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Effect of mischmetal and yttrium on microstructures and mechanical properties of Mg-Al alloy ①

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Abstract: The effect of yttrium and mischmetal(MMs) on the as-cast and solid solution treated structures of Mg-Al alloys with different Al-contents was investigated. The results show that the MMs in Mg-Al alloy existed in rod Al_4(Ce, La) compound while Y in Mg-Al alloy in polygonal Al_2Y compound. The amount of $Mg_{17}Al_{12}$ in Mg-Al alloy is decreased with increasing Y or MMs addition, and $Mg_{17}Al_{12}$ intermetallic compound is changed from continuous network to discontinuous one. The Al_4(Ce, La) and Al_2Y compounds are not dissolved into Mg-Al alloy matrix during solid solution treatment so that their high heat stability can be exhibited. The experiment of mechanical properties indicate that elongation and impact toughness of the Mg-Al-Y alloy with polygonal Al_2Y compound are higher than those of Mg-Al-MMs alloy with rod Al_4(Ce, La) compound.

Key words: yttrium and mischmetal; Mg-Al alloy; structure and property; microprobe
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1 INTRODUCTION

Because of low density, high specific strength, excellent anti-shock and good heat conductivity, the Mg alloy has been applicated as constructional materials more widely. The castability, mechanical properties at room temperature and corrosion resistance of magnesium alloy can be elevated by adding Al in it. As a result, the AZ91 alloy(9%Al) has been widely used. However, as the creep resistance at high temperature is not satisfied, this alloy can only be used as constructional material at temperature below 120 ℃. Series of researches have been undergone in alloying measure for elevating heat resistance of Mg-Al alloy[1-10]. Generally, Si and RE are used as main alloying elements. Unfortunately, Si can be combined with Mg to form Mg_2Si compound so as to reduce the toughness of this alloy, and the heat resistance of Mg-Al-Si alloy is also lower than that of Mg-Al-RE alloy[3]. Concerning the effect of RE on the structure of Mg-Al alloy, present investigations were mainly focused on(Ce, La) mischmetal. The research results indicate that Ce or La can be combined with Al to form needle or rod compounds so as to improve mechanical properties, especially ductility of the alloy[11]. Y, La and Ce are RE elements and Y located in 5^{th} period of elements and it is exhibited higher chemical activities than La located in 6^{th} period of elements. Therefore, the researchers have been interested in Y for developing heat resistance Mg alloy. As an example, WE54(5%Y, 4%RE) alloy has been developed and its creep resistance with respect of temperature has been elevated up to 260 ℃[12-14]. But the castability of Mg-Y-RE alloy was lower than that of Mg-Al alloy. Consequently, it has only a restricted application[14]. Up to now, there were seldom reports involving Y used as alloying element in Mg-Al alloy. In this paper, the effect of Y and MMs additives on the structures and properties of Mg-Al alloys containing 9%Al and 4%Al is investigated respectively.

2 EXPERIMENTAL

Raw materials used are listed in Table 1. The chemical compositions of Mg-Al base alloys are listed in Table 2.

Table 1 Compositions of raw materials(%)

Specimen	Mg	Al	Ce	La	Pr	Y	Impurites
Mg ingot	99.9						
Al ingot	99.9						
MMs			50	45	4		Fe+ Si+ S+ P< 1
Y						99.9	

Table 2 Compositions of Mg-Al base alloys(%)

Specimen	Al	MMs	Y	Mn, Fe	Mg
A9	8.9			< 0.2	Bal.
AE92	8.7	1.6		< 0.2	Bal.
AY92	8.8		1.5	< 0.2	Bal.
A4	4.2			< 0.2	Bal.
AE42	4.1	1.5		< 0.2	Bal.
AY42	4.1		1.6	< 0.2	Bal.

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The base alloys were melted in steel crucible resistance furnace using 0.5% SF_6+ CO_2 as protective gases. The melting processes were carried out as follows: The Mg and Al ingots were heated to 760 ℃, in which the Mg-Y master or MMs(50% Ce, 45% La) packed in Al-foil were added, then poured in metallic mould as test bars. Solid solution heat treatment was carried out in electric resistance furnace under CO_2 protection, in which the specimens were heated to 420 ℃ and held for 20 h, then quenched in 20 ℃ water.

