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# Effect of magnetostatic field on microstructure of magnesium alloy ZK60 ①

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**Abstract:** The microstructures of cast magnesium alloys solified without electromagnetic field, under low-frequency magnetic field, and under magnetostatic field were compared. The results show that the grain is greatly refined when the magnesium alloy solidifies in the magnetostatic field, the thickness of boundary compound decreases, and much fine massive compound appears, therefore the forming property of magnesium alloy is improved.

**Key words:** magnesium alloy; electromagnetic field; boundary compound
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## 1 INTRODUCTION

Nonferrous materials have displayed more and more important roles in the 20st century. Among these nonferrous materials, magnesium alloy is one of the lightest practical material, but magnesium is a metal with a strong electronegativity. Its standard electric potential is －2.363 V, and its erosion resistance is not good. Because of the oxidization during refining, deformation and application, the advantages of magnesium alloys and their application is limited. As the development of the refining technology and advanced formation technology since 1990s, magnesium alloy was applied practically. It was widely used in aerospace industry, automotive industry, electronic information industry and household appliances fields[1].

Magnesium alloy was firstly used in the aerospace field. Now it becomes the first choice for the structural materials in automotive industry, as the automotive industry develops in the direction of low mass, saving energy, and ambience protection.

Also, because of the special radar absorption characteristic, low density and preventing interference of electromagnetic wave of magnesium alloy, wide application in the electric product was exploited, and it has been the hot material in the telecommunication industry.

Recently, much studies about the effect of magnetostatic field on aluminum alloy have been done[2,3], but there is little on magnesium alloy. The results of the study on aluminum alloy showed that the solid solubility of the alloy elements in aluminum alloy is greatly increased, for example, the solid solubility of zinc in the aluminum alloy is increased from 4.3% to 5.1%, and the solid solubility of magnesium is increased from 1.13% to 1.9%, and the maximum is got in the magnetostatic field[4]. Therefore it is worth to study the microstructure of magnesium alloy solidified in the magnetostatic field.

## 2 EXPERIMENTAL

The schematic of experimental equipment is shown in Fig. 1. The inner diameter of induction coil is 50 mm, and its out diameter is 150 mm. The coil is made up by 8 layers of copper pipe, and the power of the coil is supplied by a special current source, which can supply both the direct current and the alternating current. Two ceramic pipes with different diameters were placed within the coils, and the gap space between two ceramic pipes is filled up with asbestos. Also a resistance wire was placed in this gap to heat the magnesium alloy. The crucible for loading magnesium alloy is set up in the center of the inner ceramic pipe, where the biggest magnetic induction intensity appears.

At first in experiment, the magnesium alloy was molten and refined, and the molten magnesium alloy was poured into the crucible. Then the molten magnesium alloy was heated by the power supplied by the resistance wire, and hold at 650 ℃for 30 min. At last, the current of the resistance wire was turned off, the current of coil was turned on, and the molten magnesium alloy was cooled

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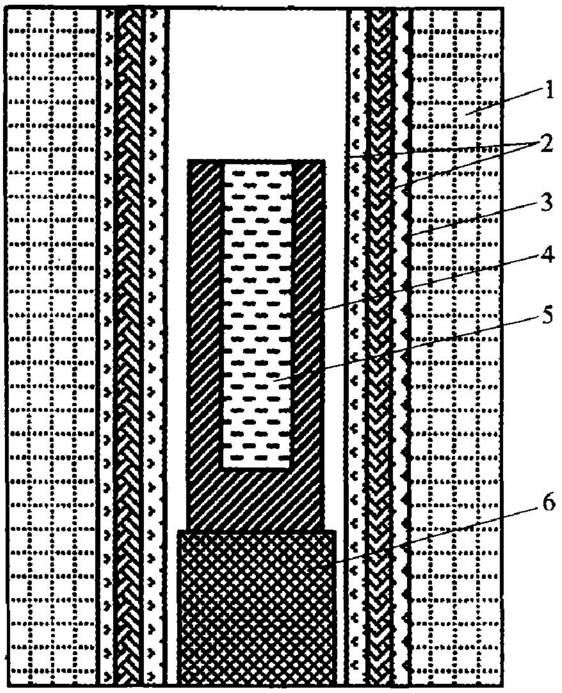


