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Microstructure refinement of AZ31 alloy solidified with pulsed magnetic field

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Abstract: The effects of a pulsed magnetic field on the solidified microstructure of an AZ31 magnesium alloy were investigated. The experimental results show that the remarkable microstructural refinement is achieved when the pulsed magnetic field is applied to the solidification of the AZ31 alloy. The average grain size of the as-cast microstructure of the AZ31 alloy is refined to 107 μm. By quenching the AZ31 alloy, the different primary α-Mg microstructures are preserved during the course of solidification. The microstructure evolution reveals that the primary α-Mg generates and grows in globular shape with pulsed magnetic field, contrast with the dendritic shape without pulsed magnetic field. The pulsed magnetic field causes melt convection during solidification, which makes the temperature of the whole melt homogenized, and produces an undercooling zone in front of the liquid/solid interface, which makes the nucleation rate increased and big dendrites prohibited. In addition, the Joule heat effect induced in the melt also strengthens the grain refinement effect and spheroidization of dendrite arms.

Key words: AZ31 magnesium alloy; grain refinement; pulsed magnetic field; solidified microstructure

1 Introduction

Magnesium alloys are potential candidates for replacing steel and other high density materials due to their low density, high specific strength and excellent machinability. Thus, magnesium related research has surged in recent years[1]. For the alloys generally exhibit limited ductility and strength at ambient temperature, new efforts on grain refinement are devoted to minimize these disadvantages. The method of use of refiners has some problems that the refiner materials are often expensive and the recycling of used materials becomes difficult[2]. The rapid cooling method also has some serious drawbacks that the size or shape of the sample is very restricted due to the necessity of achieving an extremely high cooling rate. The ultrasonic vibration technique also has serious problems such as the dissolution of the transmitter when it is applied at high temperatures and the attenuation of the vibrations in regions remote from the vibrator[3]. Therefore, an alternative method for the development of fine grain magnesium alloys with high strength is desired.

Applying electromagnetic vibration to the solidification of metals is a new method developed in recent years[4−6]. Pulsed magnetic field (PMF) processing as a new electromagnetic technology has become one of the most promising new techniques to refine solidified structures. BAN et al[7] applied a pulsed magnetic field to 2124 Al alloy solidification and found a remarkable change occurring in the solidified structures. GAO et al[8] studied the structural transformation in pure Al under external PMF. The experiments showed that totally equiaxed grains were produced for pure Al. WANG et al[9−10] researched the grain refinement effect of AZ91 alloy and Mg-Gd-Y-Zr alloy under external PMF. The experimental results showed that the remarkable microstructural refinement was achieved and the grain sizes were refined to 104 μm and 37 μm, respectively, by PMF treatment.

As mentioned above, the PMF process has been studied with different alloy systems, but there has been a lack of investigation on grain refinement mechanism. In this work, the structure refinement of AZ31 alloy by the PMF process is studied and the structure evolution is observed by quenching treatment, furthermore, the refinement mechanism is analyzed and the mechanical properties are investigated.

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2 Experimental

The commercial AZ31 alloy was selected as the raw material in this study. Its chemical composition (mass fraction, %) is as follows: Al 3.0, Zn 1.0, Mn 0.2 and Mg Balance.

The experiment was carried out on a self-designed PMF setup and the details of the experimental apparatus are presented in Ref.[11].

The AZ31 alloy was first remelted at 750 °C for 10 min in an electrical resistance furnace using a mild steel crucible, and then the melt for observing the grain refinement effect was poured into a preheated (to 400 °C) graphite mould with a diameter of 50 mm, height of 80 mm and a wall-thickness of 3 mm. The pulsed magnetic field was imposed to the melt until it was completely solidified. Different pulse frequency and fixed discharge voltage of 200 V were used in the experiments. The melt used for the microstructure evolution was poured into a preheated (to 400 °C) graphite mould, in order to achieve the better heat dissipation capacity, with the minor diameter of the mould of 20 mm, height of 50 mm and a wall-thickness of 2 mm. The eutectic temperature (β-$Mg_{17}Al_{12}$ phase) and the liquidus temperature of the AZ31 alloy are 437 °C and 648.0 °C respectively[12]. Different quenching temperatures of AZ31 alloy were used in the experiments, i.e., 610 °C, 590 °C, 570 °C and 550 °C. The 5 Hz, 200 V PMF was imposed to the melt until it was reached the quenching temperature. Then, the sample with the mould was taken out immediately for water quenching. Both melting and solidification were conducted under a protective atmosphere of 0.5%SF_6+99.5%CO_2 to prevent oxidation.