The microstructures of the alloys mentioned- above were examined by using the microprobe of type JXA8800R. The mechanical properties tests were carried out under the toughness tester and Brinell hardness tester. The dimensions of the specimen are 14 mm × 14 mm × 80mm.

3 RESULTS

3.1 Effect of MMs and Y on microstructure in as-cast Mg-9%Al alloy

The SEM microstructures of as-cast A9 alloy is shown in Fig. 1. It is composed of eutectic(δ-Mg+ $Mg_{17}Al_{12}$) and δ-Mg matrix, in which Al is dissolved in Mg matrix.

The SEM microstructures of as-cast AE92 are shown in Fig. 2(a) and EDX of Mg, Al, La, Ce are shown in Fig. 2(b), (c), (d) and (e). It can be seen that the microstructure of AE92 is composed of rod phase. The rod phase is bright and its compositions are 79.60% Al(mole fraction) and 21.40% (La, Ce) (mole fraction). The $Mg_{17}Al_{12}$ phase is gray and its compositions are 41.52% Al(mole fraction) and 58.48% Mg(mole fraction). Compared with the $Mg_{17}Al_{12}$ phase in AE92, the $Mg_{17}Al_{12}$ phase in A9 is disconnected rather than network as indicated by arrow in Fig. 2(a).

The SEM microstructures of as-cast AY92 are shown in Fig. 3(a) and EDX of Mg, Al, Y are shown in Fig. 3 (b), (c) and (d). It can be seen that the microstructure of as-cast AY92 is composed of polygonal Y_2Al phase, which is bright and whose compositions are 74.70% Al (mole fraction), 25.30% Y(mole fraction), and disconnected $Mg_{17}Al_{12}$ phase as indicated by arrow in Fig. 3(a). Both of them are distributed in δ-Mg matrix.

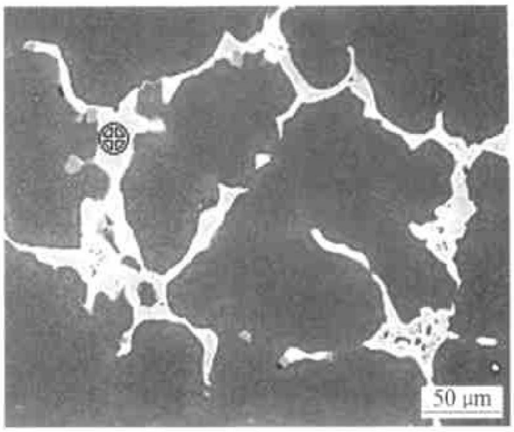

Fig. 1 SEM microstructure of as-cast A9 alloy

3.2 Effect of MMs and Y on microstructure of as-cast Mg-4%Al alloy

The SEM microstructure of as-cast AE42 is shown in Fig. 4. Because Al content is reduced, the amount of $Mg_{17}Al_{12}$ phase as indicated by arrow in microstructure of AE42 is less than that in AE92. The needle plate Al_4 (Ce, La) phase is concentrated on local area obviously.

The SEM microstructure of as-cast AY42 is shown in Fig. 5. The microstructure is composed of bright polygonal phase Al_2Y and a few Mg_{17}-Al_{12} phase.

