Temperature field in the hot-top during casting a new super-high strength Al-Zn-Mg-Cu alloy by low frequency electromagnetic process

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Abstract: The billets of a new super-high strength Al-Zn-Mg-Cu alloy in 200mm diameter were produced by the processes of low frequency electromagnetic casting (LFEC) and conventional direct chill (DC) casting, respectively. The effects of low frequency electromagnetic field on temperature field of the melt in the hot-top were investigated by temperature measurement method. Temperature curves were measured from the surface to the center of the billets by locating type K thermocouples into the casting during the processes. The results show that during LFEC process the temperature field in the melt applying the hot-top is very uniform, which is helpful to reduce the difference of thermal gradients between the surface and the center, and then to reduce the thermal stress and to eliminate casting crack.

Keywords: Al-Zn-Mg-Cu alloy; low frequency electromagnetic field; DC casting; temperature measurement; temperature field
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1. Introduction

The principles of direct-chill (DC) casting of aluminum alloys were invented in 1930's. And for the past fifty to seventy-five years, the Direct Chill (DC) casting process has been used extensively in the whole world for the industrial production of aluminum alloy billets and slabs. Due to the importance of this process to the industry in fabricating semi-finished products, intensive development work has taken place over the last 30 years [1]. So, some new technologies such as hot top casting, air-slip casting and so on were introduced for the casting of extrusion billets. However, a key problem for the DC casting process is casting crack [2-4], especially for casting high alloy with super-high strength such as Al-Zn-Mg-Cu alloy, which has not been solved perfectly, yet. Based on CREM [5,6] process, a new technique, Low Frequency Electromagnetic Casting process (LFEC) was developed by CUI and his colleagues[7-10], in which the low frequency electromagnetic field was used to control the flow and temperature fields because of its low skin effect. And the results show that the low frequency electromagnetic field can eliminate crack of super-high strength alloy Al-Zn-Mg-Cu alloy billets in diameter of 200 mm. As known, the more temperature differences between the surface and the center of the billet are, the larger thermal stress and the stronger crack trend will be generated. So, in order to understand why the low frequency electromagnetic field can enable to eliminate crack during DC casting process, the effects of low frequency electromagnetic field on the temperature field were studied in this paper. The super-high strength Al-Zn-Mg- Cu alloy billets in diameter of 200 mm were produced by the processes of the low frequency electromagnetic casting (LFEC) and conventional direct chill (DC) casting, respectively. The temperature field of melt was investigated by temperature measurement.

2. Experimental procedure

2.1 Melting and casting

The experimental equipment is illustrated schematically in Fig. 1. An 80-turn induction coil was arranged outside the mold and a graphite ring with inside diameter of 204 mm, outside diameter of 216 mm and highness of 30 mm was seated in the mold. The alloy was melted in the 500kW medium frequency induction furnace. When the temperature of the melt was at 760 °C, the melt was degassed by C_2Cl_6, slag-removed and refined, then poured into a tundish. Billets of the Al-Zn-Mg-Cu alloy with a diameter of 200 mm were cast by the low frequency electromagnetic casting (LFEC) and conventional direct chill (DC) casting processes under the following conditions: Casting temperature: 730 °C; Casting speed: 85 mm/min; Water temperature: 16 °C; Water supply:

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70 L/min; Induction coil: 80 turns; Frequency. 25 Hz; Current intensity: 120 A. The chemical composition of the high-strength Al-Zn-Mg-Cu alloy used in this experiment is shown in Table 1.

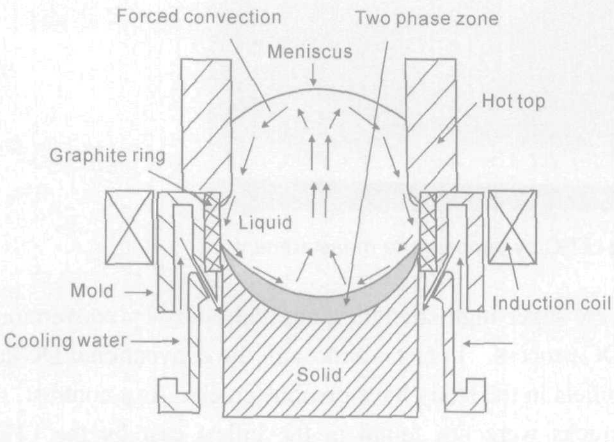

Fig.1 Schematic diagram of LFEC process

Table 1 Chemical composition of the super-high strength Al alloys (%)

