Journal of Alloys and Compounds 453 (2008) 309–315

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

Effect of Mg-based spherical quasicrystals on microstructure and mechanical properties of AZ91 alloys

Jinshan Zhang *, Lixia Pei, Hongwei Du, Wei Liang, Chunxiang Xu, Binfeng Lu

School of Materials Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, PR China

Received 7 March 2006; received in revised form 10 November 2006; accepted 16 November 2006
Available online 22 December 2006

Abstract

To lay theoretical foundations for room and elevated temperature application of AZ91 magnesium alloys, microstructure and mechanical properties of AZ91 magnesium alloys strengthened by Mg-based spherical quasicrystalline phase have been investigated using XRD, SEM, TEM, hard-meter and impact testing machine. The experiment results show that macro-hardness and impact toughness of AZ91 magnesium alloys were improved a lot as the addition level of spherical quasicrystal containing Mg–Zn–Y–Mn master alloy increased; while adding 5.1 wt.% spherical quasicrystal containing master alloy, impact toughness of AZ91 matrix composites reached the peak value, $15.3\,\mathrm{J\,cm^{-2}}$, which was about 252% as many as that of AZ91 master alloy. Majority of β-$Mg_{17}Al_{12}$ phase dissolved when spherical quasicrystal particles remained stable after 28-h T4 solution treating. Small dimples on fracture surface by impact of AZ91 magnesium alloy strengthened by quasicrystal particles exhibited the feature of ductile fracture.

Keywords: Quasicrystals; Microstructure; Mechanical properties; AZ91

1. Introduction

Recently, the issue of environment and energy has become increasingly prominent and extensive application of magnesium alloys as the lightest structural alloys has become an irresistible tendency. AZ91 alloy is the most widely used die casting magnesium alloy, offering good combination of castability, corrosion resistance and mechanical properties. However, it suffers from low creep resistance at temperatures in excess of 120 °C, which make it unsuitable for many of the components in automobile engines. So, provided that a new particle reinforced phase, which takes on peculiar characteristics such as excellent wettability, obvious strengthening and toughing effect, and which simplifies fabrication processes and lowers production cost, could be found, it would bring about great economical significance for the industrial utilization of magnesium matrix materials [1–5].

Quasicrystals have unusual properties such as high hardness, high Younger's modulus, high thermal-dynamical stability and low surface energy [6,7]. Superior wettability of Mg-based quasicrystals with the magnesium matrix makes it possible that Mg-based quasicrystals become a kind of desirable candidate for reinforcement of AZ91 alloy. Spherical morphology of reinforced particles and their dispersive distribution in the matrix bring about lower rending effects on the matrix and reduce stress concentration; controlled interfacial reactions between reinforced phase and the matrix result in stronger interfacial bonding. With two dimensions mentioned above, AZ91 alloy with high strength, toughness, and heat resistance can be obtained. Therefore, the purpose of this investigation was to introduce spherical reinforced particles into AZ91master alloy and to dramatically improve mechanical properties of AZ91master alloy at room and elevated temperature. This research achievement may provide new ways for composite strengthening of Mg-based alloys and create promising future for industrialization of spherical quasicrystal containing Mg–Zn–Y–Mn master alloy.

* Corresponding author. Tel.: +86 351 601 8154; fax: +86 351 601 8208.
E-mail address: jinshansx@tom.com (J. Zhang).

0925-8388/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2006.11.121

Table 1
Chemical compositions of AZ91 magnesium alloys in experiments (wt.%)

Alloy no.	Al	Zn	Mn	Y	Fe	Cu	Ni	Mg	SQCM addition (wt.%)
1#	9.000	0.800	0.250	0.000	0.020	0.020	0.001	Bal	0
2#	8.900	1.548	0.286	0.042	0.019	0.018	0.001	Bal	1.7
3#	8.900	2.296	0.318	0.085	0.017	0.019	0.001	Bal	3.4
4#	8.890	3.088	0.354	1.300	0.016	0.018	0.001	Bal	5.1
5#	8.870	3.792	0.386	1.700	0.016	0.018	0.001	Bal	6.8

2. Experimental

Initially, AZ91 mother melt was prepared by induction melting using magnesium (99.9 wt.% pure), aluminum (99.9% pure), zinc (99.9 wt.% pure) and manganese (99.9 wt.% pure) as raw materials. Then, medium spherical quasicrystal containing Mg–Zn–Y–Mn (SQCM) master alloy (0%, 1.7%, 3.4%, 5.1%, 6.8%) synthesized in the authors' laboratory [8,9], was added into the mother melt (shown in Table 1). Next, proper adjustment of composition was conducted at the temperature range from 740 to 760 °C so as to obtain melt with nominal composition, followed by pouring the melt into various molds to form relevant samples. Microstructure and mechanical properties were examined after processing samples according to requirements of testing standard. Constituent phases were identified by X-ray diffraction (Y-2000) using monochromatic Cu Kα radiation and by transmission electron microscopy (TEM, JEM-2010) analysis. The phase compositions were analyzed by electron dispersive spectroscopy (EDS) in scanning electron microscopy (SEM, JSU-6700F). Macro-hardness, micro-hardness and impact toughness of spherical quasicrystal particle reinforced AZ91 magnesium alloys were examined by hard-meter (HB-3000B), micro-hard-meter (M-400-HI) and impact testing machine (JB-30B), separately.