**Fig. 1** Schematic of equipment
1– Solenoid coil; 2– Ceramic tube;
3– Asbestos resistance wire; 4– Ceramic crucible;
5– Molten alloy; 6– Refractory brick

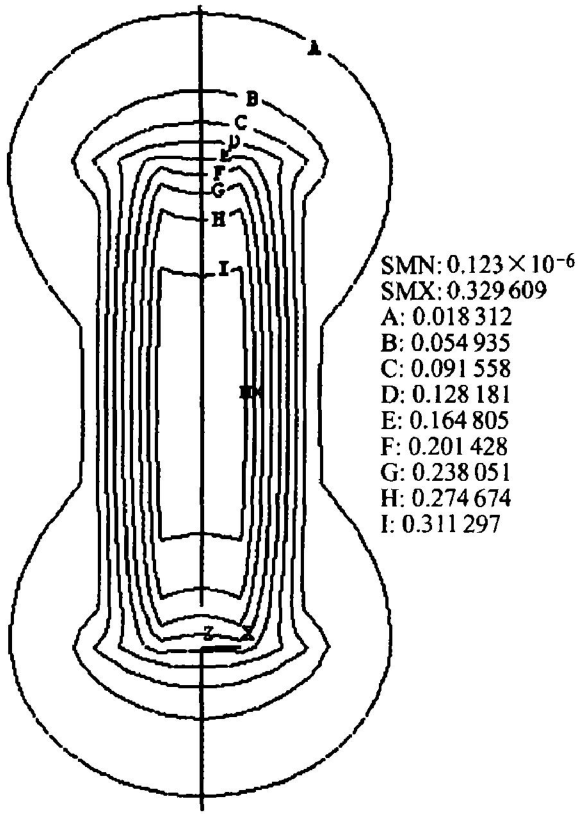


**Fig. 2** Distribution of magnetostatic induction intensity near ceramic pipe under direct current (170A)

and solidified in the electromagnetic field to ambient temperature by the cooling water in the coil.

In order to research the effect of magnetic field on the microstructure of magnesium alloy, the same process was done without electromagnetic field. The magnesium alloy used in experiment is ZK60, and its chemical composition is as the following: $w$(Zn) = 5.0%–7.0%, $w$(Zr) = 0.3%–0.8%, $w$(Fe, Si) < 0.01%, $w$(Cu) < 0.03%, $w$(Ni) < 0.005%, and balanced magnesium.

The microstructure of magnesium alloy was observed under optical microscope.

## 3 CONDITION OF ELECTROMAGNETIC FIELD

In order to supply a uniform magnetic field for the solidification of magnesium alloy, there isn't any ferrous-magnetic material used in the equipment, and most of them are made of ceramic and brick. The results of simulation on magnetic induction intensity by finite element method[5–9] are shown in Figs. 2 and 3. From the results, we can see that the distribution of electromagnetic field within the ceramic pipe is uniform.

When the current of coil is 170A (direct current), the magnetic induction intensity is shown in Fig. 2, from which, we can see that the magnetic field in the center of ceramic pipe is uniform. The magnetic induction intensity is about 0.3T, and it is closed to the measured one (0.28T).

When the low frequency current source is supplied, and its voltage is unchanged, the distribution of magnetic induction intensity is shown in Fig. 3. The strongest magnetic induction intensity also appears in the center of ceramic pipe. The intensity is near 0.20T, and it is also closed to the measured one (0.18T).

## 4 RESULTS AND ANALYSIS

Fig. 4 shows the microstructure of cast ZK60 solidified without electromagnetic field. From it we can see that the cast microstructure is composed of coarse grains, and the grain boundary is composed of continuous and thick compounds[10].