Zn	Mg	Cu	Zr	Fe	Si	Al
9.85	2.39	2.31	0.14	0.13	0.09	Bal

2.2 Temperature curve measurements

In order to study the effects of low frequency electromagnetic field on the temperature field, temperature measurements were performed at various locations in the hot-top during casting. Figure 2 shows the experimental set-up used to determine the temperature curves. As shown in Fig.2, three thermocouples (type K) were fixed at 10 mm(CH1), 60 **mm(CH2)** and 100 mm (center, CH3) from the side surface of the billet, and at the heights equivalent to the level of top edge of graphite ring. In this study, the melt temperature in the tundish was also measured (CH4) during casting. The thermocouples were linked to a data-logger system and the temperatures were recorded every 0.1 second.

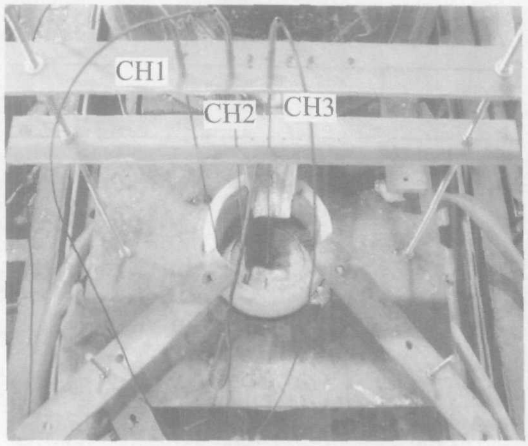

Fig.2 The schematic diagram of temperature measurement and the location of thermocouples

3. Experiment results

3.1 The temperature field

The temperature curves of DC casting and LFEC are shown in Fig.3. It can be seen that during DC casting the temperature field of the melt in the hot top is non-uniform, the temperature at the center is about 50 °C higher than that at the side border. While during the LFEC process the temperature curves of CH1, CH2 and CH3 are almost in the same line, which indicates that the temperature field along radius in the melt is very uniform. So, based on Fig.3, during LFEC process the temperature field of the whole melt in the hot-top is very uniform and almost in the same temperature (about 626 °C), which is about 6 °C lower than liquidus temperature. It also can be found in Fig.3 that the temperature of the melt in the hot-top by LFEC process is lower than that by conventional DC casting process.

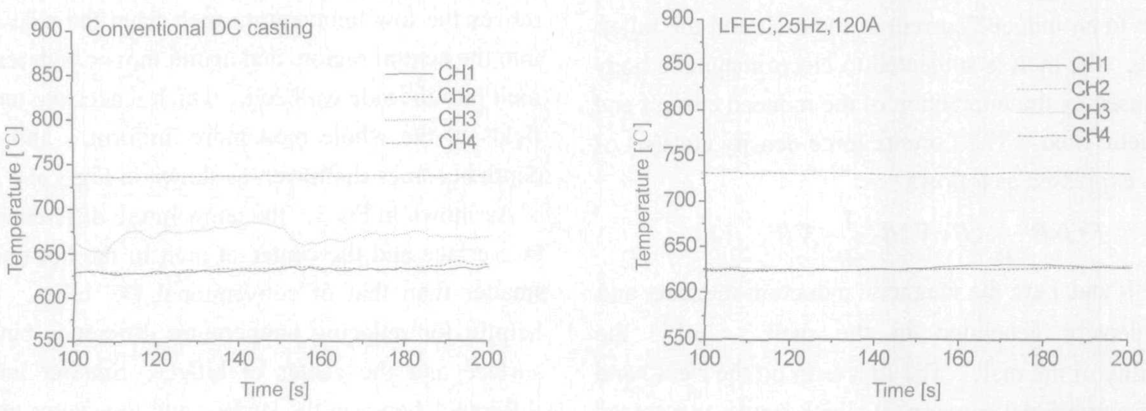

Fig.3 Temperature field distribution in the level of the upper edge of graphite ring

