Intermetallics 45 (2014) 18–23

Contents lists available at ScienceDirect

Intermetallics

journal homepage: www.elsevier.com/locate/intermet

# Effect of $Mg_{24}Y_5$ intermetallic particles on grain refinement of Mg-9Li alloy

Ying Zeng [a, b], Bin Jiang [a, c, *], Mingxing Zhang [d], Hengmei Yin [b], Ruihong Li [b], Fusheng Pan [a]

[a] National Engineering Research Center for Magnesium Alloys, Chongqing University, Chongqing 400030, China
[b] College of Materials Science and Engineering, Chongqing University, Chongqing 400030, China
[c] Advanced Materials Center, Chongqing Academy of Science and Technology, Chongqing 401123, China
[d] Division of Materials, School of Engineering, University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia

ARTICLE INFO

*Article history:*
Received 25 December 2012
Received in revised form
5 September 2013
Accepted 10 September 2013
Available online 12 October 2013

*Keywords:*
A. Rare-earth intermetallics
C. Crystal growth
D. Microstructure
F. Electron microscopy, scanning

ABSTRACT

The microstructures of the as-cast and as-extruded Mg-9Li-*x*Y alloys ($x = 0$, 0.3; wt%) were observed to investigate the effect of Y on the Mg-9Li alloy, and the crystallographic calculations between $Mg_{24}Y_5$ and the matrix were examined on the basis of the edge-to-edge matching model. The results indicated that with the addition of 0.3 wt% Y, the average grain size of α-Mg phases in the as-cast Mg-9Li alloy and β-Li phases in the as-extruded Mg-9Li alloy were reduced remarkably, which was caused by the formation of $Mg_{24}Y_5$ intermetallic compound. Furthermore, crystallographic calculations confirmed that $Mg_{24}Y_5$ particles were effective grain refiners for both α-Mg and β-Li phases in Mg-9Li alloy.


## 1. Introduction

Mg–Li alloys have drawn increasing attentions in recent years because of their low density, good ductility and good cryogenic properties [1]. It is known that with the increase of Li content, the phase component of Mg–Li alloy could be changed from α-Mg (a Mg–Li solid solution in Mg structure), to α-Mg + β-Li, further to β-Li (a Mg–Li solid solution in Li structure) [2]. As compared with the alloys of single α-Mg structure (e.g., Mg-3Li alloy) and single β-Li structure (e.g., Mg-12Li alloy), Mg–Li alloys of duplex α-Mg + β-Li phase structure (e.g., Mg-8Li alloy) have been paid more and more attentions due to their higher strength than Mg–Li alloys of single β phase and higher elongation than Mg–Li alloys of single α phase [3–5].

However, compared with Li-free Magnesium alloy, Mg–Li alloys have low strength and poor corrosion resistance, which limited their further applications. In order to overcome these drawbacks, some advanced casting methods, like composite reinforcement [5,6], rapid solidification [7,8], directional solidification [9] and equal channel angular pressing (ECAP) [10] have been introduced by many researchers in view of the grain refinement. But these techniques have apparent limitations including complicated process, high cost and so on. Thus, alloying process is still considered as one of the most important and effective approaches among the currently available grain refinement techniques due to its easy operation and cost saving.

For recent decades, Al and Zn were the most widely used elements in alloying process of duplex phase Mg–Li alloys [11–14]. But owing to the existence of metastable $Li_2MgAl$ or $Li_2MgZn$ in these alloys, the over-aging phenomenon occurs since that $Li_2MgAl$ or $Li_2MgZn$ could be transformed to AlLi or LiMgZn, which have no strengthening effect on β-Li phase. Therefore, some researchers tried to explore other alloying elements to further refine duplex phase Mg–Li alloys and then improve the mechanical properties [15,16]. For example, Dong et al. [15] reported that after adding 3 wt % Y into the as-cast Mg-7Li alloy, the average grain size was reduced from 100 μm to 2–8 μm, and the ultimate tensile strength and elongation increased by 26.3% and 27.3%, respectively. Through the analysis of Dong et al. [15] and Wu et al. [16], the refinement of the microstructure and the improvement of the mechanical properties could be attributed to the precipitates, $Mg_{24}Y_5$ dispersing in β-Li matrix and $Al_2Y$ existing at the boundary between α and β phases.

* Corresponding author. National Engineering Research Center for Magnesium Alloys, Chongqing University, Chongqing 400030, China. Tel.: +86 135 94190166; fax: +86 65111140.
*E-mail address:* jiangbinrong@cqu.edu.cn (B. Jiang).

