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Effect of deformation and heat treatment on microstructure and mechanical properties of Mg-8Li-1Al-0.6Ce alloy

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Abstract

Microstructure and mechanical properties of as-cast, as-rolled and as-annealed Mg-8Li--1Al-0.6Ce alloys are studied. The as-cast, as-rolled and as-annealed Mg-8Li-1Al-0.6Ce alloys are composed of α phase (white), β phase (gray), and AlCe phase. The grains are refined when Mg-8Li-1Al-0.6Ce alloy is rolled. The recrystallization of the as-rolled Mg-8Li-1Al-0.6Ce alloy may take place after the annealing procedure. The results of tensile tests show that the as-annealed Mg-8Li-1Al-0.6Ce alloy possesses peak strength and elongation 233.9 MPa and 24.9 %, respectively.

Key words: Mg-Li alloy, rolling, annealing, microstructure, mechanical properties

1. Introduction

Magnesium-lithium alloys possess the lowest density among metallic structural materials [1–3]. Due to their advantages of low density, high specific strength, good machinability and formability, good damping ability and high energetic particle penetration resistance, Mg-Li alloys have good prospects of applications in the fields of aerospace, electronic industry, military, etc. [4–9].

When the content of Li is larger than 5.7 wt.%, the microstructure of Mg-Li alloys changes from α (hcp) Mg-rich phase to α (hcp) Mg-rich and β (bcc) Li-rich phases [10–12]. Mg-8Li alloys are the typical double--phase alloys. However, Mg-Li binary alloys possess relatively low strength, poor corrosion resistance and thermal stability. Therefore, some alloying elements should be added to the alloys [13]. Among the alloying elements, aluminum is one of the most commonly alloying elements used for solid solution strengthening [14]. However, the density of alloys also increases with the Al content in the alloys. Therefore, the amount of Al in Mg-Li alloys is always between 1 wt.% and 3 wt.% [15, 16].

Research results show that the strength of Mg-Li alloys is improved and the grains of Mg-Li alloys are refined with the addition of Ce [17–20]. However, the reports about the effect of deformation and heat treatment on microstructure and mechanical properties of Mg-8Li-1Al-0.6Ce alloy are very deficient.

In this paper, Mg-8Li-1Al-0.6Ce alloys were prepared with vacuum melting method under the argon atmosphere. The microstructure and mechanical properties of as-cast, as-rolled and as-annealed alloys were also investigated and discussed.

2. Experimental procedure

Pure magnesium ingot (99.95 %), pure lithium ingot (99.90 %), pure aluminum ingot (99.95 %), and magnesium-cerium master alloy (containing Ce 18.26 %) were used in this experiment. The materials were melted in a vacuum induction melting furnace under the protection of argon atmosphere. The furnace chamber pressure was pumped to 1×10^{-2} Pa, then pure argon was input as protective gas before melting. The as-cast specimens were homogenized at 280 ℃ for 24 h. Then the as-cast specimens were rolled at 200 ℃. Finally, the as-rolled specimens were annealed at 370 ℃ for 3 h.

Chemical composition of alloys was measured with

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Table 1. Chemical composition of as-cast Mg-8Li-1Al-0.6Ce alloy (mass %)

Nominal composition	Actual composition
Mg-8Li-1Al-0.6Ce	Mg-8.30Li-1.17Al-0.67Ce

inductively-coupled plasma spectrometer. The results are listed in Table 1.

Microstructure was examined using optical microscopy. The samples were etched with an etchant of 3 vol.% nital. Phase composition of alloys was measured with X-ray diffraction (XRD). Micro-zone elemental analysis was measured with SEM and EDS. The mechanical properties of these alloys were measured with a tensile tester (the initial strain rate is $6.67 \times 10^{-4}\,\mathrm{s}^{-1}$, and the gauge dimensions of the tensile specimen are $\varnothing\ 6 \times 50\,\mathrm{mm}^2$).

3. Results and discussion

3.1. Microstructure and phase analysis

Microstructure of as-cast, as-rolled and as-annealed Mg-8Li-1Al-0.6Ce alloys is shown in Fig. 1. The microstructure is composed of α phase (white), β (gray) and compounds. In the as-cast alloy, α phase is virgulate and spherical in shape. After rolling, the grains are refined and elongated along rolling direction. The recrystallization of as-rolled Mg-8Li-0.6Ce alloy happens during annealing.

To observe the microstructure of the alloys more clearly, their high magnified microstructure is shown in Fig. 2. Some compounds exist in the matrix. After rolling, the compound is refined. The microstructure of as-annealed Mg-8Li-1Al-0.6Ce alloy is composed of fine equiaxed grains with an average grain size of 20.5 μm.