The sump profiles was also investigated by adding Al-30%Cu alloy melt into the molten metal pool at the steady-state. Figure 4 shows the sump profiles where the sump depth of LFEC billet is about 65 mm and about 110 mm for conventional DC, respectively. Because the temperature in the hot-top is more uniform, the sump

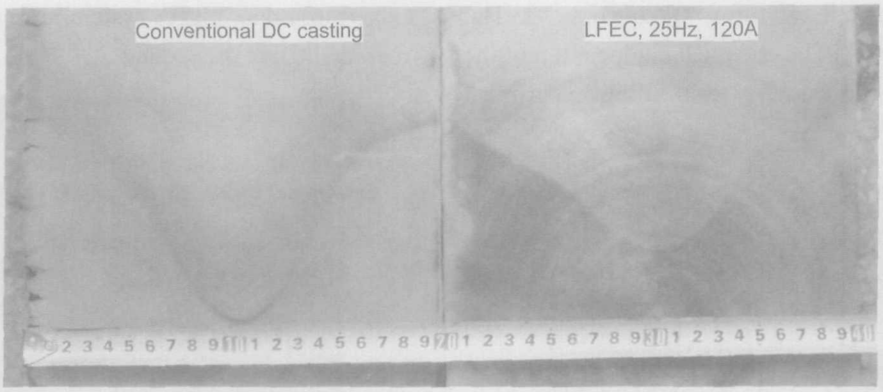

Fig.4 The sump shape and depth of DC and LFEC by temperature measurement

during LFEC process is much shallower than that of DC casting, which is helpful for reducing the thermal stress and eliminating casting crack.

3.2 Casting crack

We also investigated the cracking situations by comparing results between the casting processes. Because of high contents of alloying elements, it is difficult to cast the new super high strength aluminum alloy by conventional DC process. In fact, almost all the conventional DC cast billets in the study have obvious cracks. As a contrast, the cracks were not found in the billets cast by the LFEC process. Figure 5 shows the cross sections of the samples made by DC and LFEC billets. Obviously, the LFEC is a favorite process that can eliminate cracks in casting super high strength aluminum alloy.

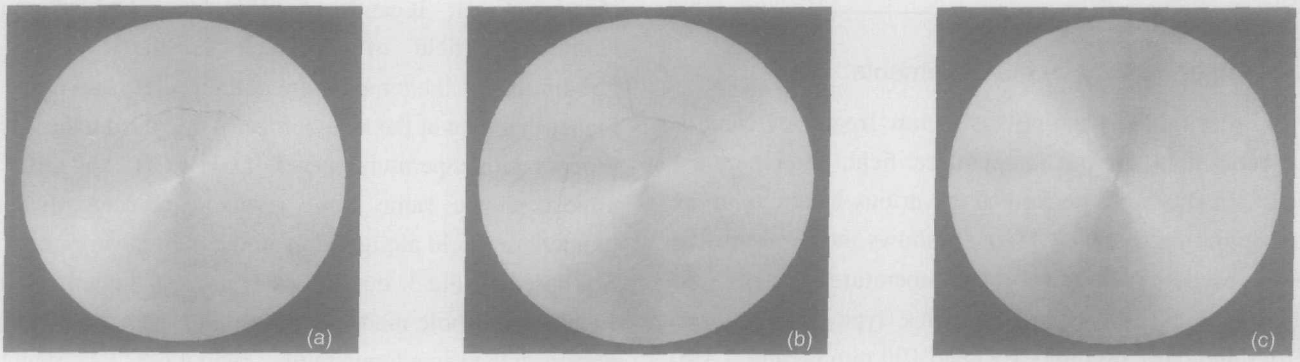

Fig.5 The cross section of DC and LFEC billets——(a), (b) DC billets; (c) LFEC billet

4. Discussion

In the LFEC process, the alternative current generates a time-varying magnetic field in the melt, which, in turn, gives rise *to* an induced current in the melt and the billet. Therefore, the melt is subjected to electromagnetic body forces caused by the interaction of the induced current and the magnetic filed. The Lorentz force density consists of two parts expressed as follows [5]:

$$F=J\times B=\frac{1}{\mu}(B\cdot\nabla)B-\frac{1}{2\mu}\nabla B^2 \quad (1)$$

Where B and J are the magnetic induction intensity and current density generated in the melt, μ is the permeability of the melt. The first term on the right hand of Eq.1 is a rotational component which results in a forced convection and flow in the melt. The second term is a potential force balanced by static pressure of the melt, resulting in the formation of meniscus and decrease in the contacting pressure on the mold (soft contact).

