



Phase equilibria of Mg-La-Zr system and thermal conductivity of selected alloys



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ABSTRACT

The investigation on phase equilibria of Mg-La-Zr system contributes to finding the alloy composition with good mechanical properties and superior thermal conductivity along with the variation of phase constitution and microstructure. In our study, four key Mg-La alloys were used to investigate the phase equilibria of Mg-La binary system via a combination of X-ray diffraction (XRD) and scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometer (EDS). Two peritectic reactions have been found among the composition of 50.0–75.0 at.% Mg. It is determined that LaMg₂ is a stable phase below 500 °C, while La₅Mg₄₁ is not stable in Mg-La system. The phase equilibria of Mg-La-Zr were investigated through one diffusion couple of Mg/La_{84.6}Zr_{15.4} and three Mg-La-Zr alloys. The thermodynamic description of the Mg-La-Zr system was assessed at 300–500 °C. By the calculation of equilibrium solidification of Mg-La-Zr alloys, it is predicted that with the increase of La content, eutectic regions composed of LaMg₁₂ and magnesium phase present a dense network in grain boundary of primary hcp(Mg) which hinder the heat transmission. Mg_{99.7}La_{0.2}Zr_{0.1} (136.6 W/(m·K)) exhibits higher thermal conductivity than Mg_{99.1}La_{0.8}Zr_{0.1} (113.9 W/(m·K)).

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1. Introduction

Developing materials with superior thermal conductivity and simultaneously low density to meet the requirements of producing radiator and cooling fin has attracted an increasing interest recently. Among common metals, copper exhibits the best thermal conductivity, whereas copper is very heavy and expensive. Aluminum alloys are also widely used as heat dissipation materials. However, with the high integration and lightweight of electronic products, the traditional aluminum alloys have been hard to meet the demand. Magnesium alloys have nowadays attracted lots of attention due to their low density, good thermal conductivity and good electromagnetic shielding characteristics, etc [1–5].

Magnesium-rare earth alloys have exhibited good creep-

resistant and high specific strength at elevated temperatures due to grain boundary strengthening via intermetallics and precipitation hardening [6,7]. Mg-RE-Zr alloys have been widely studied and developed for industrial application [8]. La is one promising rare earth element [9]. Nearly all solute lanthanum solidifies as a eutectic LaMg₁₂ phase in the Mg-rich region of the Mg-La system. The refinement of the LaMg₁₂ phase was obtained by structure modification to improve the mechanical properties, which may promote the use of lanthanum for high-temperature structural alloys [10,11]. On the other hand, zirconium as an excellent grain-refiner for magnesium alloys [12,13], is helpful to achieve small grain size that improves corrosion resistance and good mechanical properties [14]. The combined addition of zirconium and lanthanum has shown more remarkable grain refinement than zirconium alone in the previous study [11]. Since intermetallics play a key role on enhancing mechanical properties and thermal conductivity, the phase equilibria of Mg-La-Zr system with the calculation of phase diagrams (CALPHAD) method is essential for guiding the design of alloy composition with good mechanical properties and superior thermal conductivity.

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Table 1
Compositions and treatment of Mg-La/Mg-La-Zr alloys in this study.

Alloy No.	Composition (at.%)	Treatment
#A	La _{38.6} Mg _{61.4}	400 °C 40 days 500 °C 30 days
#B	La _{32.2} Mg _{67.8}	400 °C 40 days 500 °C 30 days
#C	La _{16.5} Mg _{83.5}	500 °C 5 days
#D	La _{10.8} Mg _{89.2}	500 °C 5 days
#1	Mg _{90.2} La _{3.8} Zr _{6.0}	300 °C 20 days 400 °C 10 days 500 °C 1 day
#2	Mg _{85.4} La _{9.0} Zr _{5.6}	300 °C 20 days 400 °C 10 days 500 °C 1 day
#3	Mg _{78.3} La _{16.3} Zr _{5.4}	300 °C 20 days 400 °C 10 days 500 °C 1 day