3. Results and discussion

3.1. Microstructure of AZ91 magnesium alloys

Fig. 1 shows XRD patterns of AZ91 magnesium alloys with and without the addition of SQCM master alloy. From Fig. 1(a) it is clear that alloy 1# consists of the α-Mg and β-$Mg_{17}Al_{12}$ phase (primary blocky divorced β-$Mg_{17}Al_{12}$ + eutectic β-$Mg_{17}Al_{12}$). The addition of SQCM master alloy results in diffraction peaks of a new quasicrystal phase (shown in Fig. 1(b)). Correspondingly, alloy 4# consists of the α-Mg, β-$Mg_{17}Al_{12}$ phase and $Mg_{45}Zn_{47}Y_5Mn_3$ quasicrystal phase.

Microstructure evolution occurs with the increasing addition level of SQCM master alloy into AZ91 melt (shown in Fig. 2). Grain size of the matrix microstructure decreases continuously as the addition level of SQCM master alloy increases, and finest grain size is obtained when the addition level reaches 5.1 wt.% (shown in Fig. 2(c)). The average grain size of alloy 4# is less than 30 μm, which is about 40% of the grain size of alloy 1# (about 80 μm). With the addition level surpassing 5.1 wt.%, grain size of the matrix microstructure begins to coarsen (shown in Fig. 2(d)). This phenomenon mentioned above may be explained as follows: there is an optimal addition level of reinforced phase for the grain refinement of the matrix alloy; if the nucleating number is less than the critical value, insufficient nucleating substrates will form and grain-refining effects will be poor; if the nucleating number is more than the critical value; nucleating substrates will agglomerate to form clusters and lose their nucleating functions. Majority of quasicrystal particles, confirmed by XRD pattern and diffraction spot analysis to be icosahedral phase, are distributed homogeneously in the matrix after adding SQCM master alloy into AZ91 alloy. During the solidification process, high-melting-point quasicrystal phase precipitates in solidification front, sets back the diffusion of Al and Zn atomics, and finally suppresses subsequent growth of α-Mg and β-$Mg_{17}Al_{12}$ [10], all of which result in good grain-refining efficiency of SQCM master alloy on the matrix of AZ91 alloy and morphology evolution of β-$Mg_{17}Al_{12}$ phase from continuous nets to discrete nets.

3.2. Microstructure evolution after solution treating

Fig. 3 shows microstructure of AZ91 magnesium alloys added with medium SQCM master alloy after solution treating.

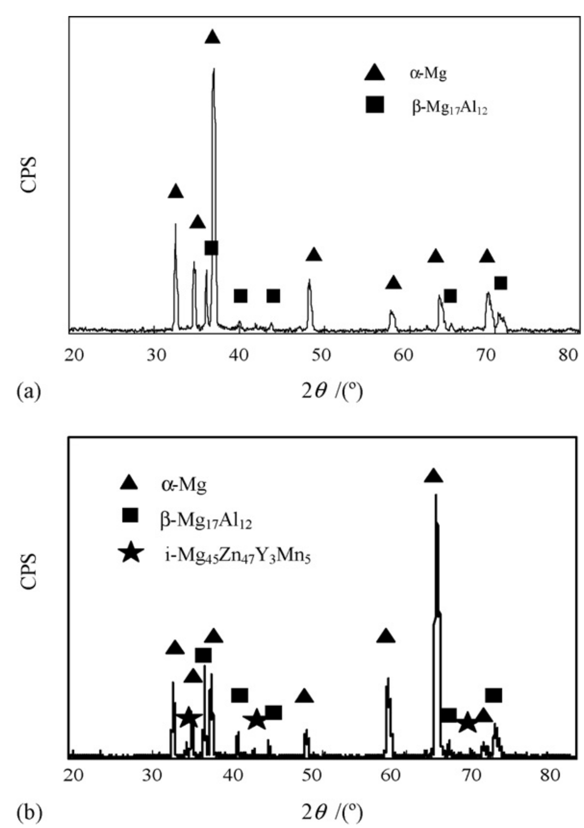

Fig. 1. XRD patterns of AZ91 magnesium alloys. (a) Alloy 1# and (b) alloy 4#.