

## Microstructure characterization and mechanical properties of Mg-9Li-5Al-1Zn-0.6RE alloy

WU Rui-zhi(巫瑞智), ZHANG Mi-lin(张密林), WANG Tao(王 涛)

Key Laboratory of Superlight Materials and Surface Technology, Ministry of Education,  
Harbin Engineering University, Harbin 150001, China

Received 15 July 2007; accepted 10 September 2007

**Abstract:** Mg-9Li-5Al-1Zn-0.6RE alloy was prepared by vacuum induction heating. The microstructure and phases composition of the alloy were analyzed with optical microscope, scanning electron microscope and X-ray diffractometer. Then the effect of homogenization temperature on microstructure and mechanical properties of the alloy was studied. The hardness of samples under different homogenization temperatures was measured. The results show that, the alloy is composed of  $\alpha$  phase,  $\beta$  phase,  $Mg_{17}Al_{12}$  and AlLi. RE added into the alloy is solved in  $\alpha$  phase and  $\beta$  phase completely. After homogenization heat treatment, the needle-like  $\alpha$  phase disappears. With the increase of homogenization temperature, the shape of  $\alpha$  phase is spherical-like first, then vermicular-like, and large block-like finally. The variation of the shape of  $\alpha$  phase causes the hardness of sample to change accordingly. The most favorable homogenization temperature for microstructure and mechanical properties is 150 °C.

**Key words:** homogenization temperature; magnesium-lithium alloy; microstructure; mechanical properties

### 1 Introduction

Magnesium-lithium alloy has lower density than the other magnesium alloys. It possesses better deformation property than the other magnesium also[1-2]. Therefore, magnesium-lithium has attracted more and more interests recently.

In Mg-Li binary alloys, Mg-(8-9)Li has the best comprehensive properties (both relatively high strength and relatively high elongation)[3-4]. Therefore, most researchers focus on Mg-(8-9)Li alloys.

However, Mg-Li binary alloy has relatively poor mechanical properties[5]. To overcome this shortcoming, alloying is an effective strengthening method. Al is one of the most effective elements for Mg-Li alloy strengthening. Accordingly, it is the most commonly used alloying element in Mg-Li alloys. However, when the Al content is larger than 6% (mass fraction), the strengthening effect is reduced and the plastic deformation property becomes poor seriously[4-6]. Zn is also an effective strengthening element for Mg-Li alloys.

However, because of its high density, Zn content in Mg-Li alloy should not be too high[7].

Microstructure refinement also has strengthening effects. In Mg-Li alloys, RE elements have obvious refining effects. The lower than 1%(mass fraction) RE content will bring out good refining effects on Mg-Li alloys[8-9].

To strengthen Mg-Li alloys further, all kinds of deforming process (such as extruding, rolling, forging) are performed on as-cast Mg-Li alloys[10-11]. Before the deforming process of Mg-Li alloys, Mg-Li alloys should be homogenization heat treated to avoid the inhomogeneous deformation in the deforming process[12].

Based on the background mentioned above, in this work, Mg-9Li-5Al-1Zn-0.6RE alloy (one of the alloys processing the most application prospects) was chosen as the research object. To provide the information of microstructure, phases composition and the optimum homogenization temperature before deformation process to the researchers and the users of this alloy, the microstructure and phase composition were characterized.

And the effect of homogenization temperature on microstructure and mechanical properties of the alloy was studied.

## 2 Experimental

The materials used in experiments were pure magnesium (99.95%), pure lithium (99.90%), pure aluminum (99.90%) and Mg-15%RE (RE contains 80%La, 15%Pr and 5%Ce) master alloy. The composition is in mass fraction. Mg-9Li-5Al-1Zn-0.6RE alloy was prepared under the ambient argon gas in vacuum induction furnace. The furnace chamber pressure was kept at  $1 \times 10^{-2}$  Pa. Pure argon was input as protective gas before melting. The melt temperature was about 700 °C. Then the melt was poured into a permanent mould. The homogenization heat treatment was carried out in vacuum electric resistance furnace.

