Journal of Alloys and Compounds 582 (2014) 161–166

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jalcom

Mechanical properties of the icosahedral phase reinforced duplex Mg–Li alloy both at room and elevated temperatures

D.K. Xu [a,*], T.T. Zu [a,c], M. Yin [a,d], Y.B. Xu [a,b], E.H. Han [a]

[a] *State Key Laboratory for Corrosion and Protection, Institute of Metal Research, Chinese Academy of Sciences, 62 Wencui Road, Shenyang 110016, China*
[b] *Shenyang National Laboratory for Materials Sciences, 72 Wenhua Road, Shenyang 110016, China*
[c] *National Center for Materials Service Safety, University of Science and Technology Beijing, 30 Xueyuan Road, Beijing 100083, China*
[d] *Shenyang Institute of Aeronautical Engineering, Shenyang 110136, China*

ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form 2 August 2013
Accepted 2 August 2013
Available online 15 August 2013

Keywords:
Mg–Li
Plastic flow
Mechanical property
Elevated temperature
Quasicrystal

ABSTRACT

Through investigating tensile properties of the duplex Mg–Li alloys with and without I-phase (Mg_3Zn_6Y, icosahedral quasicrystal structure) tested both at ambient and elevated temperatures, it demonstrates that I-phase can not only improve the tensile strength at room temperature, but also be beneficial for the mechanical improvement at elevated temperatures. Based on the microstructural observations of the sample surfaces before and after tests, the I-phase particles can effectively suppress the plastic flow of β phase at 220 °C, resulting in the I-phase reinforced duplex Mg–Li alloy having higher mechanical properties at elevated temperatures.

1. Introduction

Due to the addition of lithium, Mg–Li alloys are the lightest structural materials. Generally, their density is between 1.25 and 1.65 g/cm^3, which is about 1/2 and 3/4 that of Al and Mg alloys, respectively. Moreover, Mg–Li alloys can have some attractive properties such as high specific strength and elastic modulus, better formability, weak mechanical anisotropy and better mechanical properties at low temperature [1,2]. However, their tensile strength especially at elevated temperatures is quite poor, which greatly limits their applications as the engineering and structural components in the industry. In previous studies, researchers have tried different strengthening methods, such as adding Zn or Al alloying elements and severe plastic deformation (hot extrusion or equal channel angular extrusion) [3–6]. However, the yield and ultimate tensile strength (UTS) of these processed Mg–Li alloys can hardly exceed 150 and 200 MPa, respectively [3–6]. Recently, Xu et al. reported that through adding Zn and Y and controlling Zn/Y atomic ratio of 6 to form I-phase (Mg_3Zn_6Y, icosahedral quasicrystal structure, quasiperiodically ordered) in Mg–Li alloys, the yield and ultimate tensile strengths were effectively improved and their maximum values can reach 166 and 247 MPa, respectively [7]. Meanwhile, the I-phase strengthened Mg alloys can also have a better plasticity due to the excellent plastic compatibility coming from low interfacial energy of I-phase/matrix [8]. Therefore, the formation of I-phase is an effective way for the mechanical improvement of Mg–Li alloys. Additionally, quasicrystals have many interesting properties such as high hardness, thermal stability, high corrosion resistance, low coefficient of friction, and low interfacial energy [9,10]. Bae et al. reported that the presence of stable I-phase particle/matrix interfaces in the Mg–Zn–Y alloys can strongly resist the microstructural coarsening and suppress the microstructural evolution of the α-Mg matrix during the deformation at elevated temperatures [11,12]. Therefore, it can be predicted that I-phase should also be helpful for the high temperature properties of the other Mg alloys. Following this hypothesis, the presence of I-phase can be considered as a novel way for improving the strength of Mg–Li alloys at elevated temperatures. However, so far, few relevant literatures can be referred. In this work, the aim is to investigate and compare the mechanical properties of the as-rolled (α + β) duplex Mg–Li alloys reinforced with and without I-phase (Mg–6%Li and Mg–6%Li–6%Zn–1.2%Y) tested both at room and elevated temperatures. Through observing the microstructural evolution before and after the testing, the effect of I-phase on the mechanical improvement of the Mg–Li alloys will be deeply explained.

