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Microstructure Evolution of AZ31 Mg alloy with Ultrasonic Injection Time

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1. Introduction

Magnesium alloys have been widely used in automotive and aircraft parts, mobile electronics, and sports equipment due to their interesting combination of engineering properties such as low density, high specific strength and stiffness, improved damping property, electromagnetic shield capacity, excellent machinability and good castability [1]. The importance of the magnesium alloys would increase more and more because of a weight reduction of transport facilities to improve energy efficiency, and the request for advanced properties increases as well [2]. The studies to make mechanical properties of the alloys improve have been carried out for a long time, and it is well accepted that grain refinement is one of effective methods of achieving improvements in structural uniformity, strength and ductility due to the high Hall–Petch coefficient [3]. A number of processes to refine the microstructure have been proposed: the major ones may be summarized as superheating and addition of a refiner. The addition of the refiner, such as carbon, manganese, and silicon carbide, is the major grain-refining approach for magnesium alloys. Intermetallic phases formed by the refining elements which react with the magnesium melt could act as heterogeneous nucleation sites for magnesium grains. In this paper, a new processing concept, Nucleation Enhanced Ultrasonic Melt Treatment (NENUMT) is suggested to refine the grain structure by the mechanism based on the addition of particles provided from a sonotrode. The driving force of NEUMT is the cavitation effect; The shock waves result in very slight erosion of the sonotrode while the ultrasonic melt treatment is carried out. The atoms and/or clusters parted from that would be uniformly distributed in melt by the acoustic streaming and the cavitation effect. These could react with the melt and form the proper intermetallic compounds which can act as heterogeneous nucleation sites.

2. Experimental procedure

AZ31 alloy that is a representative alloy for rolling and extrusion due to the high ductility was selected

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Table Ⅰ. Chemical composition of AZ31 Mg alloy.

Elements	Content (wt%)
Al	3
Zn	0.7
Mn	0.3
Si	0.01
Cu	<0.01
Ni	<0.01
Mg	Bal.
Solidus Temp.(°C)	605
Liquidus Temp.(°C)	630

as the material to be investigated in this study. The alloy ingot was melted in an electric furnace using a crucible made of mild steel under a protective gas which is the mixture of SF_6 and dried air to prevent serious ignition of Mg melt. The chemical compositions of AZ31 alloy is shown in Table 1. 530 g ingot was melted at 700 °C for AZ31 alloy. When the alloys melt reached the experimental temperature, the sonotrode which was preheated to 400 oC was immersed in the melt with a depth of 20 mm. Before irradiation of the ultrasound in the melt, the sonotrode was kept to be immersed in the melt for 5 minutes to decrease a temperature difference between the melt and the sonotrode. The frequency of the ultrasonic generator is 20 kHz at 25 °C and about 19 kHz at 700 °C, and the ultrasonic power up to 1900 W/cm^2. To confirm the effect of the NEUMT with injection time, NEUMT was carried out for 1, 3, 5, 7, and 10 minutes. The melt after NEUMT was poured into the steel permanent mold (120 × 130 × 12 mm) preheated to 100 °C.

3. Results and discussions

Fig. 1. shows the experimental procedure and conditions in detail. The grain refinement mechanism of NEUMT is based on heterogeneous nucleation by the atoms and/or clusters of the sonotrode separated by the cavitation. The most important two conditions for NEUMT are the following: the first is the enough ultrasonic intensity to generate the cavitation in a melt, and the second is the formation of an appropriate intermeta-