3.3 Effect of solid solution treatment on microstructure of AE92 and AY92

The solid solution treated microstructure of

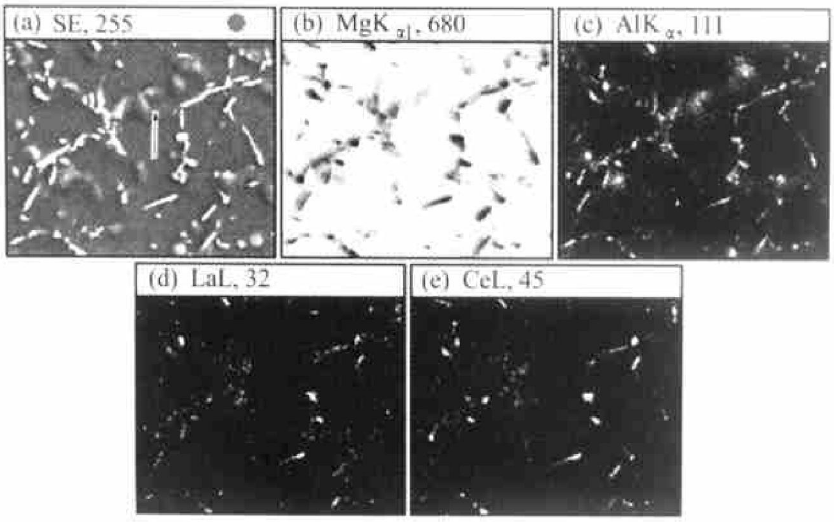

Fig. 2 SEM microstructures and EDX of as-cast AE92

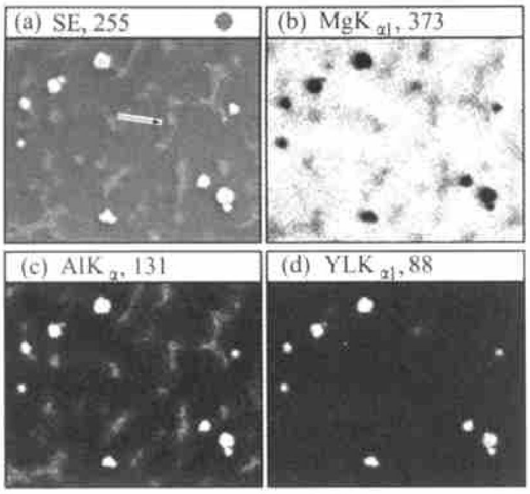

Fig. 3 SEM microstructures and EDX of as-cast AY92

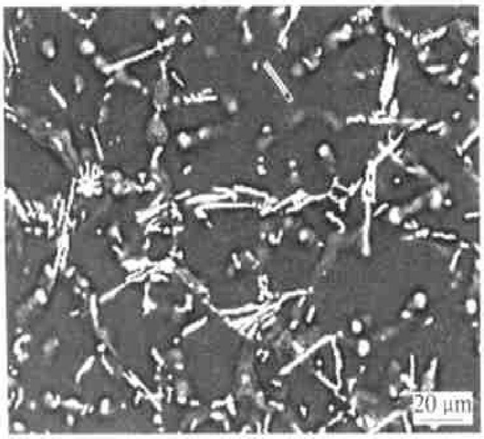

Fig. 4 Microstructure of as-cast AE42

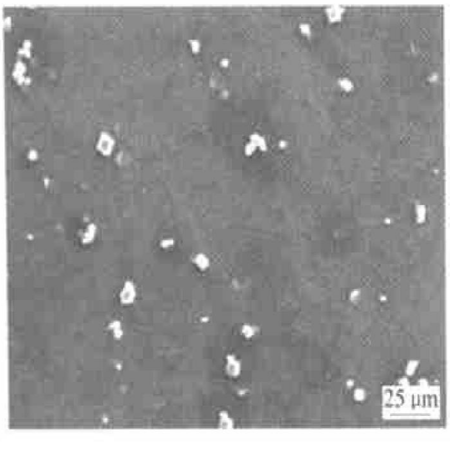

Fig. 5 Microstructure of as-cast AY42

AE92 is shown in Fig. 6. The rod phase $Al_4(Ce, La)$ is distributed in δ-Mg matrix, while the Mg_{17}-Al_{12} phases in original microstructure are mostly dissolved in the matrix.

The microstructure of solid solution treated AY92 is shown in Fig. 7. The $Mg_{17}Al_{12}$ in original microstructure is dissolved in the matrix too. EDX analysis for single polygonal grain is shown in Fig. 8, in which only Al and Y rather than Mg in the polygonal structure can be seen. The results indicated that both Al_2Y phase in

