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The effect of lanthanum on the solidification curve and microstructure of Al-Mg alloy during eutectic solidification

Shikun Xie*, Rongxi Yi, Xiuyan Guo, Xiaoliang Pan and Xiang Xia

School of Mechanical and Electrical Engineering, Jinggangshan University,
28 Xueyuan Road, Ji'an 343009, China

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Abstract. The influence of rare earth lanthanum (La) on solidification cooling range, microstructure of aluminum-magnesium (Al-Mg) alloy and mechanical properties were investigated. Five kinds of Al-Mg alloys with rare earth content of La (i.e., 0, 0.5, 1.0, 1.5 and 2.0 wt.%) were prepared. Samples were either slowly cooled in furnace or water cooled. Results indicate that the addition of the rare earth (RE) La can significantly influence the solidification range, the resultant microstructure, and tensile strength. RE La can extend the alloy solidification range, increase the solidification time, and also greatly improve the flow performance. The addition of La takes a metamorphism effect on Al-Mg alloy, resulting in that the finer the grain is obtained, the rounder the morphology becomes. RE La can significantly increase the mechanical properties for its metamorphism and reinforcement. When the La content is about 1.5 wt.%, the tensile strength of Al-Mg alloy reaches its maximum value of 314 MPa.

Keywords: Al-Mg alloy; rare earth lanthanum (La); solidification curve; microstructure; extrusion; tensile strength

1. Introduction

The combination of low density, high strength, high fracture toughness, and excellent resistance to stress corrosion and fatigue performance are most desirable properties for those materials in high-strength applications, such as in aerospace, automotive, and mechanical industry (Montalba *et al.* 2015, Chen *et al.* 2007, Su *et al.* 2012, Yu *et al.* 2007). Due to its low density, high specific strength, easy processing and the economic advantages, cast aluminum alloy are widely used in a variety of industries (Liu and Hu 2008, Yi *et al.* 2009, Xie *et al.* 2010). Al-Mg-based alloy is a class of high-strength heat-resistant alloys. The Al-Mg-based alloys are widely used in earlier industrial applications, owing to their high temperature stability and high heat resistance. However, its wide solidification zone usually leads to a pasty solidification and synchronous solidification in the cross section of the cast when the alloy liquid is cooled gradually (Liang *et al.* 2013). As a result, dendritic crystals solidified firstly block the flow of liquid metal, resulting in a poor fluidity of the alloy liquid. The growth of alloy dendritic crystal will cause dendritic segregation with a lower melting temperature (Bai *et al.* 2012). The presence of such a dendritic segregation will

∗Corresponding Author, Professor, E-mail: xskun@163.com

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Table 1 The solidification temperature parameters for the Al-Mg alloys containing different La contents

La content (wt.%)	Start temperature (℃)	End temperature (℃)	Temperature range (℃)	The growth rate
0	652.5	628.5	24	--
0.5	651.5	627.3	24.2	0.83%
1.0	649.7	625.2	24.5	1.24%
1.5	648.9	618.7	30.2	23.27%
2.0	647.7	616.8	30.9	2.32%

Samples were taken from the casts and extrusion parts in the same positions and were ground up to 2000 grits SiC paper then polished for metallographic microstructural observations. All the prepared metallographic samples were etched in 0.5 vol.% HF solution.

3. Results

3.1 Effects of La on solidification curves

Fig. 3 shows the solidification curves of aluminum-magnesium alloys with different amount of La, i.e. at 0 wt.%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%, and 2.0 wt.%. As shown in Fig. 3, when La content is at 0 wt.%, the solidification of the alloy begins at 652.5℃ and finishes at 628.5℃. While the addition of La increases to 0.5 wt.%, the alloy begins to solidify at 651.5℃, and ends solidification at 627.3℃. When the La content increases to 1.0 wt.%, 1.5 wt.%, and 2.0 wt.%, respectively, the alloy starts to solidify at 649.7℃, 648.9℃, and 647.7℃, and ends solidification at 625.2℃, 618.7℃, 616.8℃, respectively. Therefore, the addition of rare earth La could significantly alter the solidification range of aluminum-magnesium alloy.

In general, a wide two-phase region temperature of alloy is helpful in the solidification processes of semi-liquid metals during cooling (Liang *et al.* 2013). The solidification data of these Al-Mg alloys containing La contents were summarized in Table 1. As shown in Table 1, without rare earth La, the two-phase region in the Al-Mg alloy is from 652.5℃ to 628.5℃, resulting in the solid-liquid interval temperature is about 24℃. The two-phase region in the aluminum-magnesium alloy is broadened with the addition of La. When the La content reaches about 2.0 wt.%, the two-phase region temperature of the alloy is from 647.7℃ to 616.8℃, and the temperature range is 30.9℃. The growth rate of temperature range reaches its maximum value of 23.27% at 1.5 wt.% addition of La. It is concluded that the highest growth rate of temperature range and largest two-phase region temperature is the Al-Mg alloy containing 1.5 wt.% La and 2.0 wt.% La, respectively. But when La content is more than 1.5%, the growth rate of temperature range is not obvious. In addition, the solidification time of the alloy increases with the doping of rare earth La.

3.2 Effects of La on cast microstructure

Fig. 4 shows the metallographic microstructure of the cast Al-Mg alloys at 700℃ slope copper water-cooled casting with La content of at 0%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%, and 2.0 wt.%. As seen from Fig. 4(a), when the addition of La is 0%, the grain size of the alloy is coarse with developed dendrite, and the grain boundary is not evident. However, the micro-alloying of rare