To know the compounds in as-cast Mg-8Li-1Al-0.6Ce alloy, the specimen was analyzed with XRD and EDS. Figure 3 shows the XRD patterns of as-cast Mg-8Li-1Al-0.6Ce alloy. It is known that the Mg-8Li-1Al-0.6Ce alloy is composed of α (Mg), β (Li) and AlCe phases.

The EDS result is shown in Fig. 4. The compound at point 001 is composed of Mg, Al and Ce elements. Elements composition of point 001 is listed in the table. The atomic ratio of Al to Ce is about 1. Based on the electronegativity difference between elements, the trend to form compounds can be valued. The electronegativity difference between Ce and Al is larger than that between Ce and Mg. Therefore, Al is easier than Mg to react with Ce to form compounds. Combined with the XRD patterns, it can be concluded that the compound is AlCe.

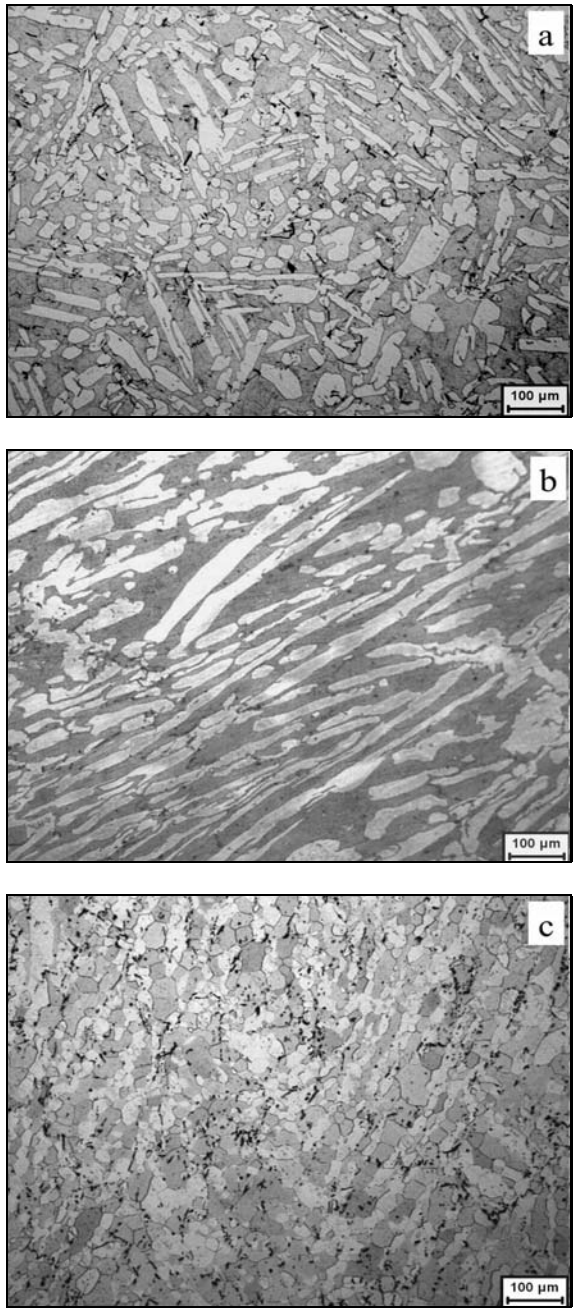

Fig. 1. Microstructure of Mg-8Li-1Al-0.6Ce alloy: a) as-cast, b) as-rolled, c) as-annealed

3.2. Mechanical properties

Figures 5 and 6 show mechanical properties of a Mg-8Li-1Al-0.6Ce alloy. The strength of the as-rolled and as-annealed alloys is increased. Compared with as-cast alloy, the elongation of the as-rolled alloy is reduced, and the elongation of the as-annealed alloy is increased. The alloy possesses peak strength and elongation (233.9 MPa and 24.9 %, respectively), when the as-rolled alloy is annealed.

