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Grain refinement and mechanical properties of Mg–5Li–3Al alloy inoculated by Al–5Ti–1B master alloy

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ABSTRACT

The grain refinement efficiency of Mg–5Li–3Al alloy inoculated by Al–5Ti–1B master alloy and the influences of grain size on the mechanical properties were investigated. With the addition of 1.0 wt% Al–5Ti–1B, the average grain size of Mg–5Li–3Al alloy decreases markedly from ~120 μm to 50 μm, leading to significant increases in both strength and elongation. The tensile yield strength (YS), ultimate tensile strength (UTS) and elongation increased from 82 MPa, 154 MPa and 7.8% to 110 MPa, 216 MPa and 12.2%, respectively. XRD and EDS analysis show that Al–5Ti–1B master alloy is composed of α-Al, Al_3Ti and TiB_2. Crystallographic calculations and EDS analysis indicate that TiB_2 particles are the potent heterogeneous nucleating substrates for α-Mg grains, which is the main reason for grain refinement. In addition, solute element, Ti also plays an important role in grain refinement.

1. Introduction

As the lightest alloys, Mg–Li alloys have attracted considerable attention in automobile and aerospace industries owing to their low density, high specific strength and elastic modulus [1–3]. However, Mg–Li alloys usually suffer from connatural drawback of low strength due to micro-porosity and shrinkage porosity. In addition, when Li content is less than 5.7 wt%, Mg–Li alloys are composed of entirely α-Mg phase with a hexagonal closed packed (hcp) structure [4], which has poor formability and ductility at room temperature. These drawbacks hinder the further application of *hcp*-structured Mg–Li alloys.

Grain refinement is one of the most effective methods to synchronously improve strength and ductility for most engineering alloys [5], which is of great importance for the production of Mg–Li alloys. In general, the mechanical properties are directly related to the grain size according to the Hall–Petch equation and thus it is necessary to reduce grain size of the cast alloys as much as possible to achieve superior mechanical properties [6,7]. In addition, a refined microstructure provides a more uniform distribution of solute elements and secondary phases in the metal components [8]. Adding a grain refiner to the molten metal is one of the most important methods to obtain fine equi-axed grain structure. Studies on grain refinement of Mg alloys have been focused for many years. Many carbides, such as Al_4C_3 [8,9] and SiC [10] were regarded as effective refiner for Mg alloys. Zhang et al. [11] set up a novel edge-to-edge model to design intermetallics as refiners. The effectiveness of some intermetallics, such as Al_2Y [12], AlN [13], and AlMn [14] have been verified by experiments. Some other researchers have also tried to use alloying elements such as Ca [15] and Y [16,17] to refine Mg–Li alloys.

It is well known that Al–5Ti–1B master alloy is widely used to refine aluminum alloys in industries [18]. Recently, it was reported that Al–5Ti–1B master alloy could also refine magnesium alloys, such as AZ61 [19], AZ91D [20] and Mg–14Li–1Al (LA141) magnesium alloys [21]. To date, however, there are seldom reports on refining α-phase Mg–Li alloy using Al–5Ti–1B master alloy. Moreover, the previous investigations are most focused on the mechanisms of refinement, and little work has been done on the effect of grain refinement on the mechanical properties.

It is well known that grain size exhibits strong influence on mechanical properties for alloys with *hcp* structure [22]. Hereby, Mg–5Li–3Al (LA53) alloy is chosen as the matrix alloy in the present work. Various amounts (0.5, 1.0 and 1.5 wt%) of Al–5Ti–1B master alloy were added to LA53 alloy to investigate the grain refinement efficiency and the effects on the mechanical properties. The refinement mechanism is discussed in terms of heterogeneous nucleation and the effect of solute-element.

2. Experiment procedure

The Mg–5Li–3Al alloy used in this study was smelted in an induction furnace with commercial pure magnesium, pure lithium

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and pure aluminum. The furnace chamber pressure was kept at 1×10^{-2} Pa under argon environment and Al–5Ti–1B master alloy was added into the melt at 750 °C. The melt was held for 10 min and then poured into a permanent mold with a size of 135 mm × 40 mm × 225 mm. The mold was preheated to 200 °C before casting. Metallographic samples were cut from the same position of the ingots. After grinding with emery paper, the specimens were polished and etched with 2% (volume fraction) nital. The metallographic structures were observed using LEICA DMIRM optical microscope. The grain size was evaluated using the linear intercept method as described in ASTM standard E112-88. Phase and element compositions were analyzed using XRD (TTRIII Rigaku) and SEM (SM-6360LV) equipped with EDS (EDAX FALCON60S). XRD was performed using Cu Kα radiation operating at a speed of 4°/min. The mechanical properties of the alloys were determined using an Instron 1121 materials testing machine equipped with extensometer at room temperature under an initial strain rate of 1×10^{-3} s^{-1}. The tensile tests were conducted according to ASTM E8/E8-11 standard using a rectangular specimen with dimensions of 25 mm gage length, 6 mm width and 2 mm thickness. The tensile test data given below are an average value of six specimens.

3. Results

3.1. Characteristics of Al–5Ti–1B master alloy

Fig. 1 shows the XRD pattern of the Al–5Ti–1B master alloy. As can be seen from Fig. 1, this alloy consists of α-Al, Al_3Ti and TiB_2 phases. SEM image and EDS results of the Al–5Ti–1B master alloy are shown in Fig. 2. The zone 'A' does not contain boron element while large amounts of B were determined around zone 'B.' These results suggest that large plate-like particles (zone A) are Al_3Ti and fine particles with an average size of ~2 μm are TiB_2, which segregates along the grain boundaries.