However, the experimental data and thermodynamic calculation of the Mg-La-Zr ternary system are quite limited. The available results for Mg-La-Zr ternary system are the isothermal section in Mg-rich region (Mg $\geq$ 99.7 at.%) at 300 °C reported by Effenberg et al. [15]. Since no ternary compound has been found in Mg-La-Zr system due to the low solubility of Zr/La in Mg, thus Mg-La-Zr system is extrapolated by three binary systems. In our previous study [16], we have modified the thermodynamic parameters in the La-Zr system which was established by Mattern et al. [17]. The thermodynamic parameters for the binary La-Zr and Mg-Zr systems are taken from Refs. [16–18] respectively. Nevertheless, the phase equilibria of the La-Mg system are still controversial. The stability of LaMg₂ and La₅Mg₄₁ still exists some arguments. Recently, Zhang et al. [9] reported that the decomposing temperature range of LaMg₂ was determined at 360–500 °C and La₅Mg₄₁ decomposed below 500 °C. However, Nayeab-Hashemi et al. [19]

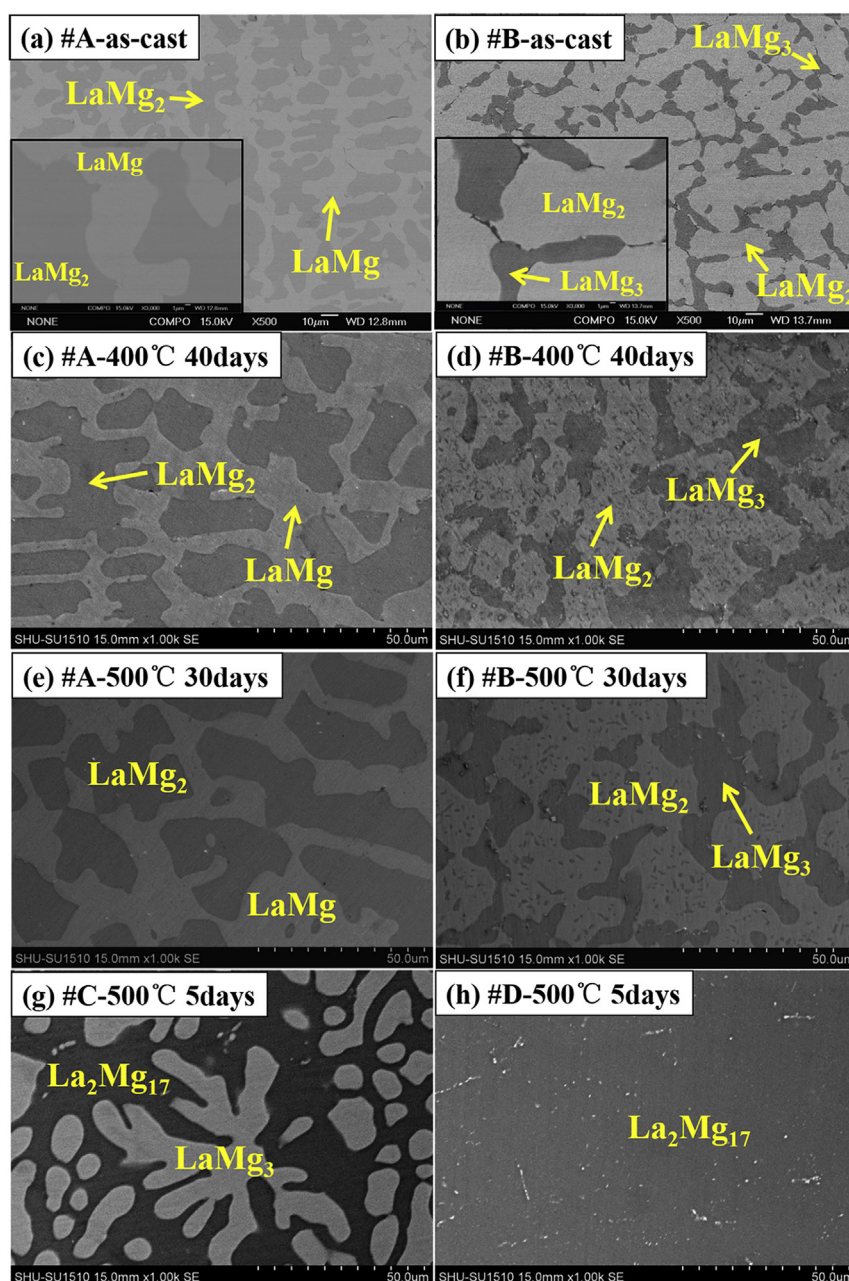


Fig. 1. Microstructure of Mg-La alloys (a), (b) alloy #A and #B at as-cast state; (c), (d) alloy #A and #B annealed at 400 °C for 40 days; (e), (f) alloy #A and #B annealed at 500 °C for 30 days; (g), (h) alloy #C and #D annealed at 500 °C for 5 days.

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