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ISSN 0543-5846
METABK 56(1-2) 43-46 (2017)
UDC – UDK 621.346:669.015:548.2:536.5:536.24:620.18=111

STUDYING AS - CAST MICROSTRUCTURE OF THE COLD CORE (CC) INGOT

Received – Primljeno: 2016-09-01
Accepted – Prihvaćeno: 2016-12-10
Original Scientific Paper – Izvorni znanstveni rad

In this study, the mechanism of the formation in structure of Cold Core ingot which is prepared by cold core casting method in lab is studied. The structure of the CC ingot is obtained by optical microscopy and macroscopic examination. And finite element simulation result is used to illustrate the heat transfer process of the CC ingot. The results indicated that the macrostructure of the CC ingot is consists of diffusion layer, chilling solidified layer, directional growth, isometric layer and isometric fine grain region layer. In addition, forced heat transfer patterns of the CC ingot affects the orientation distributions and boundary structures of the crystallites combining on the results of the computer simulation, and the influence on the microstructure can be observed clearly under the microscope.

Key words: Casting, Cold core ingot, Heat transfer, Macrostructure, Microstructure

INTRODUCTION

It is generally known that elements segregation, solidifying defects and microsized inclusions clustering often happen at the center of the ingot during the solidification process[1]. And the coarse equiaxed grains is the intrinsic structure of the center of ingot due to the inherent solidification characteristics [2,3]. The mentioned factors would severely damage the performance and service life of the ingot. At present, the methods to improve the quality of steel ingot concentrated in the mold design, ingredient optimum design of the insulating plates and so on [4~6]. But there is few information about the description to improve the quality of the steel ingot by using the liquid - solid composite casting technology.

Cold core casting is an ingot casting method which can improve the quality of ingot by placing a good quality core material at center of mold before pouring steel. Utilizing the microscopic examination and finite element simulation, the mechanism of the formation in structure is studied to find out the regular characteristics of it.

Experimental and Calculation model

Figure 1 shows the schematic diagram of the CC ingot which is prepared by cold core casting method. As can be seen, the cold core ingot is consist of cold core (CM), interface transition zone (ITZ) and outside material (OM). The simplified processes is used to prepare CC ingot in laboratory. Induction furnace is used for smelting of steel liquid, and pouring the molten steel into a crucible mold, in which a cold core is placed in the core position beforehand. The steel in crucible mold is covered by exothermic covering flux at last. By absorbing the overheating of the molten steel, the surface of the CM layer is remelted to mushy metal, which can effectively unify CM and OM. The parameters of the process and CC ingot can be seen in table 1. After

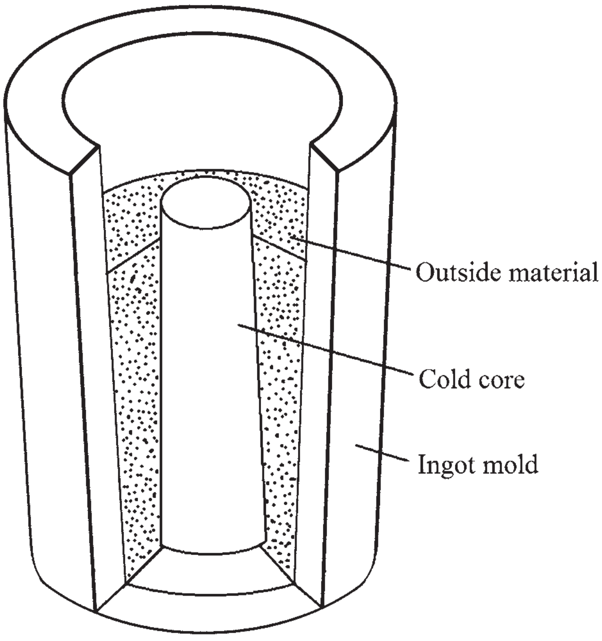

Figure 1 Schematic diagram of CC ingot (no riser)

Table 1 **Parameters of process and CC ingot**

Parameters	Values
Preheating temperature / °C	250
Pouring temperature / °C	1 560
Liquid - Solid ratio	3 : 1
Operating Frequency of Induction Furnaces / Hz	2 500
Inner diameter of mold / mm	135
Mold length / mm max	285
Cold core material / mm	45
Cold core length / mm max	260

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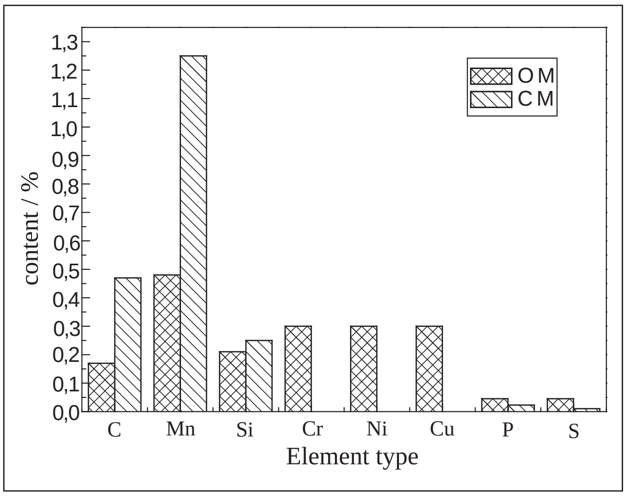

Figure 2 The major element content of CC ingot

the preparation, the structure of the CC ingot is examined by means of microscopy.