The specimens for microstructure observation were made from the transverse section of the 1/2 height of the castings. After grinding and polishing, the specimens were etched with a solution of 100 mL ethanol, 5 g picric acid, 5 mL acetic acid and 10 mL water. The average grain size was measured by the linear intercept method.

The compressive specimens with a gauge length of 15 mm and a gauge diameter of 10 mm were made from longitudinal sections of the sample. Compression tests were conducted with an initial strain rate of 10^{-3} s^{-1} at room temperature.

3 Results

The macrostructures of AZ31 alloy solidified without or with the pulsed magnetic field are shown in Fig.1. Without PMF treatment, the constitution of the morphology in Fig.1(a) is equiaxed grains in the centre and thin columnar grains at the edge. With the 5 Hz, 200 V PMF treatment, totally refined equiaxed grains are achieved as shown in Fig.1(b). Therefore, the solidification structure of AZ31 alloy can evidently be refined under the effect of a pulsed magnetic field. Correspondingly, the grain size is uniform on the whole surface under PMF casting, which is beneficial to the uniformity of mechanical performance on the whole casting. Namely, the solidification structure of AZ31 alloy could be evidently refined under the effect of PMF.

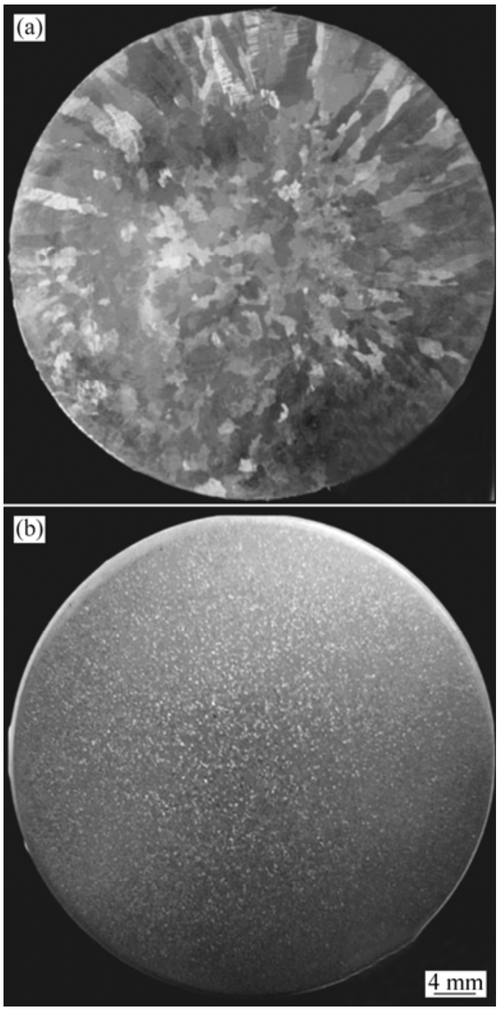

Fig.1 Macrostructures of AZ31 alloy: (a) Without PMF treatment; (b) With 5 Hz, 200 V PMF treatment

Adjusting the pulse frequency can change the effect of grain refinement. Fig.2 presents the solidification structures of AZ31 alloy after the 200 V PMF treatment with different pulse frequencies. The optimized grain refinement effect can be achieved at 5 Hz pulse frequency, as shown in Fig.2(b). The lower or the higher pulse frequency, e.g. 2.5 Hz, 10 Hz and 20 Hz in Figs.2(a, c, d), are not the desirable technological parameters. However, it can also achieve remarkable microstructural refinement effect in contrast to that without the PMF treatment. Fig.3 shows that the average grain size of AZ31 alloy is 2 400, 227, 107, 216 and 274 μm,