no cracks are possible with three-roll clamping technology due to compression stresses.

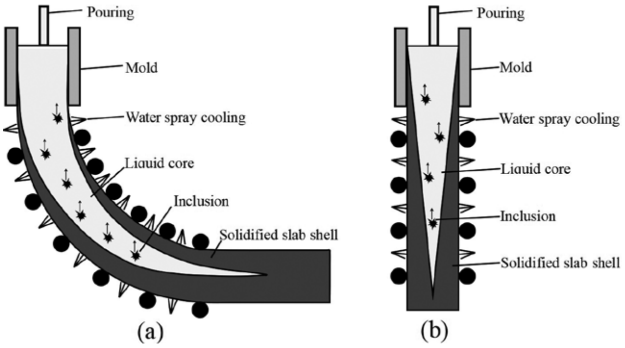

Figure 1 Inclusions movement trend of vertically curved caster (a) and vertical caster (b)

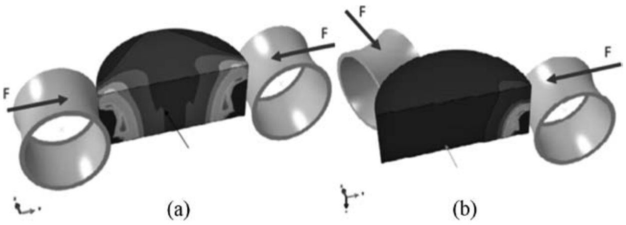

Figure 2 Pressure field of vertically curved caster (a) and vertical caster (b)

L.W. Zhang, J.P. Wang: School of Materials Science and Engineering, Yingkou Institute of Technology, Yingkou, China. C. Lei, N.N. Liu: Zhongyuan Special Steel CO. LTD, Jiyuan, China. C.J. Xu: School of Materials and Metallurgy, University of Science and Technology Liaoning, Anshan, China. Corresponding author: L.W. Zhang (zhanglianwang92@163.com). J.P. Wang. (283295486@qq.com.)

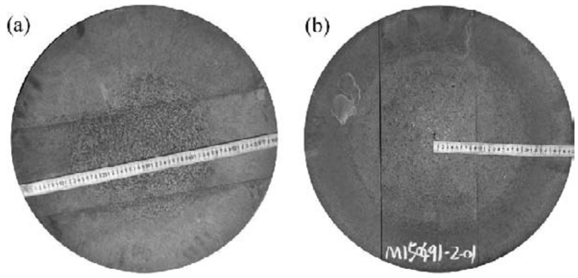

Figure 3 Billet grain structure of vertically curved caster (a) and vertical caster (b)

The liquid core structure of the vertically curved caster is curved. The secondary cooling zone of the vertical caster is not divided into internal and external arcs; thus, the inside of the round billet has a symmetrical liquid core structure. With significant ferrostatic pressure in the vertical casting billet, liquid steel can flow downwards more easily, which greatly improves the solidification feeding capacity.

Figure 3 shows the grain structure of both the vertically curved caster and the vertical caster. The C content was measured every 30 mm for a diameter of 600 mm. Figure 4 shows a line graph of C content. The carbon deviation of the vertically curved caster is larger and asymmetrical at both ends. Bending, straightening, and uneven cooling conditions lead to an uneven chemical composition in the vertically curved caster.

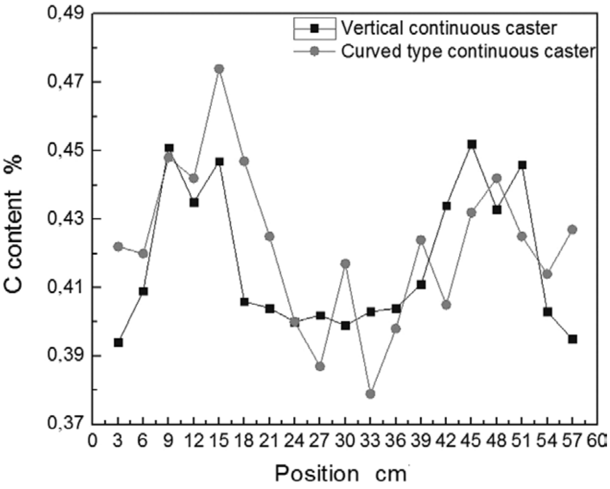

Figure 4 The line graph of C content

NUMERICAL SIMULATION MODEL

According to the characteristics of heat transfer in the vertical caster and for convenience in calculation, the following assumptions were adopted regarding the temperature field: 1.The influence of molten steel flow on heat transfer was ignored. 2.Axial heat transfer was ignored. 3.The influence of mold vibration on heat transfer was ignored. 4.It was assumed that mold heat transfer uses the average heat flux. 5.It was assumed that secondary cooling water is sprayed evenly.