2. Experimental procedures

The materials used in this study were as-rolled Mg–6%Li and Mg–6%Li–6%Zn–1.2%Y (in wt%) magnesium alloys, which were prepared under the protection of the fluxes of LiCl and LiF in the Magnesium Alloy Research Department of IMR, China. With the protection of several layers of wrapped Al foil, the ingots were homogenized

---

[*] Corresponding author. Tel.: +86 24 23915897; fax: +86 24 23894149.
E-mail address: dkxu@imr.ac.cn (D.K. Xu).

0925-8388/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jallcom.2013.08.020

at 400 °C for 6 h. Then, the wrapped Al foil was removed and ingots were hot rolled from the thickness of 33 mm to 6 mm at the temperature of 200 °C without any protection. Phase analysis was determined with a D/Max 2400 X-ray diffractometer (XRD) using monochromatic Cu Kα radiation (wavelength: 0.154056 nm), step size of 0.02° and scan rate of data acquisition of 4°/min. Microstructures of the as-cast specimens with cross-section of 15 mm (TD: transverse direction) ×20 mm (RD: rolling direction) and a thickness of 4 mm were examined by using scanning electron microscopy (SEM; XL30-FEG-ESEM). Tensile samples with a gauge length of 25 mm, width of 5 mm and thickness of 3 mm were machined from the rolled plates. The axial direction of the tensile specimens was parallel to the rolling direction. Tensile experiments were conducted on a MTS (858.01 M) testing machine at a constant strain rate of $1 \times 10^{-3}\ s^{-1}$ both at room temperature and elevated temperatures of 220 and 300 °C. To ensure the reliability of the measured data, three repeated tests were carried out for each condition. After testing, the fracture surfaces and the polished wide surface near to the fracture were observed using SEM with secondary electron (SE) and backscattered electron (BSE) imaging.

3. Results

3.1. Microstructure analysis

Fig. 1 shows the microstructures of two as-cast alloys. For the Mg–6%Li alloy, the typical duplex phase structure of α (Li solid solution in Mg) + β (Mg solid solution in Li) can be easily observed, as shown in Fig. 1(a). After the addition of Zn and Y, besides α and β phases, eutectic pockets and finely dispersed particles with the size less than 1 μm are formed in the Mg–6%Li–6%Zn–1.2%Y alloy, as shown in Fig. 1(b). To quantitatively evaluate the volume fraction of different phases, SEM images were taken at three random sites for each sample. By using Image J software, the fractions of α, β, eutectic pockets and dispersed particles in two alloys were determined, as listed in Table 1. However, Image J software often provides a large error in owing to threshold effects. In this work, the images before and after the image processing have been compared and the estimated error is controlled to be less than 0.1%. It can be seen that the addition of Zn and Y to the Mg–6%Li alloy can increase the volume fraction of β-Li phase from 7.6% to 16.5%, which is probably ascribed to the barrier effect of the formed eutectic pockets on the homogenous diffusion of Li during the solidification. It has been reported that the phase having higher atomic mass elements appear brighter under backscatter electron imaging (BEI) [13]. Therefore, the formation of these bright phases is ascribed to the addition of Zn and Y. It reveals that these bright eutectics are mainly distributed in the α-Mg matrix and around the β phase interfaces (Fig. 1(b)). XRD result confirms that the main phases in the Mg–6%Li–6%Zn–1.2%Y alloy are α-Mg, β-Li, LiMgZn, I-phase and W-phase, as shown in Fig. 2. Meanwhile, the diffraction peaks corresponding to the W-phase are very weak. Generally, I-phase could form eutectic pockets with the α-Mg matrix [11,12,14–18]. Therefore, the bright phase in the eutectic pockets is I-phase and only a very little of W-phase exists at some particular αβ phase interfaces. Moreover, previous work indicated that the tiny dispersed LiMgZn phase can form in the α-Mg matrix of the I-phase strengthened duplex Mg–Li alloys due to the Zn addition [7]. Following this, the main phases present in two alloys are labeled in Fig. 1(a–d). After the hot rolling, for the Mg–6%Li alloy, the network distributed β phase was deformed and slightly broken along the rolled direction, as shown in Fig. 1(c). Due to the in situ formation of I-phase, the destroyed degree of the β phase network structures can be obviously reduced because of the protection from the surrounding distributed I-phase, as shown in Fig. 1(d). Meanwhile, the I-phase eutectic pockets were severely broken and still distributed at their original areas and the β phase interfaces.