Microstructure of alloy was measured by optical metallography(OM), as well as by scanning electron microscopy (SEM). The samples for OM and SEM have been etched by using an etchant consisting of 10 mL  $\text{KNO}_3$  and 90 mL alcohol. Phase analysis was performed by X-ray powder diffraction(XRD). Mechanical properties of the alloy were characterized by hardness. The hardness of alloy was measured on micro-hardness tester (50 N load for 30 s).

## 3 Results and discussion

### 3.1 Microstructure and phase analysis of as-cast alloy

Fig.1 shows the OM graph and SEM graph of the as-cast alloy. The OM graph shows that  $\alpha$  (Mg solid solution) distributes in  $\beta$  (Li solid solution) evenly. The shape of  $\alpha$  is rod-like or needle-like. The SEM graph shows the detailed microstructure of the sample. It shows that, besides  $\alpha$  phase and  $\beta$  phase, some block-like phase (A) and rod-like phase exist in the sample. From the XRD result of the sample, it can be known that A is  $\text{Mg}_{17}\text{Al}_{12}$ . It mainly exists at the boundary between  $\alpha$  phase and  $\beta$  phase[9]. B is  $\text{AlLi}$  existing at the boundary between  $\alpha$  phase and  $\beta$  phase, or in the  $\beta$  phase[11].

The RE elements are not found in both microstructure graphs and XRD result, as shown in Fig.2. This is maybe because the RE addition content is low (0.6%). RE added into the alloy is solved in  $\alpha$  phase and  $\beta$  phase completely.

### 3.2 Effect of homogenization temperature on microstructure of sample

The effect of homogenization temperature on microstructure of Mg-9Li-5Al-1Zn-0.6RE alloy is shown

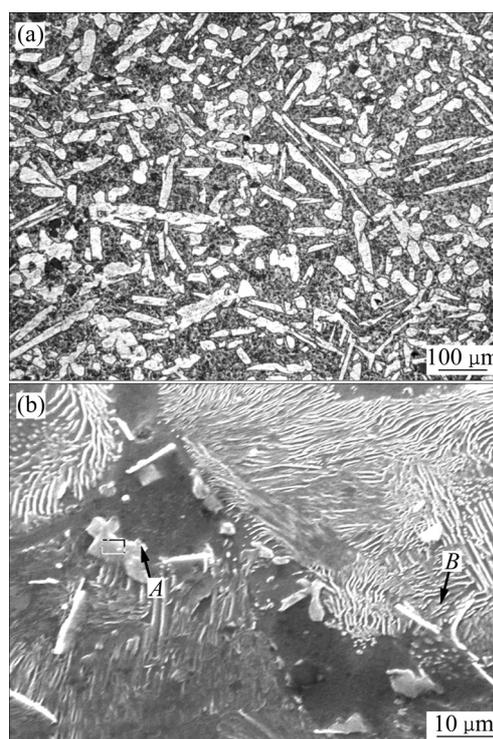


Fig.1 Microstructures of as-cast sample: (a) OM graph of as-cast alloy; (b) SEM graph of as-cast alloy