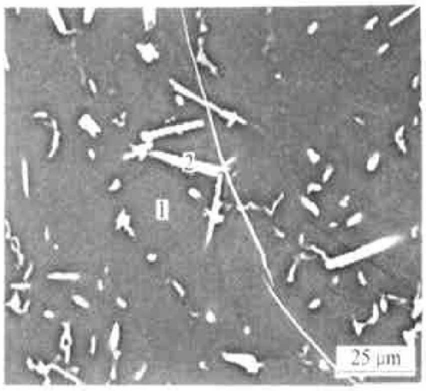

Fig. 6 Microstructure of solid solution treated AE92

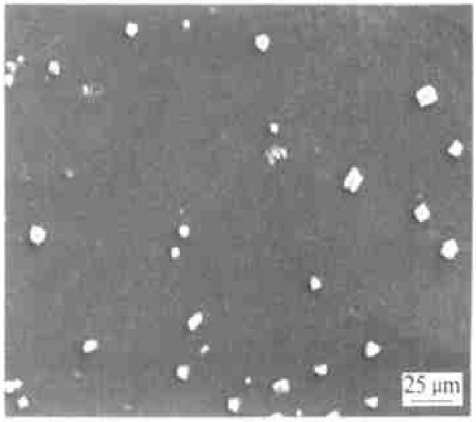

Fig. 7 Microstructure of solid solution treated AY92

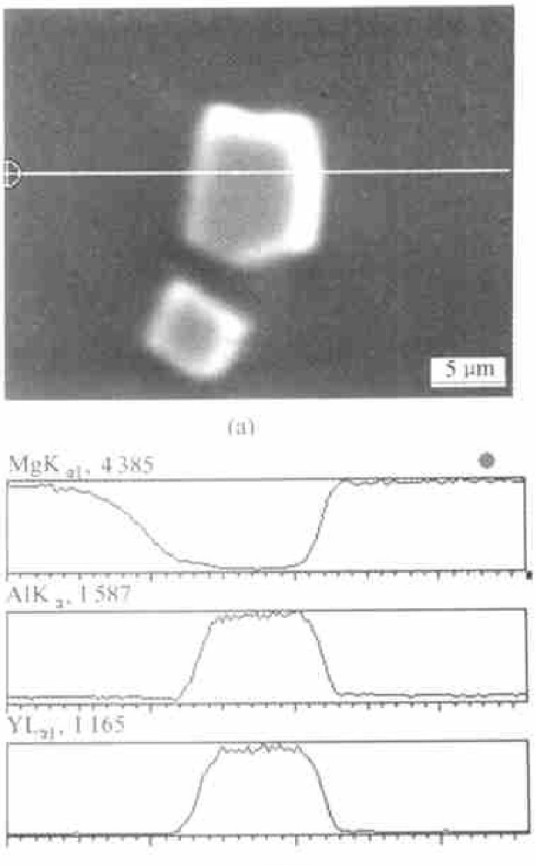

Fig. 8 SEM image(a) and EDX analysis(b) of polygonal phase in AY92

AY92 and $Al_4(Ce, La)$ phase in AE92 can exist stability, which implied that heat resistance of the alloy can be improved.

3.4 Effect of MMs and Y on mechanical properties of Mg-Al alloy

The mechanical properties of tested alloys at room temperature are listed in Table 3. It can be seen from Table 3 that the elongation and impact toughness of Mg-Al-Y alloy are higher than those of Mg-Al-MMs alloy.

Table 3 Mechanical properties(25 ℃) of tested alloys

Specimen	HB	Tensile strength /MPa	Elongation /%	Impact toughness/J	
				As-cast	solution treated
A9	67.1	171	3.1	0.8	4.3
AE92	71.7	188	1.7	0.4	2.2
AY92	69.9	192	2.6	0.7	3.9
A4	49.6	152	4.2	3.9	6.2
AE42	52.6	165	2.9	2.6	4.2
AY42	51.9	169	3.8	3.7	5.8

Note: The figures except impact toughness in the table take average value for 3 samples in as-cast state and the impact toughness are both in as-cast and solution treated.

4 DISCUSSION

As the RE elements such as La, Ce, Y are situated in the ⅢA family in the elemental periodic table and their 4f layer around the nucleus have been not filled by electrons, their uncommon characteristics, i.e, quite strong chemical activity can be exhibited.

Normally, the electronnegativity differences of two elements are used for predicting the possibility to form metallic compound. The more the differences, the stronger the familiarity and the easier the possibility to form metallic compound[15]. In Mg-Al-RE alloys, because the values for Al and(Ce, La) are 1.5 and 1.1 respectively, the difference is 0.4; while the difference between Mg and(Ce, La) is only 0.1, which means that Al is much easier to form Al-Ce and Al-La compounds than Mg is. Similarly, because the values for Al and Y are 1.5 and 1.2 respectively, the difference between Al and Y is 0.3. Meanwhile, because the values for both Y and Mg are 1.2, the difference between Mg and Y is zero. Therefore, it is concluded that Al-Y and Al-(La, Ce) compounds rather than Mg-RE compounds can be formed when RE elements are added in Mg-Al alloys.

