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Microstructure and rolling capability of modified AZ31–Ce–Gd alloys

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ABSTRACT

AZ31–Ce–Gd alloys were studied and the influence of cerium (Ce) and gadolinium (Gd) on the microstructure and rolling capability of AZ31 alloy was investigated. The results indicated that the grains of AZ31 alloy were refined with Ce and Gd addition. Ce and Gd addition resulted in the formation of Al_4Ce, Al_2Gd and Mg_3Gd. After homogenization and rolling, the Al_4Ce, Al_2Gd and Mg_3Gd still existed. The rolling capability of AZ31 alloy was improved obviously with Ce and Gd addition. However, once Gd content increased to a certain value, the rolling capability of the modified alloy declined but still better than that of AZ31 alloy.

1. Introduction

Magnesium alloys are attracting great attention from the ecological point of view, since magnesium alloys are the lightest among structural alloys [1]. Furthermore, magnesium alloys have several good characteristics: high specific strength and stiffness, superior damping capacity, high thermal conductivity, high dimensional stability, good electromagnetic shielding characteristics and good machinability [2,3]. However, the applications of magnesium in automobiles are currently limited to castings (such as covers, housing and brackets). It can be increased if wrought Mg alloy products are more readily available.

There is a wrought Mg alloy that is extensively commercially available, namely, AZ31. Generally, magnesium alloys possess poor formability and limited ductility at room temperature. It is mainly ascribed to their hexagonal close-packed (HCP) crystal structure [4,5]. If the formability of Mg alloys is improved, their applications will be expanded. Generally, grain refinement is one of the important methods to improve the strength and formability of Mg alloys [6].

In this paper, two approaches are proposed for the development of grain-refined AZ31 alloy. One is adding RE elements into the alloy. The other is rolling the alloy, in particular, hot rolling plus heat treatment involving re-crystallization. It is aimed to obtain a more readily rolled Mg sheets due to the improvement of rolling capability. Among RE elements, it has been reported that addition of 1.05 wt.% Ce into magnesium alloy could increase the strength and refine the grains [7]. Furthermore, Gd is often used in Mg–Zn alloys and Mg–RE alloys because of the relatively high solubility limit of Gd in Mg solid solution [8,9]. However, their studies are based on a single element; few studies have been conducted about the effects of multiple trace-elements on the microstructure and rolling

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Table 1 – Design alloy compositions (wt.%).

Alloy type	Ce	Gd
AZ31	–	–
AZ31–0.35 Ce	0.35	–
AZ31–0.35 Ce–1.5 Gd	0.35	1.5
AZ31–0.35 Ce–3.5 Gd	0.35	3.5

capability of AZ31 alloy. In this work, 0.35 wt.% Ce and different amounts of Gd were added into AZ31 alloy to investigate the effect.

Usually, AZ31 alloy must be homogenized at high temperature before rolling [10,11]. The rolling pass and rolling reduction are limited. In this paper, AZ31–Ce–Gd alloys were rolled after being homogenized for different times to study the effect of grain size and precipitated phase on rolling capability of the alloy.

2. Materials and Experimental Procedures

2.1. *Experimental Materials*

AZ31 alloy was chosen as the staring alloy with chemical compositions of 3% Al, 1% Zn, 0.35% Mn and Mg in balance. Gd and Ce were added with the form of master alloys Mg–20% Gd and Mg–22.5% Ce, respectively. The designed compositions of the alloys are listed in Table 1.