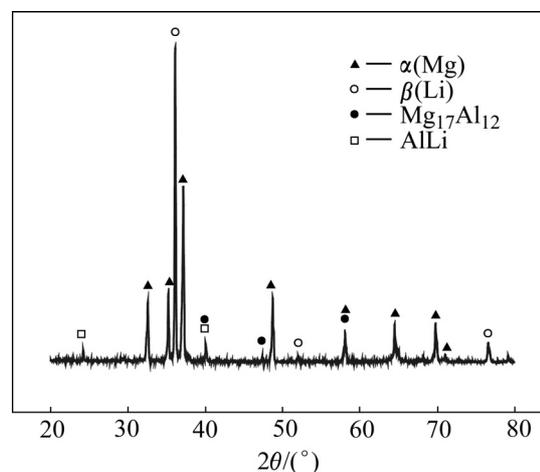
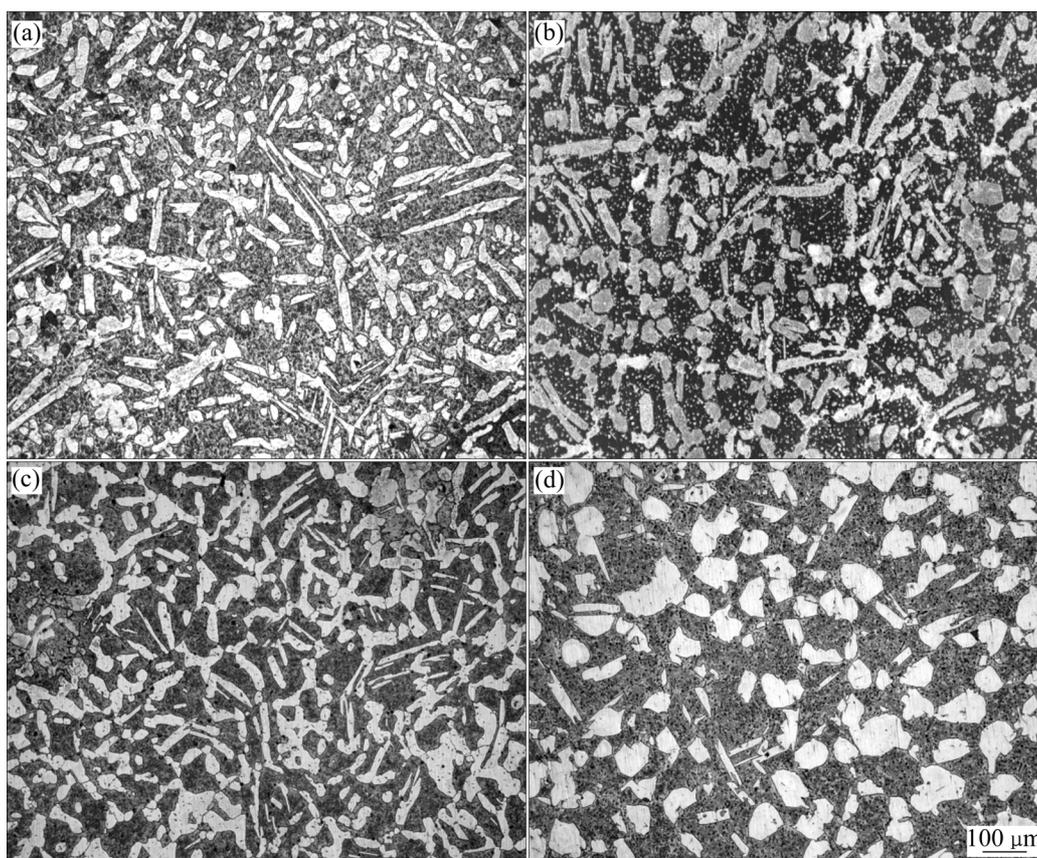


Fig.2 XRD pattern of as-cast sample

in Fig.3. In the as-cast sample, most of  $\alpha$  phase is needle-like or rod-like. After the homogenization heat treatment at 150 °C for 8 h, the needle-like  $\alpha$  phase disappears. The shape of  $\alpha$  phase mainly becomes spherical-like. And a little amount of rod-like  $\alpha$  phase still exists. If the homogenization temperature is 200 °C, after 8 h, the spherical-like  $\alpha$  phases combine each other and become vermicular-like. This causes the size of  $\alpha$  phase to be larger. If the homogenization temperature is increased further to 250 °C, after 8 h, the shape of  $\alpha$  phase will be changed to large block-like. The size of  $\alpha$  phase is increased further.



**Fig.3** Microstructures of samples under different homogenization temperatures for 8 h: (a) As-cast; (b) 150 °C; (c) 200 °C; (d) 250 °C

### 3.3 Effect of homogenization temperature on mechanical properties of sample

Table 1 lists the hardness of samples under different conditions (each sample was measured 10 times and the average value of them is used). The homogenization heat treatment time is 8 h. From Table 1, it is known that, when the homogenization temperature is 150 °C, the hardness of corresponding sample is the maximum. The reason is that, after homogenization, the needle-like  $\alpha$  phase is changed to spherical-like (as shown in Figs.3(a) and (b)). The cleaving effect of needle-like  $\alpha$  phase on the matrix is removed. When the homogenization is 200 °C, the hardness is larger than that of the as-cast sample, but less than that of the sample corresponding to 150 °C homogenization temperature. In the microstructure of the sample, the shape of  $\alpha$  phase is vermicular (as shown in Fig.3(c)). On one hand, it removes the unfavorable effect of needle-like shape. On the other hand, the size of  $\alpha$  phase is larger than that of 150 °C. This causes the hardness to be between that of the as-cast sample and that of the 150 °C homogenized sample. When the homogenization temperature is increased further to 250 °C, the size of  $\alpha$  phase is increased further and the hardness of the corresponding sample is reduced further (lower than that of the as-cast sample).