The concrete compositions of CM and OM are shown in the Figure 2 .

In addition, the mechanism of the heat transfer is illustrated by the finite element simulation results of the solidification process. The ingot geometric parameters is shown in Table 1. All dimensions are based on the real CC ingot that prepared in the laboratory. A triangle grid composed of more than 2, 5 × 10^5 quadrilateral control volumes is used in the present model. The mold filling process is ignored, and the melt is assumed to be initially quiescent at the temperature of 1 565 °C, while the other parts are assumed to be initial temperature at 80 °C [7].

RESULTS AND DISCUSSIONS

The solidification process of the CC ingot

Figure 3 shows the solidification process of the CC ingot. It can be seen that the radial rate of heat transfer is faster than the vertical rate in the initial stage of the solidification, due to a greater temperature gradient exist between the CM and OM. Later, the rapid radial rate of heat transfer will change the normal solidification process of the CC ingot. Molten metal which close the CM solidify in advance, then the contact process of two parts transform from liquid - solid to solid - solid. So the heat transfer rate of the CC ingot is decreased. Obviously, the temperature gradient across the OM to CM will heat up the outer CM to melting point during solidification process and change the rate of heat transfer. Since the CM absorbing overheating and bringing the heat conducted between the CM and OM into balance. Then both combine as a whole and a progressive solidification from the top to down can be obtained.

The structure of the as - cast CC ingot

It is shown that the macrostructure of the as - cast CC ingot from center line of the CM to the edge of the CC ingot mainly consists of the following parts as shown in Figure 4a: ①The diffusion layer: it is formed together with metallurgical bonding when the OM and CM are remelted and regelated with each other. ②The chilling solidified layer: located in the innermost layer of the OM, due to the effect of chilling of the IM, a layer of equiaxed fine grain zone is formed based on the ITZ surface with rapid solidification. ③The directional growth layer: the solidified structure formed the apparent directional growth outside the chilling solidified layer. The reason for this phenomenon is that outside the chilling solidified layer, there is large radial temperature gradient in the outer material during its solidification. ④The normal solidified layer: outside the directional growth layer, due to the small temperature gradient in this area, the solidified structure of outer material has no obvious directivity, thus the normal solidified layer of equiaxed coarse grainis formed. ⑤The isometric fine grain region: The great temperature gradient between the high temperature liquid steel and room temperature mold makes this layer formed in the outside of OM [8].

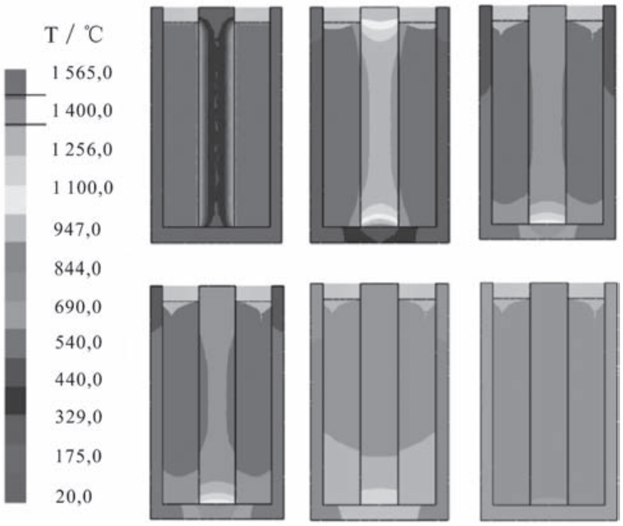

Figure 3 The solidification process of the CC ingot

Figure 4b, c and d show the microstructure of the isometric fine grain region layer, the normal solidified layer, the directional growth layer, the interfacial transition layer and the core material, respectively. It can be seen that the structure of OM, ITZ and CM is consisted of eutectoid ferrolites and pearlite, but the pearlite content vary with the distance from the center line of the CC ingot. The microstructure of OM is consisted of considerable eutectoid ferrolites and a small amount of pearlite. Compare with the size of grains of the ITZ and CM, the ferrite grain of OM is larger and directionless. The CM is full of pearlite.