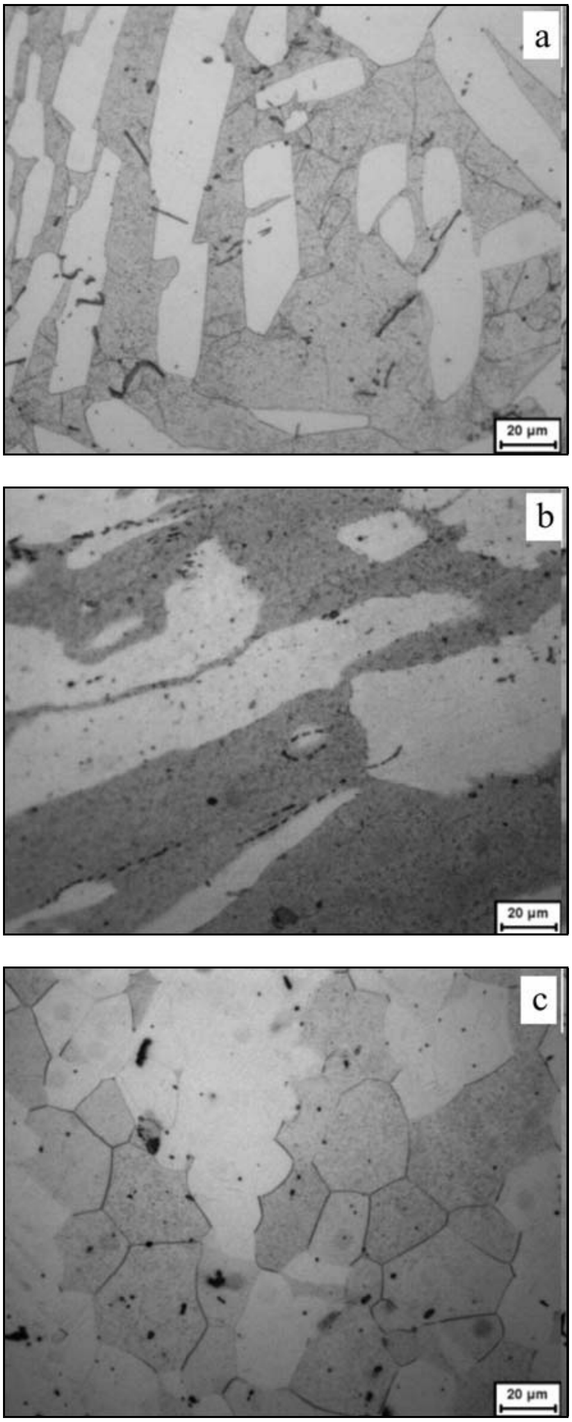

Fig. 2a,b,c. High magnified microstructure of Mg-8Li-1Al--0.6Ce alloy.

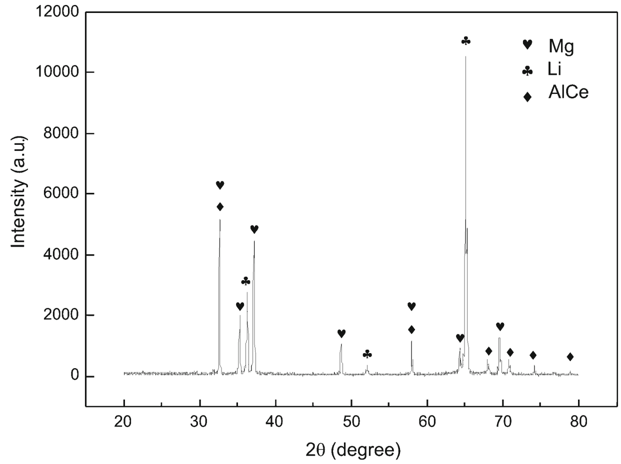

Fig. 3. XRD pattern of as-cast Mg-8Li-1Al-0.6Ce alloy specimen.

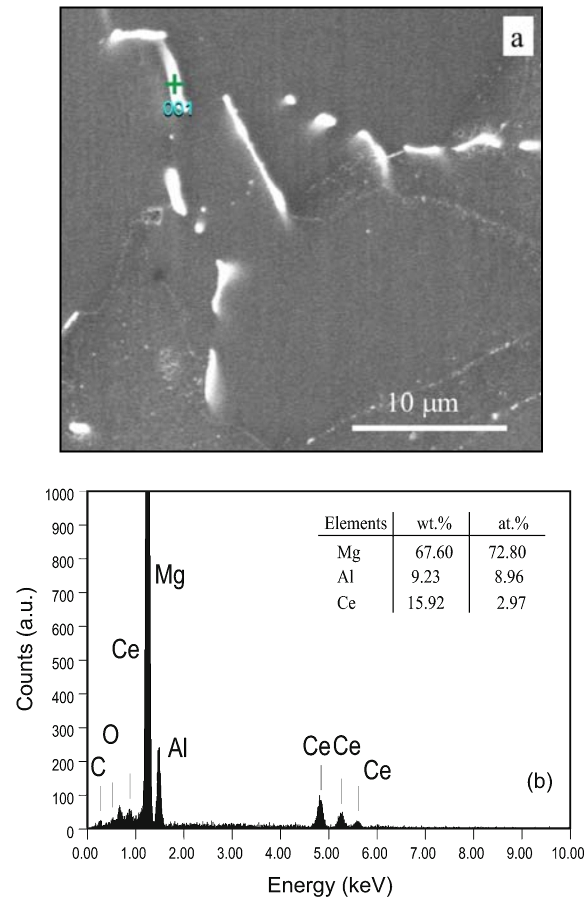

Fig. 4a,b. SEM image and EDS pattern of as-cast Mg-8Li--1Al-0.6Ce specimen.