For 42CrMo steel, a Φ600 x 20 mm round billet was used as the computational model. A tetrahedral mesh was adopted, and a two-dimensional non-steady-state model was established [4]. The chip-moving boundary method was used to conduct numerical simulations. Starting from the mold meniscus, the slice continuously passed through the mold, secondary cooling system, and air cooling system. Table 1 shows the computational formula of the heat transfer model. Among them, the boundary condition of the secondary cooling system was treated by the MCA method to obtain the comprehensive heat transfer coefficient h. Table 2 shows the working condition of the mold.

Table 1 **The computational formula of heat transfer model**

Stage	Computational formula
Mold	$Q = Q_W C_W \Delta T_W / F$
Secondary cooling system	$h=350\times W^{0,351}$
Air cooling system	$q_r=k\sigma[(T_b+273)^4-(T_a+273)^4]$

In Table 1, Q is the average heat flux density of the mold, in W/m^2; Q_W is the cooling water consumption of the mold, in kg/s; ΔT_W is the water temperature difference between inlet and outlet of the mold, in K; F is the effective cooling area of the mold and round billet, in m^2; h is the surface heat transfer coefficient of round billet, in W/(m^2·K); W is water flow density, in L/(m^2·s); q_r is the radiant heat flux, in W/m^2; σ is the Boltzmann constant; k is the surface emissivity; T_b is the surface temperature of round billet, in °C; T_a is the environment temperature, in °C.

Nucleation number of volume and area as follows:

$$\Delta T_{v,max}=5{,}5\ \mathrm{K},\ \Delta T_{v,\sigma}=1{,}5\ \mathrm{K},\ n_{v,max}=1\times10^8,$$
$$\Delta T_{s,max}=0{,}5\ \mathrm{K},\ \Delta T_{s,\sigma}=0{,}1\ \mathrm{K},\ n_{s,max}=1\times10^7.$$

Figure 5 shows the temperature field and solidification organization of round billet cross section. The structure of vertical caster is symmetrical, and the second cooling zone has a uniform distribution water spray. The uniform temperature field is beneficial to improve

Table 2 **The working condition of mold**

Project	Numeric
Casting Temperature /°C	1523
superheat /°C	30
Water temperature difference /°C	5
Cooling water /L·min^{-1}	2650
Lengh /m	0,7
casting speed /m·min^{-1}	0,18

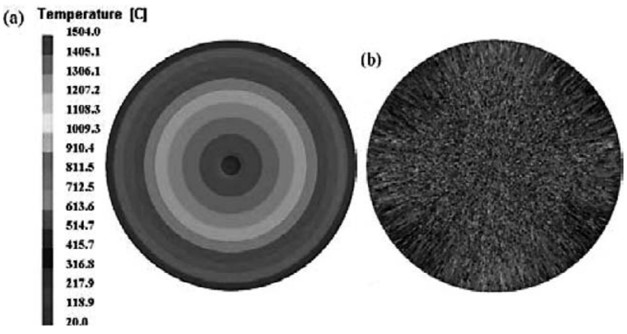

Figure 5 Temperature field (a) and solidification organization (b) of the round billet cross section

element uniform distribution. The simulation result of solidification organization conform to the structure of Figure 3b. It can clearly identify the chilling layer, the columnar zone, and the center equiaxial zone. Firstly, the high temperature molten steel is subjected to strong cooling in the mold, and the surfaces of round billet is formed with a thin layer of fine equiaxial crystal is the chilling layer. Secondly, the columnar zone is then formed by the directional growth of bulky columnar crystal. Finally, with the growth of columnar crystal, the temperature gradient of solid-liquid mixed areas gradually decreased, the columnar crystal growth getting slowly and CET transformation occurs, form the center equiaxial crystal zone.