At the layer of OM, the heat transfer rate decrease due to the air gap appear among the mold and ingot in the initial stage of solidification. But the undercooling in a forward position of the solid - liquid interface increase with the release of latent heat during solidification process. The increase of the undercooling accelerate

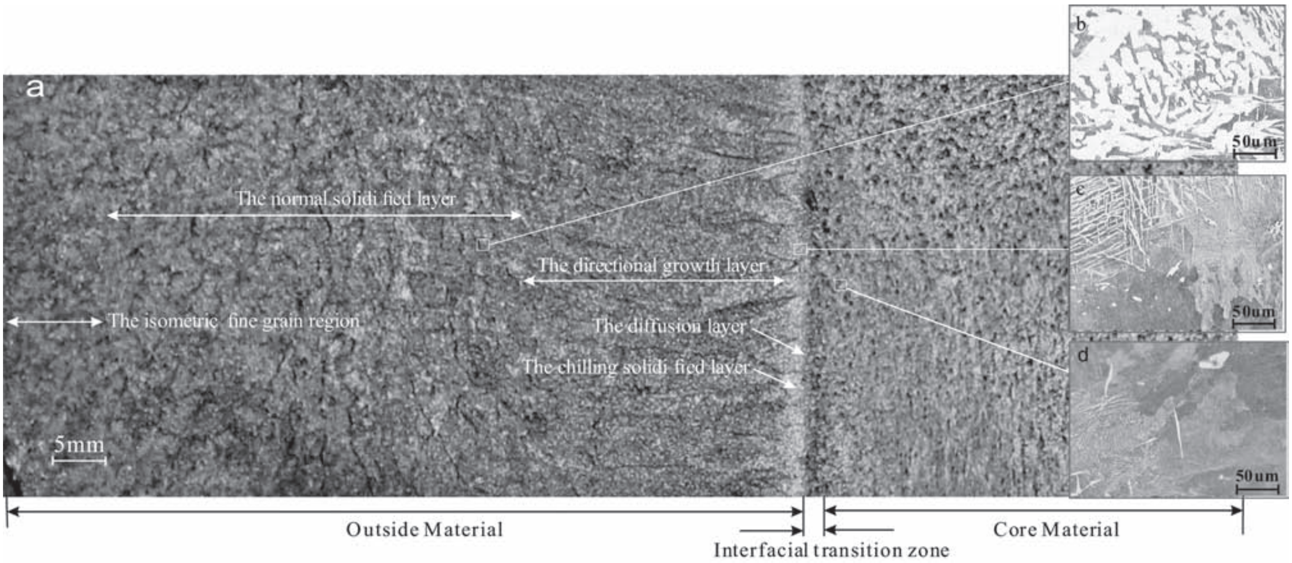

Figure 4 The macro and micro structure of the cold core ingot

the diffusion velocity of atoms and increase the concentration of the alloy in the solidification front. In addition, the nucleation rate will decrease due to the weakening of constituent fluctuation. Moreover, the size of grains at the normal solidified layer is decided by the rate of heat transfer due to the slow heat transfer rate extend the time of grains growth. Meanwhile, the greater undercooling results in the crystalline growth direction points to the liquid along the normal liquid - solid interface. In sum, the result that the release of the solidification latent heat of the molten metal promote the mentioned region freeze slowly can be got from the observed result of structure evolution process. In addition, compare with the Figure 4b, the characteristic of the temperature distribution in the OM makes micro - crystal growth so that the grain size is greater, and the columnar growth is kept [9,10].

As shown in Figure 4c, it is apt to form a larger scale crystal at the solidification front under a great undercooling, but the existence of the CM prevent the grains growing any futher and induce the heterogeneous nucleation crystallization. Meanwhile, the heat transfer rate is increase, and results in the molten metal solidify in disequilibrium. In the initial stage of solidification, the convection is signification in the molten flow. And with the release of solidification latent heat, the solute atoms are fully mixing by convection and diffusion mode. Moreover, the rapid heat transfer rate promotes the grains grow in planar extension way in the solidification front. These columnar crystals grow into cystiform dentrite and epitaxial solidification with CM due to constitutional supercooling. In the final stage of solidification, the latent heat of the high temperature OM is released fully, and the rate of heat transfer decrease. The cystiform dentrite would not grow into dentrite due to the decrease of the heat transfer at the solidification front.

According to the principle of heat equilibrium, it can be calculated that the CM can be heated above Ac_1 critical temperature. And the grains at the CM had austenitizing. As Figure 4d shown, a part of austenite changed into ferrite in advance and then the further reduce undercooling transform the remaining austenite to the large banded pearlite.

CONCLUSIONS

The macrostructure of the CC ingot included the CM, ITZ (diffusion layer) and OM (chilling solidified layer, directional growth, isometric layer and isometric fine grain region layer). And the structure of mentioned region is consisted of eutectoid ferrolites and pearlite.

With the acceleration of the heat transfer, the grains in the OM not only get finer but a phenomenon of equiaxedr - to - columna transition exists.

Moreover, the molten will epitaxial solidification with CM in the ITZ. And the high temperature OM will coarsen the pearlite grains of CM.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (Grant No. 51474125, 51504130) and Henan Province Key S&T Special Projects (No.QT-JS2016 - 004). Partial support was also provided by Anshan city and Liaoning University of Science and Technology for top - level science - technology talents (No. 3335, 2014RC07).

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Note: The responsible translator for English language is Zhi - Wen Hang - University of Science and Technology Liaoning, China