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Effects of Zn/Y ratio on microstructure and mechanical properties of Mg-Zn-Y alloys

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Abstract

Microstructures and mechanical properties of Mg-Zn-Y alloys containing icosahedral phase (I-phase) as a secondary solidification phase have been investigated in the composition range where the total solute content (Zn and Y) is less than 10 wt.%. The optimum Zn/Y ratio for the formation of two-phase microstructure consisting of α-Mg and I-phase is 5∼7. The strength increases with increasing total solute content (Zn and Y), i.e. with increasing volume fraction of I-phase. In particular, the alloys containing I-phase exhibit high elongation to failure, >25%, which is ascribed to the low interfacial energy between the I-phase particle and surrounding α-Mg crystalline matrix.

Keywords: Mg-Zn-Y alloys; Icosahedral phase (I-phase); Ratio of Zn/Y

1. Introduction

In order to use magnesium alloys as structural material, one of the critical issues is to improve formability. Recently, it has been reported that the Mg-Zn-Y alloys containing icosahedral phase (I-phase) as a secondary solidification phase exhibit good mechanical properties at room temperature as well as at elevated temperature [1].

Tsai et al. have reported the presence of thermodynamically stable I-phase with composition of $Mg_{42}Zn_{50}Y_8$ in the Mg-Zn-Y system [2]. Langsdorf et al. reported that the I-phase forms through a peritectic reaction and coexists with brittle intermetallic compounds in the Zn-rich ternary alloys with the yttrium contents higher than 4 at.% [3,4]. Yi et al. reported that the addition of a small amount of yttrium to the $Mg_{74}Zn_{26}$ binary alloy changed the primary phase from α-Mg to I-phase in the Mg-rich corner of the Mg-Zn-Y alloy system [5]. Moreover, it has been reported that Mg-Zn-Y alloys containing thermally stable I-phase exhibit a significantly high level of yield strength and ductility at ambient temperature, depending on the volume fraction of the I-phase [6].

It has been reported that the quasicrystal reinforced Mg-Zn-Y alloys exhibits a better formability than the conventional wrought magnesium based alloys such as AZ31. It has been shown that quasicrystal reinforced Mg-9Zn-2Y (in wt.%) alloy exhibits a combination of high strength and ductility, and good formability at high temperature [1]. Also, enhanced mechanical properties have been achieved due to nano-precipitation of the I-phase in the extruded Mg-Zn-Y alloys [7]. Although it has been reported that there exists a two-phase region consisted of I-phase and α-Mg in the Mg-rich composition range of the Mg-Zn-Y system, there has been no report on the effect of Zn/Y ratio on the formation of two-phase region in the Mg-rich composition range. Therefore, in the present study, we have examined the change of the as-cast microstructure depending on the ratio of Zn/Y in the composition range where the total solute content (Zn and Y) is less than 10 wt.%, and suggested the composition range for the α-Mg/I-phase two-phase micro-

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Table 1
Nominal alloy compositions and constituent phases in the as-cast samples identified by X-ray diffraction

Group	Alloy no.	Composition (wt.%)			Zn/Y ratio	Vol. fraction of other phase	Phases
		Zn	Y	Mg			
A	01	4	0.4	Bal.	10	–	α-Mg and
	02	8	0.8	Bal.	10	–	Mg_7Zn_3
B	03	3	0.5	Bal.	6	1.2%	α-Mg and
	04	3	0.6	Bal.	5	1.2%	I-phase
	05	4	0.6	Bal.	6.7	2.2%	
	06	4	0.8	Bal.	5	2.3%	
	07	6	1.2	Bal.	5	2.9%	
	08	6.7	1	Bal.	6.7	2.7%	
	09	8	1.6	Bal.	5	3.7%	
C	10	3	1.2	Bal.	2.5	1.2%	α-Mg,I-phase
	11	4	1.6	Bal.	2.5	2.4%	and W-phase
	12	4	2	Bal.	2	2.6%	
	13	5.5	2.5	Bal.	2.2	2.9%	
D	14	3	1.6	Bal.	1.9	–	α-Mg and
	15	4	2.2	Bal.	1.8	–	W-phase

structure. Moreover, mechanical properties of alloys containing I-phase have been investigated. The samples for mechanical test were prepared from the hot-rolled sheet (thickness: ~1 mm).