3.2. Mechanical characterization

Fig. 3 shows the true stress–strain curves of two alloys tested both at room and elevated temperature. To describe and compare the measured data conveniently, the mechanical properties of 0.2% proof yield stress ($\sigma_{0.2}$), ultimate tensile strength (UTS) and elongation to failure for the alloys are listed in Table 2. It can be seen that at room temperature (25 °C), the yield strength and UTS of the Mg–6%Li alloy are 125 and 180 MPa, respectively. When the I-phase is introduced, the yield strength and UTS of the Mg–6%Li–6%Zn–

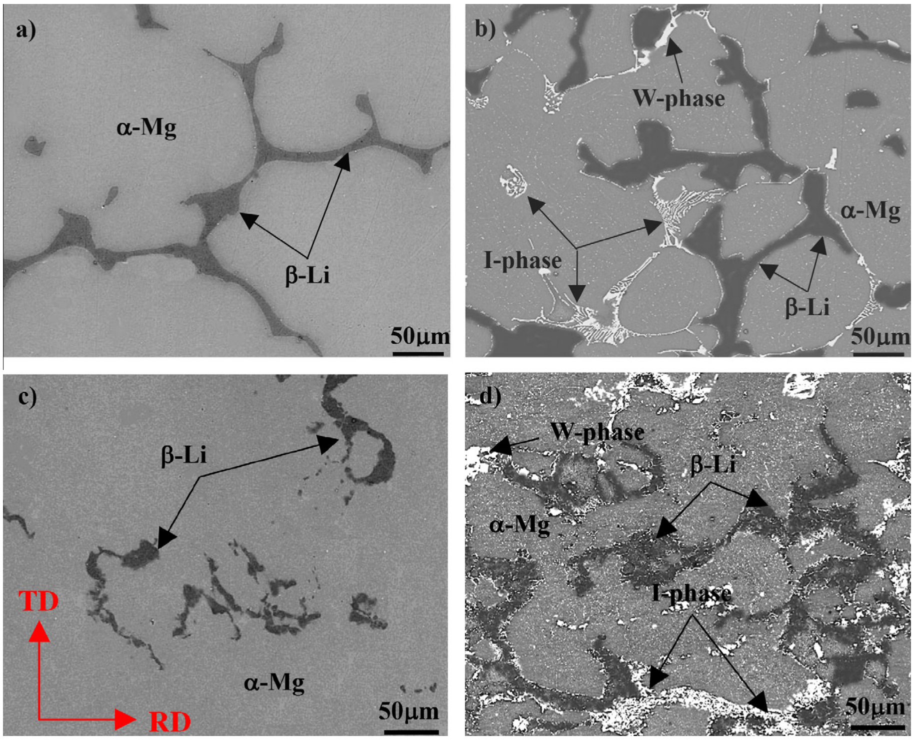

Fig. 1. Backscattered electron images of Mg–6%Li before (a) and after hot rolling (c), Mg–6%Li–6%Zn–1.2%Y before (b) and after hot rolling (d).