Low frequency electromagnetic casting of large size ZA21 magnesium alloy slab ingot

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Abstract. Surface quality and microstructure of ZA21 magnesium slab ingots by the direct-chill (DC) casting and low frequency electromagnetic direct chill casting (LFEC) were deeply and systematically investigated. The surface quality of alloy ingot by LFEC casting is better than that without electromagnetic casting. The crack of ingot was avoided by applying electromagnetic field. The microstructure of ingot without electromagnetic field is coarse columnar grains, on the contrary, the microstructure of ingot by applying electromagnetic field is uniform equiaxed grains. The electromagnetic field can accelerate the flow of the melt and make the dendrite arm break to form equiaxed grains. In addition, the flow of the melt reduces the stress concentration in the solidification process, so that the crack can be avoided.

1. Introduction

The density of Mg alloys is about 1.74 g/cm³[1]. It is obviously lower than that of traditional alloys, such as Al alloys (~2.70 g/cm³) and ferrous materials (~7.87 g/cm³) [2]. Therefore, Mg and its alloys are recognized as the next generation of light-weight metallic materials[3-4]. In addition, Mg alloys has the advantages of good castability and high specific strength (strength-to-weight ratio). Nevertheless, Mg and its alloys are not widely used as structural materials. This is due to the close packed hexagonal (HCP) structure of magnesium alloys[5]. The HCP structure leads to its difficult forming property, low strength and plasticity[6, 7]. For magnesium alloys, grain refinement is an effective method to improve its formability and mechanical properties[8].

It is an effective way to refine grains by applying external physical fields such as magnetic and ultrasonic during the casting process[9, 10]. But the ultrasonic field can make the ultrasonic rod extend into the melt and lead to the melt pollution[11]. In contrast, the application of electromagnetic field has the advantages of no pollution and easy control of intensity[12]. Direct chill (DC) casting technology can produce large magnesium alloy billets. However, the magnesium alloy ingots produced by traditional DC casting often have the disadvantages of coarse microstructure, serious chemical segregation, hot tearing porosity and so on[13]. These characteristics not only impose a burden on the
next hot forming process, but also it is not conducive to improve the mechanical properties of the alloy. Low frequency electromagnetic direct chill casting (LFEC) can well refine the grains of as-cast magnesium alloys, reduce elemental segregation and improve the quality of casting products[14]. LFEC is mostly used in the production of round ingots but seldom used in the production of magnesium alloy flat ingots especially large-scale flat ingots.

In the present work, LFEC is applied to the production of large scale ZA21 magnesium alloy flat ingots. And the metallurgical quality of magnesium alloy ingots obtained by applied and unapplied electromagnetic fields is compared to explore the effect of the application of electromagnetic field on grain refinement.

2. Experimental procedures
ZA21 magnesium alloy is used in this study. The nominal composition was 2.0% Zn, 1.0% Al with balance Mg (in wt.%). The ZA21 magnesium alloy was synthesized with pure Mg ingot, pure Al ingot, and pure Zn ingot. The ZA21 magnesium alloy ingots can be obtained by traditional DC and LFEC methods. The first step, to heat pure Al, Zn and Mg ingots to melt by the resistance melting furnace. Second, to cool it to 700~710°C. Finally, to clear Fe by MnCl₂. When the temperature of the melt dropped to 680~700°C, to do DC and LFEC treatments respectively under gas protection. The shielding gas is a mixture of CO₂ and SF₆, and the volume ratio is 99:1. The DC method was to keep the water flow at 200L/min and the casting speed at 60mm/min. The LFEC conditions was to set ampere turns of excitation coil 8000AN and electromagnetic frequency 20Hz, the water flow rate was 200L/min, the casting speed is 60mm/min. The obtained ingot section size is 300mm×200mm.

Fig. 1 shows the casting process by the DC and LFEC treatments. In order to study the effect of electromagnetic field on the microstructure of alloy ingot, the microstructure of ingots was investigated, and Fig. 2 shows the specific sampling method.

![Fig.1 Schematic diagram of DC and LFEC casting](image-url)
3. Results and discussions

The surface photos of the ZA21 alloy ingot obtained by DC and LFEC in the experiment are shown in Fig.3. It can be seen that the surface quality of the two ingots is quite different. The surface of DC ingot is very rough and obvious crack can be observed. In the contrast, the surface of LFEC ingot is relatively flat and free of cracks. This is because the Lorentz force generated by the electromagnetic field makes the melt to flow fully so that the melt can be better filled in the inner wall of the mold. Therefore, the surface of the ingot by LFEC is smoother than the ingot by DC. On the other hand, the full flow of the melt can release the internal stress of the melt and reduce the stress concentration during the solidification process, thus cracks can be avoided by LFEC. The result shows that the surface quality of ingot can be improved by applying electromagnetic field during DC casting.

The microstructures of the ingot by DC can be seen in Fig.3. Fig. 2 shows the location of microstructure observation. It can be seen that from Fig.4(a) there is a thin layer of chill grain zone on the edge. Columnar grain zone is next to the chill grain zone, and the long axis direction of the columnar grains is about 45° with the casting direction, which can be seen in Fig.4(a). There is a large columnar grain zone, which can be seen in Fig.4(b) (c) (d), and the long axis direction of these columnar grains is parallel to the casting direction. The central position of ingot is coarse equiaxed grains which is shown in fig.4(e). The formation of chill grain zone is due to the rapid cooling effect of cooling water, and the edge region quickly crystallizes and solidifies to form fine grains. High temperature gradient and the specific shape of solid-liquid boundary leads to the formation of columnar crystals. The coarse grains are formed because of the slow heat dissipation at the center of the ingot.
Fig. 4 Microstructures of ingot by DC

Fig. 5 is the microstructures of ingot by LFEC. The central part of the ingot is the mixed grain state of coarse grains and columnar grains (see Fig. 5e). The other part of the ingot is relatively uniform equiaxed grains (see Fig. 5a, b, c and d). In addition to the uniformity of grains, the size of grains is smaller than that of DC ingot. The Lorentz force generated by the electromagnetic field makes the melt to flow and a large number of dendrite arms were broken to form equiaxed fine grains. From another perspective, the flow of the melt makes the temperature gradient in the solidification process more uniform, so the grains formed are also more uniform.

Fig. 5 Microstructures of ingot by LFEC

4. Conclusions
In this work, the DC and LFEC were carried out to study the influence of electromagnetic field on surface quality and microstructures of large size slab ingot. The main conclusions are as follows.

(1) ZA21 magnesium alloy slab ingot with good surface quality was obtained by LFEC casting.
(2) The Lorentz force produced by the electromagnetic field can promote the melt flow and make the melt fill the inner wall of the mold better and the surface of the ingot smoother.
(3) The sufficient liquidity of the melt brought by Lorentz force can reduce the stress concentration and avoid the crack.
(4) Equiaxed fine grains can be obtained by LFEC, the reason is that Lorentz force makes the melt to flow and a large number of dendrite arms are broken to form equiaxed fine grains.

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