The microstructure in Fig. 5 shows the microstructure of cast ZK60 when it solidified in low frequency magnetic field. Compared with the common microstructure of cast ZK60, the grain is refined, and the amount of the boundary compounds decreases. But most of boundary compounds are still continuous.

Fig. 6 shows the microstructure of cast magnesium alloy ZK60 solidified in magnetostatic field. When the solidification of magnesium alloy finishes in magnetostatic field, the microstructure is greatly changed. The grain is finer than that solidified in low frequency magnetic field or without electromagnetic field, the thickness of boundary compounds is reduced, and the grain boundary becomes discontinuous. Also much small massive

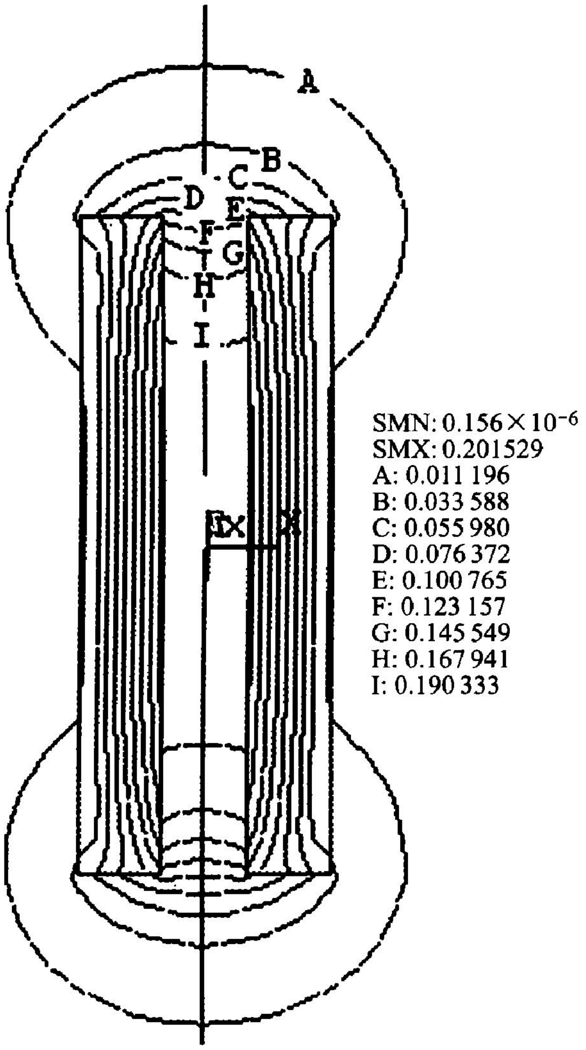


**Fig. 3** Distribution of low-frequency(15Hz) magnetic induction intensity near ceramic pipe

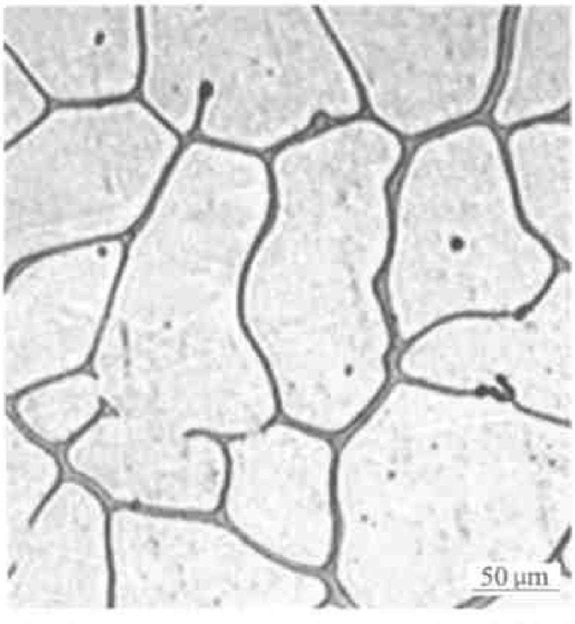


**Fig. 4** Microstructure of cast ZK60 solidified without electromagnetic field

compounds appear near the grain boundary. All these will increase the strength, especially the plasticity of magnesium alloy . It can be foreseen