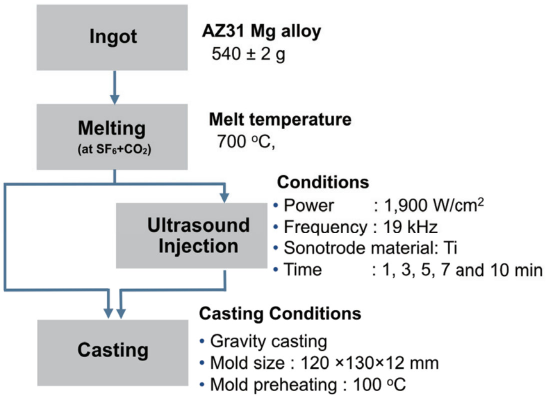

Fig. 1. Experimental procedure

llic compound. Fig. 2 (a) and (b) shows a macro structure of AZ31 alloy cast without and with NEUMT. These figures reveal that the grain refinement was accomplished at AZ31 ally and the grain size was rapidly decreased from 470 μm to 110 μm. To discuss this result quantitatively, the solute content was measured for comparing the amount of Ti injected into melt with injction time from a perspective on the mechanism of the grain refinement. At the most effective refining injection time, 5 minute, Ti content was about 10 ppm, and this results in the formaiton of the proper intermetallic compound. The phase diagram of Mg-Ti, intermetallic compound is not generated by the reaction of Mg and Ti. Ti is just mixed physically in Mg melt and made solid solution after solidification, and Ti added into Mg does not affect the grain refinement. Thus, the phase compositions that can be composed by Mg, Al, and Ti are Mg-Ti, Al-Ti, and Mg-Al-Ti except for Mg-Al. Generally, the degree of dis-registry between the substrate phase and the crystalline phase, δ, proposed by Turnbull and Vonnegut [4] is used. It is believed

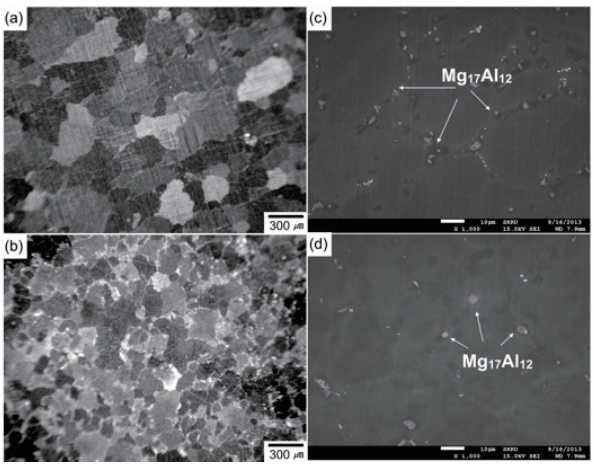

Fig. 2. Macro((a) and (b)) and grain boundary ((c) and (d)) structure of AZ31 alloy cast without (((a) and (c)) and with NEUMT((b) and (d))

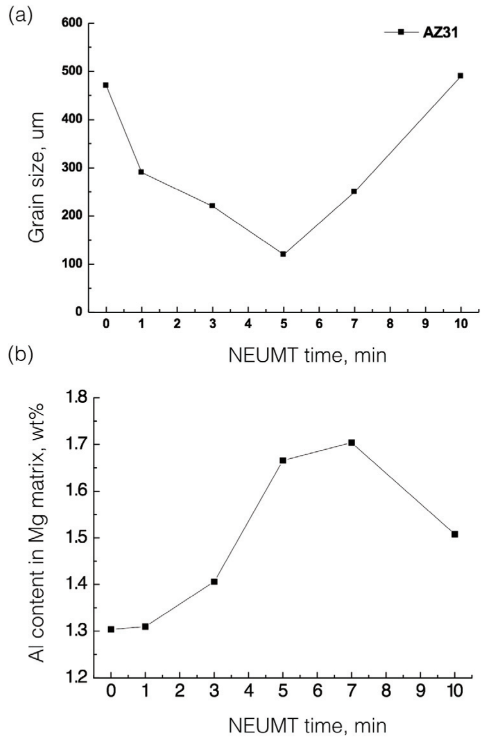

Fig. 3. (a) Grain size and (b) Al content in matrix of AZ31 alloy with increasing NEUMT time

that a good registry between the low-index planes of adjoining phases is important, and the lower of the degree of dis-registry is better to act as nuclei. The Al_3Ti shows the lowest plane dis-registry value that any other candidate phase, and this reveals that the phase is easier to match with Mg phase and act as heterogeneous nuclei on the basis of the orientation relationship. The Al content in matrix of AZ31 alloy as shown in Fig. 3 support the discussion that the Al is the main element for the intermetallic compound with Ti injected by NEUMT.

4. Conclusion

The grain size of AZ31 Mg alloys was decreased with increasing injection time to the optimum condition. The refining mechanism was established by the analysis of composition. The effective intermetallic compound was formed by the Al in the alloy and Ti injected by NEUMT.

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