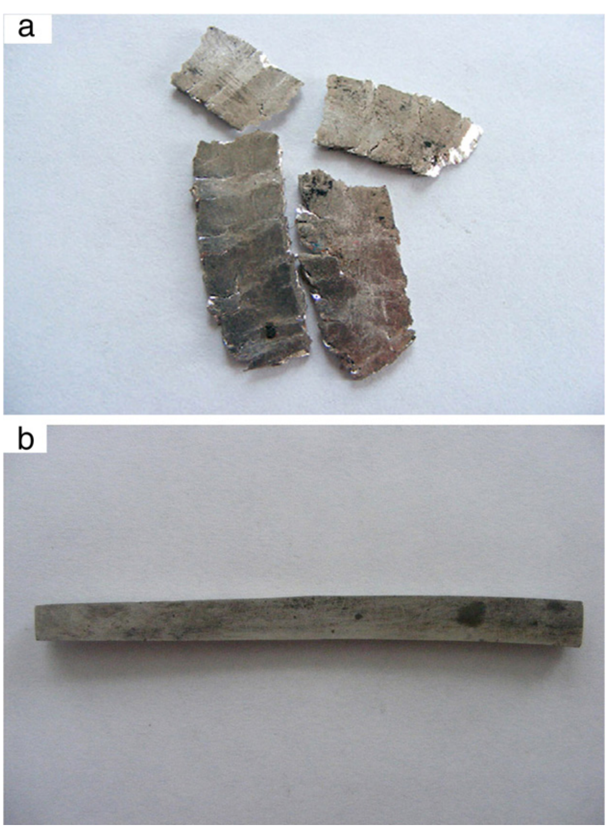

Fig. 1 – The macroscopic photographs of some rolled sheets after 10 h homogenized treatment (a) AZ31 alloy with one pass of 53% reduction; (b) AZ31–0.35% Ce–1.5% Gd alloy with one pass of 53% reduction.

2.2. *Experimental Procedure*

The alloys were melted in a resistance furnace and cast into a steel mould (110 mm×100 mm×6 mm). The castings were then machined into sheets with dimensions of 100 mm× 15 mm×4 mm. The testing of the rolling capability of the alloys was taken in two steps. The maximum reduction per pass was achieved at the first step. Prior to being rolled, the sheets were, respectively soaked in heat treating furnace for 4 h or 10 h at the rolling temperature. The sheets were then immediately rolled at 400°C. The initial reduction was designed as 60%. However, cracking appeared on the sample. Then the same process was repeated with 1% of the reduction for the next sheet until the cracking disappeared. At the second step, the alloy was rolled repeatedly to test the maximum total reduction. The sheets were homogenized under the same condition as concerned previously and then rolled at 400°C. The reduction of the first rolling pass was designed to be 10% and then increased 5% for the next pass until cracking appeared. The specimens were returned to the heated salt bath between passes to regain the desired rolling temperature. Fig. 1 shows the macroscopic photographs of some rolled sheets after 10 h homogenized treatment. Metallographic specimens were observed under optical microscope after grinding, polishing, and etching with 4% nitric acid alcohol. Scanning electron microscopy (SEM) and JSM 6700F field emission scanning electron microscopy (FESEM) was used to observe the precipitated phase in details. The grain size was measured with OLYMPUS PMG3 Microscope on Study and Profound Steel Image Analysis System. X-ray diffraction was used to analyze the phase constitutes. Energy spectrum analysis was done to confirm the phase composition.

3. Results and Discussion

3.1. *Microstructure Analysis*

Table 2 displays the grain size of the alloys as-cast. With addition of Ce and Gd in AZ31, the grain size decreases. The grain size of AZ31-0.35%Ce-1.5%Gd alloy is the smallest. Fig. 2 shows the microstructures of AZ31–Ce–Gd alloys as-cast. The microstructure of AZ31 alloy is composed of α-Mg matrix and irregular β phase ($Mg_{17}Al_{12}$) precipitated along grain boundaries (Fig. 2a). The α-phase presents clear coarse dendrites. With the addition of Ce, the volume fraction of the β phase decreases and β phase changes into small particles. Moreover, a rod-like phase can be observed. When Gd is added into the alloy, the β phase further decreases and the rod-like phase still

Table 2 – Grain size of as-cast AZ31 and the modified alloys.

	AZ31	AZ31–0.35 Ce	AZ31–0.35 Ce–1.5 Gd	AZ31–0.35 Ce–3.5 Gd
Average grain size range (μm)	87	47	40	52