There are three aspects for the strength of as-rolled and as-annealed alloy being increased. Firstly, the amount of as-cast defects, such as shrinkage porosity and gas porosity, is decreased after rolling. Secondly, the grains are refined after rolling and annealing, and the microstructure of as-annealed Mg-8Li-1Al-0.6Ce alloy was composed of fine equiaxed grains. Thirdly, the work hardening is the main factor which causes an increase in strength after rolling. The work hardening that results from the increase in dislocation density is responsible for the dislocation tangle. Therefore, the

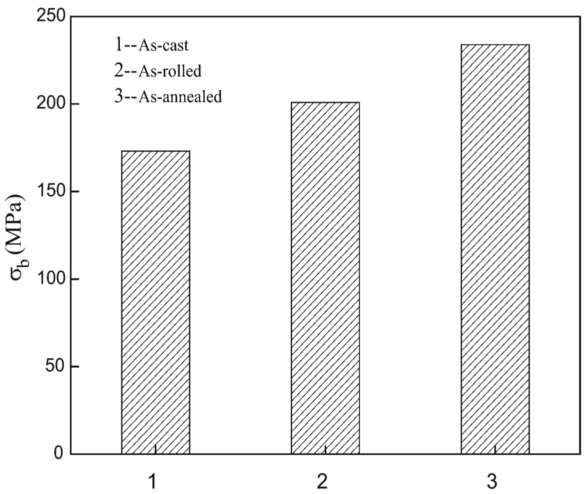

Fig. 5. Strength of Mg-8Li-1Al-0.6Ce alloy.

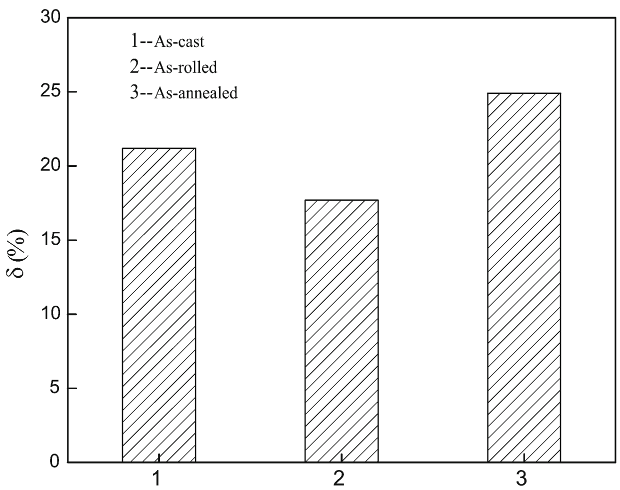

Fig. 6. Elongation of Mg-8Li-1Al-0.6Ce alloy.

motion of dislocations becomes more difficult and the strength of alloy is improved accordingly [10].

From Fig. 1b and Fig. 2b, it is shown that α (Mg) phase is elongated along the rolling direction. Therefore, the stress concentration is produced on the tips of grains while they are suffering from external force, which may lead to the reduction of the elongation of as-rolled alloy. From Fig. 1c and Fig. 2c it stems that the microstructure of as-annealed Mg-8Li-1Al-0.6Ce alloy is composed of fine equiaxed grains. Therefore, the elongation of alloy is increased after annealing.

4. Conclusions

1. The microstructure of the as-cast, as-rolled and as-annealed alloys is composed of α phase (white), β phase (gray), and AlCe phase. The grains of the as-cast alloy are refined and elongated after rolling. The recrystallization of as-rolled Mg-8Li-0.6Ce alloy happens during annealing.

2. The strength is increased and the elongation is reduced when the alloy is rolled. The strength and elongation of as-rolled alloy are increased after annealing. The as-annealed Mg-8Li-1Al-0.6Ce alloy possesses peak strength and elongation 233.9 MPa and 24.9 %, respectively.

3. The work hardening is the main factor which causes an increase in strength after rolling. The stress concentration and dislocation tangle are primary factors which cause the reduction of elongation after rolling. The recrystallization is primary factor which causes that the strength and elongation of as-rolled alloy are increased after annealing.

Acknowledgements

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