EFFECT OF PROCESS PARAMETERS

Figure 6 shows the grain structure at superheats of 30 °C, 40 °C, and 50 °C, with all other parameters held constant. As the superheat of the molten steel increases, the grain structure gradually coarsens, and the central equiaxed crystal region decreases from 63,56 % to 42,25 %.

The nucleation number decreases with increasing superheat of the molten steel, which reduces the maximum nucleus density. Additionally, with increasing superheat, it is not easy for the cellular structure to undergo cooling to form a crystal nucleus, which is conducive to the growth of columnar crystals. Conversely, low superheat is conducive to the formation of crystal grains. These grains grow and form a central equiaxed crystal, which prevents the growth of columnar crystals. Low superheat accelerates the transition from columnar to equiaxed crystals, forming a central equiaxed crystal zone.

Figure 7 shows that as cooling intensity decreases, the grain structure gradually refines and the central equiaxed crystal region increases from 43,69 % to 65,27 %. High cooling intensity results in a lower surface temperature for the round billet, which increases the temperature gradient in the liquid-solid phase area and accelerates columnar crystal growth. High cooling intensity easily reaches average nucleation undercooling. Low cooling intensity is beneficial for forming a central equiaxed crystal region.

The solidification rate was maintained for actual production, with different drawing speeds matching different cooling parameters. The equiaxed crystal content gradually increased with decreasing drawing speed.

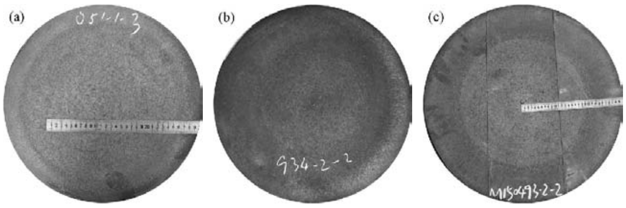

Figure 6 Grain structure of 30 °C (a), 40 °C (b) and 50 °C (c) superheat

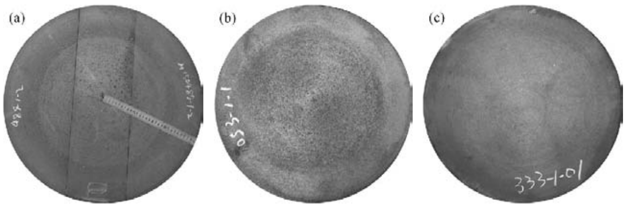

Figure 7 Grain structure of Hard (a), Medium (b) and Soft (c) cooling intensity

CONCLUSION

Based on ZYSS's continuous casting process parameters and CAFE nucleation parameters, ProCAST was used to conduct a numerical simulation of round billet. The simulation result of solidification organization conforms to the structure of round billet. The vertical caster does not require a bending or straightening process compared with vertically curved caster, significantly reducing crack defects on round billet surfaces. As molten steel superheat increases, causing grain structure to gradually coarsen, the central equiaxed crystal region decreases from 63,56 % to 42,25 %. Conversely, as cooling intensity decreases causing grain structure to gradually refine, the central equiaxed crystal region increases from 43,69 % to 65,27 %.

Acknowledgments

The authors are grateful for the financial support from Yingkou Institute of Technology's Talent Introduction Fund (No. 110505049), (No. 110505010); Partial support was also provided by Henan Postdoctoral Scientific Research Fund (No. HN2022017).

REFERENCES

[1] K. Y. Jong, Applications of Numerical Simulation to Continuous Casting Technology. ISIJ International 48 (2008) 879-884.

[2] D. Mazumdar, R. I. L. Guthrie, Physical and Mathematical Modeling of Continuous Casting tundish systems. ISIJ Internationa 39 (1999) 524-547.

[3] B. Wang, J. Y. Zhang, X. M. Li, W. H. Qi, Simulation of solidification microstructure in twin-roll casting strip. Computational Materials Science 49 (2010) S135-S139.

[4] M. G. Xu, M. Y. Zhu, G. D. Wang, Numerical Simulation of the Fluid Flow, Heat Transfer, and Solidification in a Twin-Roll Strip Continuous Casting Machine. Metallurgical and Materials Transactions B 46 (2015) 1510-1519.

Note: The responsible for English language is L.W. Zhang-Yingkou Institute of Technology, China.