During LFEC process, the hot metal jet coming out of gutter and entering the hot-top is submitted to a very strong electromagnetic agitation. The forced convection moves the low temperature melt from the side wall zone into the central region, and again, moves high temperature melt into the side wall zone, which makes the temperature fields of the whole melt more uniform, and the sump depth becomes shallower, as shown in Fig.3 and Fig.4.

As shown in Fig.3, the temperature difference between the surface and the center of melt in the hot-top is much smaller than that of conventional DC billet, which is helpful for reducing temperature difference between the surface and the center of billet. Smaller temperature difference between the surface and the center gives lower thermal stress and thermal strain. Apparently, during the process of LFEC, much less crack initiation will be generated and much more difficult for the crack initiation, if any, to propagate because of low thermal stress and uniform temperature field. Hence, the process of LFEC is helpful for eliminating casting crack, as shown in Fig.5.

5. Conclusions

(1) During LFEC process, the temperature field of the melt in the hot-top is more uniform and temperature values are also slightly lower than those during conventional DC casting process.

(2) Compared with the conventional direct chill (DC) billet, the sump during LFEC process is much shallower, which is helpful for reducing the thermal stress and eliminating casting crack.

(3) For the new super-high strength aluminum alloy, the low frequency electromagnetic casting process can enable to eliminate the casting cracks effectively. Almost all conventional DC billets in the study are with cracks, but the LFEC billets have no cracks observed.

Acknowledgements

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Reference

[1] Wolfgang Schneider, D. C. Casting of aluminum alloys - past, present and future [J]. Light Metals, 2002. pp 953-960

[2] A. B. Phillion and S. L. Cockcroft, Prediction of hot tears in DC-cast aluminum ingots [J]. Light Metals, 2004: pp 673-678

[3] M. Rappaz, J. M. Drezet, and M. Gremaud. A new hottearing criterion [J]. Metallurgical and Materials Transactions A, 1999, 30A (2): 449-455

[4] Hiromi Nagaumi and Takateru Umeda. Prediction of internal cracking in a directchill cast, high strength, Al-Mg-Si alloy [J]. Journal of Light Metals, 2002,(2): 161-167

[5] C. Vivès. Electromagnetic refining of aluminum alloys by the CERM process: part I. working principle and metallurgical results [J]. Metallurgical Transactions, 1989, 20B: 623-629

[6] C. Vivès. Electromagnetic refining of aluminum alloys by the CREM process: part II. Specific practical problems and their solutions [J]. Metallurgical Transactions, 1989, 20B: 631-643

[7] Beijiang ZHANG, Jianzhong CUI, Guimin LU, Qin ZHANG, Chunyan BAN, Effect of frequency on microstructure of electromagnetic casting 7075 aluminum alloy [J]. Acta Metallurica Sinica, 2002, 38(2): 215-218

[8] Beijiang ZHANG, Jianzhong CUI, Guimin LU and Qin ZHANG. Effect of electromagnetic field on macrosegregation of continuous casting 7075 aluminum alloy [J]. Journal of Northeastern University (Natural Science), 2002, 23 (10): 968-971 (in Chinese)

[9] Jie DONG, Jianzhong CUI, Xiaotao LIU, Zhihao ZHAO and Weiping Bao. Super-high strength 7A60 Al alloy by low frequency electromagnetic cast(1): as-cast structures of billets with diameter of 0.2 m [J]. The Chinese Journal of Nonferrous Metals, 2003, 13 (12):1494-1499 (in Chinese)

[10] Yubo ZUO, Jianzhong CUI, Yang WANG, Xiaotao LIU, Zhihao ZHAO and Haitao ZHANG. Effect of low frequency electromagnetic field on the as-cast microstructure of a new super high strength aluminum alloy by horizontal continuous casting [J]. China Foundry, 2005, 2 (1): 48-51