0966-9795/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.intermet.2013.09.005

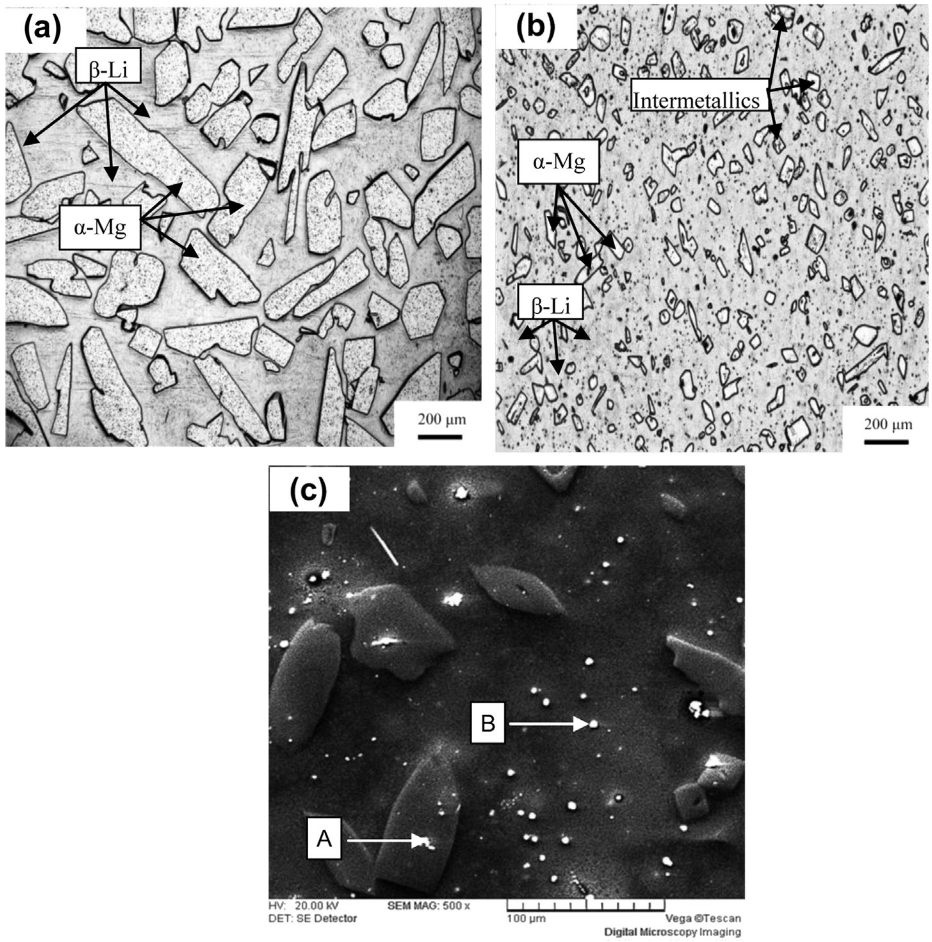


**Fig. 1.** Microstructures of (a) the as-cast Mg-9Li alloy, (b) the as-cast Mg-9Li-0.3Y alloy, and (c) SEM images of the as-cast Mg-9Li-0.3Y alloy.

However, the detailed refinement mechanism of $Mg_{24}Y_5$ or $Al_2Y$ in Mg–Li alloys has not been reported. In previous studies, many available crystallographic models have been used to analyze grain refinement mechanism of some certain compounds, such as the structural ledge model [17], near-coincidence site model [18], invariant line model [19], O-lattice theory [20] and the early model by van der Merwe [21]. More recently, edge-to-edge matching model was favorably used to predict all the orientation relationships (ORs) between crystals that had simple hexagonal close packed (HCP), body-centered cubic (BCC) structures. This model was proved to be a powerful tool to understand and examine the atomic matching between two adjacent crystalline phases. The crystallography examination using the edge-to-edge matching model has successfully predicted $Al_2Ca$ [22], $Al_2Y$ [23,24], $TiB_2$ and $Al_3Ti$ [25] compounds as effective grain refiners for magnesium alloys.

In this work, Mg-9Li-*x*Y ($x = 0$, 0.3; wt%) alloys were prepared through a simple alloying process and hot extrusion. According to Mg–Li–Y ternary phase diagram [25], $Mg_{24}Y_5$ will be formed in the Mg-9Li-0.3Y alloy. Atomic matching between $Mg_{24}Y_5$ and the matrix (α-Mg and β-Li) was calculated. Meanwhile, the mechanism of the grain refinement of Mg-9Li-0.3Y alloy was also investigated in detail.

**Table 1**
The EDS results at different positions in Fig. 1.

| Position | Mg (at%) | Y (at%) |
|---|---|---|
| Fig. 1-A | 50.86 | 49.14 |
| Fig. 1-B | 92.05 | 7.95 |

## 2. Experimental procedure

The materials used in this experiment include commercial pure magnesium, commercial pure lithium and Mg-40 wt% Y master alloy. The charging (700 g) of Mg-9Li-0.3Y alloy was placed in a stainless steel crucible (90 mm in diameter, 250 mm in height). Then, the crucible with the charging was placed into an induction furnace, followed by pumping the furnace chamber to vacuum state and inputting pure argon as protective gas. Subsequently, the charging was heated to 700 °C and then the alloy melt was isothermally held under this temperature for 10 min. Finally, the crucible with the melt was cooled in the furnace under argon atmosphere and an ingot with rough surface was obtained. In order to acquire better material quality, the ingot should be machined before extrusion. The extrusion of the ingot was carried out at 250 °C and the extrusion ratio was 28, leading to an ingot with 75 mm in diameter and 150 mm in height The Mg-9Li-0.3Y bars with the diameter of 16 mm were obtained. As a control sample, Mg-9Li ingot and bar were prepared using the same process.

The samples used for microstructure observation were cut from the center of Mg-9Li-*x*Y bars and characterized by using optical microscopy and scanning electron microscopy (SEM, TESCAN VEGA). Before that, the specimens were polished and etched with an etchant of 2.0 vol% nitric-ethanol solution. The grain size was