3.2. Effects of Al–5Ti–1B master alloy addition on the microstructure of LA53 alloy

Optical microstructures of LA53 alloys with various additions of Al–5Ti–1B master alloy are shown in Fig. 3. It can be seen that equiaxed grains were obtained in all the samples. Moreover, lamellar-like eutectic phase can be found along the grain boundaries. The average grain size as a function of Al–5Ti–1B additions is presented in Fig. 4. The addition of Al–5Ti–1B master alloy leads to

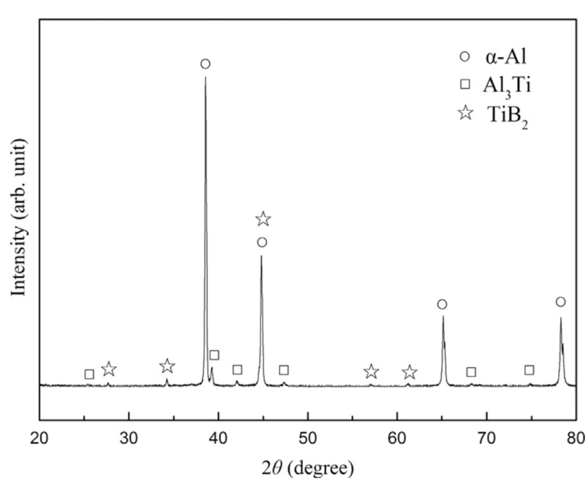

Fig. 1. XRD pattern of the Al–5Ti–1B master alloy.

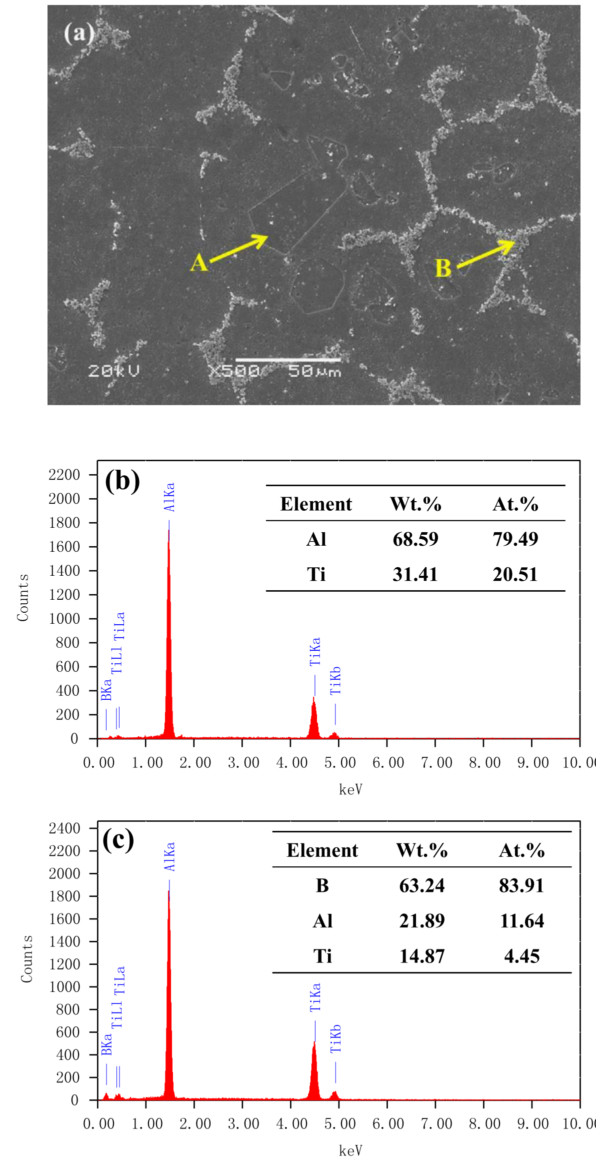

Fig. 2. SEM micrograph and EDS spectrums of the Al–5Ti–1B master alloy: (a) SEM image; (b) EDS result of zone 'A' and (c) EDS result of zone 'B.'

a significant grain refinement as shown in Figs. 3 and 4. With the addition of 0.5 wt% Al–5Ti–1B, the grain size decreased from 120 μm to 70 μm. Increasing the addition of Al–5Ti–1B to 1.0 wt %, the finest grains with an average grain size of 50 μm were achieved. Increasing the content of Al–5Ti–1B further to 1.5 wt% led to a larger grain size. These results indicate that there exists an optimum content of Al–5Ti–1B addition for the grain refinement. XRD patterns of alloys without and with 1.0 wt% Al–5Ti–1B addition are shown in Fig. 5. As can be seen from Fig. 5(a), AlLi phase was detected, which can be regarded as the lamellar eutectic phase as shown in Fig. 3. With 1.0 wt% Al–5Ti–1B addition, TiB_2 phase was detected in the alloy (Fig. 5(b)).

3.3. Influence of grain refinement on mechanical properties of LA53 alloy

Fig. 6 shows the engineering stress–strain curves of the LA53 alloys with various amounts of Al–5Ti–1B addition. The mechanical properties including yield strength (YS), ultimate tensile strength (UTS) and elongation at room temperature are summarized in Table 1. It can be