2. Materials and experimental procedures

The alloys with the nominal compositions listed in Table 1 were prepared by induction melting high purity magnesium (99.9%), zinc (99.95%) and yttrium (99.9%) in the boron nitride (BN) coated graphite crucible under a dynamic argon gas atmosphere. The alloy ingots with a dimension of 1.5 cm in thickness, 6 cm in width, and 10 cm in height were prepared by pouring the melt into the preheated steel mold. Phase identifications ware performed by X-ray diffraction (XRD, Rigaku CN2301) using monochromatic CuK_α radiation. For optical observations (Leica DMRM), the as-cast specimens were etched with a solution of nitric acid (10 ml) and ethanol (100 ml). Volume fractions of the second phase in the as-cast microstructure were estimated using image analyzer program (IMT VT4) connected to optical micrograph. The microstructures were observed by optical microscopy (OM; Leica DMRM) and Transmission electron microscopy (TEM; JEM 2000 EX). Thin foils for TEM observation were prepared by an ion milling method (Gatan, model 600) after a mechanical grinding.

Four alloys containing I-phase were hot-rolled to 1 mm final thickness (reduction ~90%). Before rolling, the rolls were preheated up to ~373 K. The cast ingots (70 × 50 × 10 mm) were homogenized at 673 K for 12 h. The ingot preheated at 673 K for 20 min were rolled with a reduction ratio of ~15% per pass. Uniaxial tensile tests were carried out on dog-bone specimens of the sheets (specimen gauge length 10 mm) annealed at 673 K for 15 min. after hot-rolling under a constant cross-head speed condition with initial strain rate of 10^{-3} s^{-1} at room temperature.

3. Results

The alloy compositions investigated in the present study can be classified into four groups based on the Zn/Y ratios. As described in Table 1, A, B, C and D groups include the alloy compositions with Zn/Y ratio of ~10, 5~7, 2~2.5 and 1.5~2, respectively. The phases existing in the as-cast microstructure were identified by XRD, and the results are also included in Table 1. Typical examples of the XRD patterns obtained from the alloys in each group are shown in Fig. 1, illustrating that phases in the as-cast microstructure were different depending on the Zn/Y ratio. As described in Table 1, the phases in the as-cast microstructure were different in four groups of alloys; i.e. A group (Zn/Y ratio: ~10): α-Mg+Mg_7Zn_3 (Cubic, a=1.417 nm), B group (Zn/Y ratio: 5~7): α-Mg+I-phase, C group (Zn/Y ratio: 2~2.5): α-Mg+I-phase+W-phase ($Mg_3Zn_3Y_2$; Cubic, a=0.683 nm [8]) and D group (Zn/Y ratio: 1.5~2): α-Mg+W-phase. Fig. 2 (a)~(c) show the optical microstructures of the as-cast alloys in B group (alloys B-04, B-06 and B-09). The microstructure consisted of dendritic primary α-Mg and interdendritic α-Mg/I-phase eutectic. The fraction of the interdendritic eutectic increased with increasing zinc and yttrium contents. The volume fraction of the interdendritic eutectic region measured using image analyzer was 1.2%, 2.3% and 3.7% in alloys B-04, B-06 and B-9, respectively. The data on the volume fraction of the second phase in the as-cast alloys investigated in the present study is included in Table 1. Fig. 2 (d) and (e) shows the bright field TEM image and corresponding selected area diffraction pattern (SADP) obtained from the interdendritic I-phase in alloy B-10. The five-fold-symmetry in the SDAP clearly confirmed the icosahedral quasicrystalline structure of the interdendritic phase.

Fig. 3 (a) shows the optical microstructure of the as-cast alloy in C group (alloy C-11). The microstructure consisted of dendritic primary α-Mg, interdendritic α-Mg/I-phase eutectic and interdendritic W-phase, as marked in the microstructure. Fig. 3 (b) and (c) shows the bright field TEM image and corresponding SADP obtained from obtained from the interdendritic W-phase in alloy C-

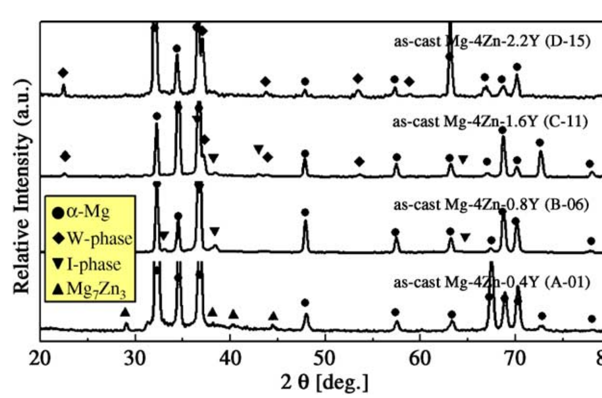

Fig. 1. X-ray diffraction patterns of the as-cast alloys: Mg-4Zn-0.4Y (A-01), Mg-4Zn-0.8Y (B-06), Mg-4Zn-1.6Y (C-11) and Mg-4Zn-2.2Y (D-15).