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# A new approach to grain refinement of an Mg–Li–Al cast alloy

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ABSTRACT

Crystallographic calculation based on the edge-to-edge matching model predicted that both $TiB_2$ and $Al_3Ti$ intermetallic compounds have strong potential to be effective grain refiners for β phase in the Mg–14Li–1Al alloy due to the small atomic matching misfit across the interface between the compounds and β phase. Experimental results showed that addition of 1.25 wt%Al–5Ti–1B master alloy reduced grain size of β phase in the alloy from 1750 to 500 μm. The possible grain refining mechanisms were also discussed.



## 1. Introduction

As the lightest engineering alloy, Mg–Li alloy has attracted increasing interests in transportation industries as these sectors seek increasing fuel efficiency through weight reduction. The most common and typical Mg–Li based alloy is LA141 (Mg–14Li–1Al) that contains full β-Li phase at room temperature and is the most common wrought alloy due to its superior plasticity and ductility. However, this alloy also suffers from low strength [1], which limits its wider applications. Although higher strength can be achieved through multi-elements alloying [2–4] and composite reinforcement [5,6], the plasticity and lightness of the alloys have to be sacrificed. Hence, grain refinement is a more proper approach to strengthening the alloy without reduction of its plasticity and lightness. Among the currently available grain refinement techniques, addition of grain refiners into molten metal to inoculate heterogeneous nucleation is a simple and cost-effective method that is particularly suitable for big ingot production, compared to other techniques, such as equal channel angular pressing [7] and rapid solidification method [8]. A few positive results have been reported. Higashi et al. [9] used yttrium addition to refine the microstructure of Mg–10 wt%Li alloy. Although reduction of grain size was observed, unlike LA141 alloy, this alloy still contains nearly full HCP structure α-Mg phase at room temperature. Chen et al. [10] used zirconium as grain refining agent in a modified LA141 alloy, but the addition led to reduction of ductility and of age-hardening response due to the formation and aggregation of Al–Zr compounds in the matrix during solution-treatment. The present work is based on the success of applications of the edge-to-edge matching model [11–13] in understanding the mechanism of grain refinement of cast Mg and Al alloys [14–16] and in development of new grain refiners, such as ZnO [17], AlN [18] and $Al_2Y$ [19], for cast Mg alloys. Because both $TiB_2$ and $Al_3Ti$ are very effective grain refiners for Al cast alloys [20–22] and the master alloy containing particles of such compounds are commercially available, the present work focuses on these two candidates. First, atomic matching between β-Li phase in the LA141 alloy and $TiB_2$ and $Al_3Ti$ will be calculated using the edge-to-edge matching model to clarify whether these two compounds fulfill the crystallographic requirements as heterogeneous nucleation sites for β-Li phase. Then, their grain refining efficiency will be experimentally investigated and the grain refinement mechanism will be discussed in terms of the segregation power of solute atoms and the crystallography inoculation particles with the β-Li matrix.

## 2. Experimental

Commercial LA141 alloy with chemical composition of Mg–13.5 wt%Li–1.2 wt%Al and Al–5Ti–1B master alloy were used in the experiment. The master alloy will provide both $TiB_2$ and $Al_3Ti$ particles in the melt [20]. 500 g commercial LA141 alloy small blocks together with various addition level of the master alloy (in mass percentage) were placed in different steel crucibles that have the same size (80 mm in diameter, 200 mm in height). Then, the crucibles were placed into an induction furnace and were heated to 730 °C in argon atmosphere. After isothermal holding for 10 min, all the melts were solidified and cooled to room temperature in the crucibles with argon protection in the furnace in order to minimize the oxidation that could be caused if the liquid metal was cast into different moulds. Metallographic samples were horizontally sectioned at the position that is 20 mm from the bottom of the ingots. The as-cast grains of the etched samples were examined using polar-

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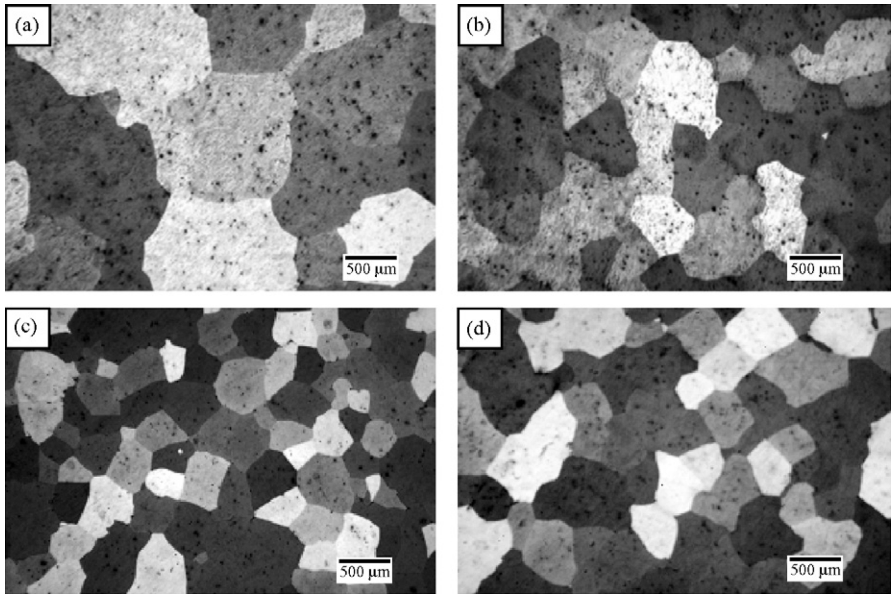


**Fig. 1.** Optical micrographs showing the grain size of as-cast LA141 alloy with addition of Al–5Ti–1B master alloy. (a) without addition, (b) 0.5 wt% addition, (c) 1.25 wt% addition and (d) 1.75 wt% additions.