**Table 1** Vickers hardness of samples under different homogenization temperatures

As-cast	Homogenization temperature/°C		
	150	220	250
60	75	68	57

## 4 Conclusions

1) The alloy is composed of  $\alpha$  phase,  $\beta$  phase,  $Mg_{17}Al_{12}$  and  $AlLi$ . The shape of  $\alpha$  phase is rod-like or needle-like.  $Mg_{17}Al_{12}$  is block-like and mainly exists at the boundary between  $\alpha$  phase and  $\beta$  phase.  $AlLi$  is rod-like and exists at the boundary between  $\alpha$  phase and  $\beta$  phase, or in the  $\beta$  phase.

2) RE added into the alloy is solved in  $\alpha$  phase and  $\beta$  phase completely.

3) After homogenization heat treatment, the needle-like  $\alpha$  phase disappears. With the increase of homogenization temperature, the shape of  $\alpha$  phase is spherical-like first, then vermicular-like, and large block-like finally.

4) The variation of the shape of  $\alpha$  phase causes the hardness of sample to change accordingly. When the homogenization temperature is 150 °C, the hardness is the maximum (corresponding to the spherical-like shape of  $\alpha$  phase). If the homogenization temperature is larger

than 150 °C, because the size of  $\alpha$  phase is increased, the hardness of the corresponding sample will decrease.

## References

- [1] HAFERKAMP H, NIEMEYER M, BOEHM R. Development, processing and applications range of magnesium lithium alloys [J]. Mater Sci Forum, 2000, 350/351: 31–42.
- [2] CRAWFORD P, BARROSA R, MENDEZ J. On the transformation characteristics of LA141A(Mg-Li-Al) alloy [J]. J Mater Process Technol, 1996, 56: 108–118.
- [3] ZDENVEK D, ZUZANKA T, STANISLAV K. Deformation behavior of Mg-Li-Al alloys [J]. J Alloy Compd, 2004, 378: 192–195.
- [4] SIVAKESAVAM O, PRASAD Y. Characteristics of superplasticity domain in the processing map for working of as-cast Mg-11.5Li-1.5Al alloy [J]. Mater Sci Eng A, 2002, 323: 270–277.
- [5] YU H S, MING G H. Effect of alloying elements on Mg-Li base alloys [J]. Rare Met Mater Eng, 1996, 25(2): 1–5. (in Chinese)
- [6] LIU T, ZHANG W, WU S D. Mechanical properties of a two-phase alloy Mg-8%Li-1%Al processed by equal channel angular pressing [J]. Mater Sci Eng A, 2003, 360: 345–349.
- [7] YAMAMOTO A, ASHIDA T, KOUTA Y. Precipitation in Mg-(4–13)%Li-(4–5)% Zn Ternary Alloys [J]. Mater Trans, 2003, 44(4): 619–624.
- [8] TANG D X, MEN J, CHEN Y G. Research and application of new-type Mg-RE alloys [J]. Sichuan Rare Earth, 2003, (2): 14–18. (in Chinese)
- [9] WANG T, ZHANG M L, NIU Z Y, LIU B. Influence of rare earth elements on microstructure and mechanical properties of Mg-Li alloys [J]. J Rare Earth, 2006, 24(6): 797–799.
- [10] LI L, ZHOU T T, LI H X, CHEN C Q, WU Q L, ZHANG Q Q. Texture evolution in rolled Mg-13wt%Li-x alloy [J]. Mater Sci Forum, 2007, 546/549: 347–350.
- [11] CHANG T C, WANG J Y, CHU C L. Mechanical properties and microstructures of various Mg-Li alloys [J]. Mater Lett, 2006, 60(27): 3272–3276.
- [12] FURUI M, CHENG X, AIDA T. Improving the superplastic properties of a two-phase Mg-8% Li alloy through processing by ECAP [J]. Mater Sci Eng A, 2005, 410/411: 439–442.

(Edited by PENG Chao-qun)