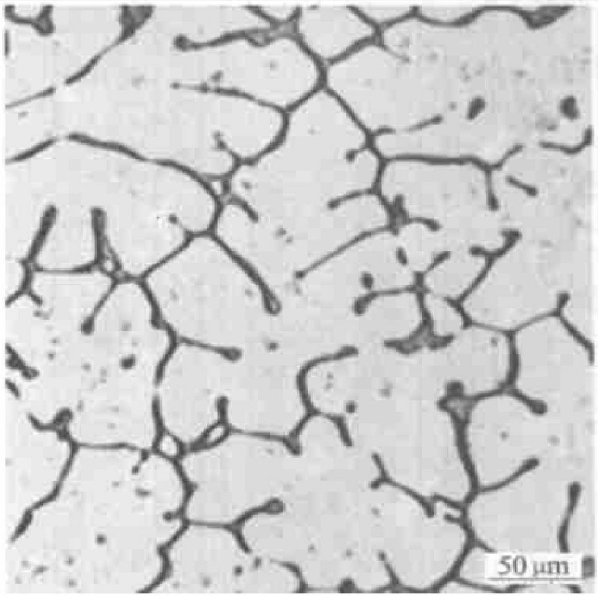


**Fig. 5** Microstructure of ZK60 cast solidified in low-frequency electromagnetic field

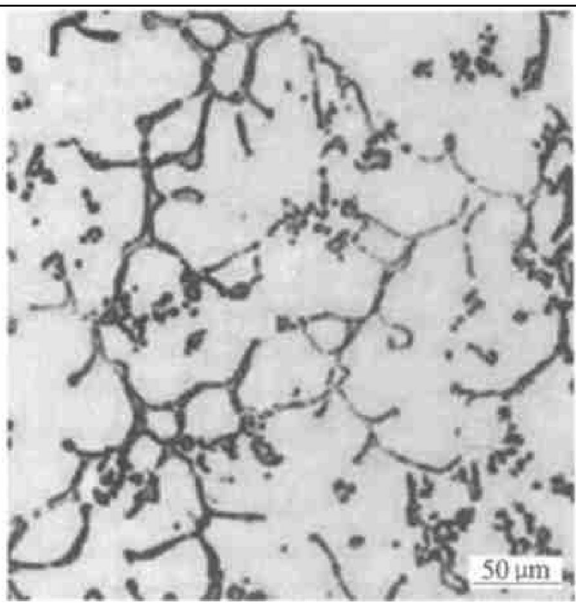


**Fig. 6** Microstructure of cast ZK60 solidified in magnetostatic field

that the boundary compounds will be greatly reduced, and even disappears with the enhancement of the magnetic induction intensity during the solidification, so the plasticity and forming property of magnesium alloy will be greatly improved.

Like the aluminum alloy, all these phenomena of magnesium alloy are resulted from the increment of solid solubility of alloying elements in magnesium alloy when it solidified in magnetic field. In the low frequency magnetic field, especially in the magnetostatic field, the solid solubility of alloying elements in ZK60, such as zinc and zirconium, are greatly increased, which makes much alloying elements remain in the matrix during the procedure of the solidification, and then these elements precipitate as small massive texture in the grain. Also, the increment of solid solubility of alloying elements results in the decrement of the thickness of boundary compounds in microstructure. On the other hand, the increment of solid solubility will increase the concentration of alloying agent in the remained molten magnesium alloy during solidification, and this supplies the small grains the chance to grow up, which forms later, and prevents the large grain from growing coarse. Therefore, the grain is refined, and the boundary compound becomes thinner than that of common cast microstructure.

## 5 CONCLUSIONS

1) When the magnesium alloy ZK60 solidifies in low frequency magnetic field, the microstructure is refined, and the boundary compound is reduced.

2) When magnesium alloy ZK60 solidifies in magnetostatic field, the grains of magnesium alloy are greatly refined, the boundary compound becomes thin and discontinuous, and much massive compounds appear in grains.

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