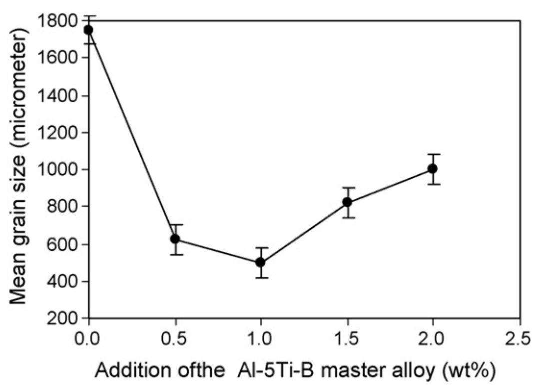


**Fig. 2.** Variation of grain size of as-cast LA141 alloy with the addition levels of Al–5Ti–B master alloy.

ized light in optical microscopy. The grain size was measured by the linear intercept method at the centre of transverse sections.

## 3. Results and discussions

Optical micrographs of the as-cast LA141 alloys with different addition levels of Al–5Ti–1B master alloy are shown in Fig. 1. Equiaxed grains were obtained in all samples and no columnar structure was observed. Dramatic grain refinement occurred at addition of 0.5 wt% the master alloy, which reduces the grain size to 640 from 1750 μm, as shown in Fig. 1(a) and (b). The finest grains with the average grain size of 500 μm were achieved at the addition level of 1.25 wt%. However, further addition of master alloy led to grain coarsening. The variation of the average grain size with the addition level of the master alloy is presented in Fig. 2. Although the grain refining efficiency of the master alloy in the present LA141 alloy is not as significant as that in Al alloys [21,22], the reduction of grain size is still remarkable.

One may argue that the grain refinement of LA141 alloy may be resulted from solute effect due to the change of solute concentration after addition of the master alloy. Because the concentration of Ti and B in the Al–5Ti–1B master alloy is very low and most of Ti and B is in the form of stable $TiB_2$ and $Al_3Ti$ compounds [21,22], addition of the master alloy only introduces extra Al into the Mg alloy melt [23]. To clarify the effect of extra Al solute on grain sizes, three additional castings were performed at the same conditions as described above. One is to add 1.25 wt% the master alloy into the LA141 alloy, the second is to add 1.25 wt% pure Al instead of the master alloy; and another without any additions. Examination of the as-cast micrographs of the three ingots indicates that grain size of the sample with addition of the master alloy is close to 500 μm, which is consistent with the results in Figs. 1 and 2. But, both the samples with 1.25 wt% pure Al addition and without any addition show similar coarse grains. The average grain sizes are around 1300 and 1280 μm, respectively. These results lead to the conclusion that

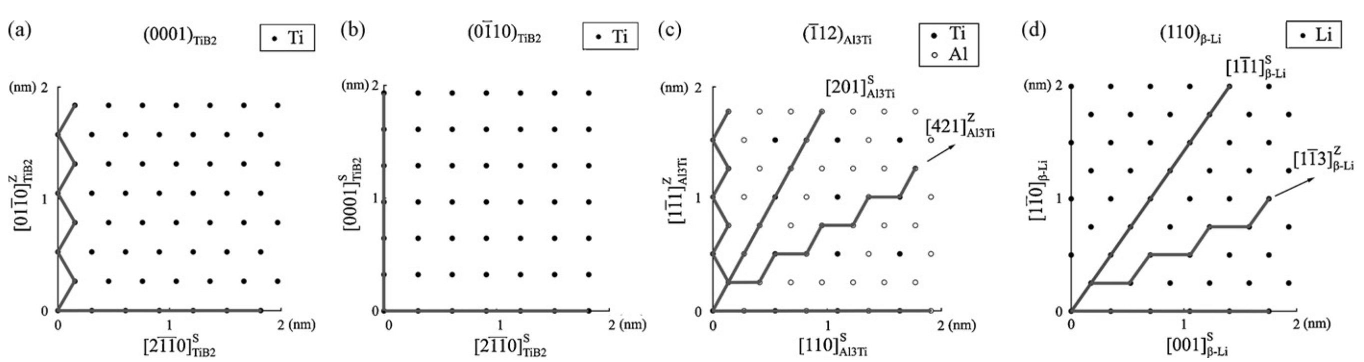


**Fig. 3.** Atomic configurations in the CP planes containing CP directions as indicated by the bold solid lines. (a) $(0\ 0\ 0\ 1)_{TiB_2}$, (b) $(0\ \bar{1}\ 1\ 0)_{TiB2}$, (c) $(\bar{1}\ 1\ 2)_{Al_3Ti}$, and (d) $(1\ 1\ 0)_{\beta\text{-Li}}$.