Al in Mg-Al-Y and Mg-Al-MMs alloys can be changed along three directions: firstly it can form solid solution in matrix; secondly, it can form Al-Y and Al-MMs compounds with Y and MMs, respectively; thirdly, it can form $Mg_{17}Al_{12}$ compound with Mg. $Mg_{17}Al_{12}$ is inherent in thermal unstability and can be dissolved into matrix during solid solution treatment at 420 ℃. Contradictionaly, both $Al_4(Ce, La)$ and Al_2Y phases have high melting point(> 420 ℃) and high thermal stability which makes them free from dissolving in matrix during solid solution treatment.

The amount of $Mg_{17}Al_{12}$ phase can be decreased with decreasing Al content in Mg-Al alloy. Similarly, when RE is added in Mg-Al alloy, as the reason of the formation of Al_2Y and $Al_4(Ce, La)$ phase with consumption of partial Al atom, $Mg_{17}Al_{12}$ phase can be reduced and Al_2Y and $Al_4(Ce, La)$ phases can be increased. Therefore, the heat resistance of this alloy is elevated. Because the hardness of Al_2Y and $Al_4(Ce, La)$ is higher than that of $Mg_{17}Al_{12}$, hardness and tensile strength of this alloy can be increased. By adding MMs in Mg-Al alloy, as the rod or needle $Al_4(Ce, La)$ phase forms, the ductility of AE92 and AE42 is reduced greatly. However, by adding Y in Mg-Al alloy, the polygonal Al_2Y phase can form and the matrix can not be separated by them, so the ductility of this alloy is higher than that of A9. From the SEM fractographs, the fish scale with brittleness character in AE92 by solid solution treatment can be exhibited as shown in Fig.9(a), while the toughness one in AY92 as shown in Fig.9(b).

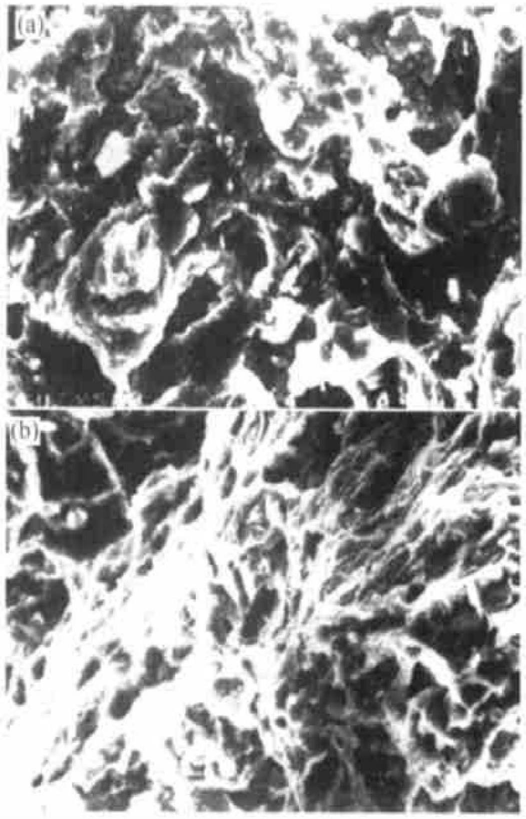

Fig. 9 SEM fractographs of AE92(a) and AY92(b) after solid solution treatment

5 CONCLUSIONS

1) With decreasing the aluminum content, the amount of $Mg_{17}Al_{12}$ phase can be decreased in both Mg-Al-Y and Mg-Al-MMs alloys. The rod Al_4(Ce, La) phase forms in Mg-Al-MMs alloy, while the polygonal Al_2Y phase in Mg-Al-Y alloy. Both Al_4(Ce, La) and Al_2Y phases are thermally stable and are not dissolved in the matrix during solid solution treating at 420 ℃.

2) The hardnesses and tensile strengths of both Mg-Al-MMs and Mg-Al-Y alloys are higher than those of Mg-Al alloy. The toughness value of AY92 is obviously higher than that of AE92. The toughness character in AY92 can be exhibited by the SEM fractograph.

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