Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 17
ISSUE 1-2
July-August
2006

Effect of rare earth elements on the microstructure of Mg-Al alloys

T. Rzychoń*, A. Kiełbus
Faculty of Materials Science and Metallurgy, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice. Poland
* Corresponding author: E-mail address: tomasz.rzychon@polsl.pl

Received 15.03.2006; accepted in revised form 30.04.2006

Materials

ABSTRACT

Purpose: The automotive use of magnesium is currently restricted to low-temperature structural components. Rare earth additions such as Ce, Nd, La and Pr are known to improve the creep performance. The aim of the research was to determine the effect of rare earths elements on the as-cast microstructure of magnesium alloys containing 4 wt% aluminum.
Design/methodology/approach: The study was conducted on Mg-4Al-2RE (AE42) and a new Mg-4Al-4RE (AE44) alloys in the as-cast condition. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). The phase identification of these alloys was identified by X-ray diffraction (JDX-75).
Findings: The microstructure of AE42 alloy consists of α-Mg solid solution with divorced eutectic Mg17Al12 + α-Mg, RE-rich phases and Mn-rich phase. The increase of RE contents from 2 wt% to 4 wt% leads to a change of microstructure of these alloys. In AE44 alloy was observed globular, lamellar and acicular precipitations of Al11RE3 and Al3RE phases. Moreover, there was found globular Mn-rich phase existence, but the Mg17Al12 phase was not observed.
Research limitations/implications: The increase of RE content to 4 wt% caused the formation of new phases in the microstructure and prevented the formation Mg17Al12 phase. These factors can improve the creep resistance of the Mg-Al-RE alloys. The future research will contain creep tests and microstructural investigations of cast and die-cast alloys using TEM microscopy.
Practical implications: The improvement of creep resistance of Mg-Al alloys can cause their application in automotive industry on the elevated-temperature structural components (above 150 °C). Results of investigation may be useful for preparing die casting technology of the Mg-Al-RE alloys.
Originality/value: paper includes the results of microstructural investigations of new AE44 magnesium alloy for die casting technology.
Keywords: Metallic alloys; Magnesium-aluminum-rare earth alloys; Microstructure

1. Introduction

Magnesium alloys with their weight advantage have unique application opportunities in the automotive industry. AZ91D alloy has been used to fabricate a variety of automobile parts, such as cam covers, oil adapters, steering wheels and so on. AM60 and AM50 alloys are frequently employed to manufacture instrument panels, steering wheel armatures and seat risers, with a view to its good toughness [1-3]. Typical microstructure of these alloys is composed of α-Mg matrix, $Mg_{17}Al_{12}$ precipitations and small volume of Al_8Mn_5 phase [4]. However, their applications are restricted when the temperature surpasses 120 °C, due to instability of β-$Mg_{17}Al_{12}$ phase [2-3]. A casting alloy that was developed for high temperature applications is AE42 (Mg-4Al-2RE). Aluminum is added to improve castability and room temperature mechanical properties and RE for creep resistance.

However, the properties of AE42 deteriorate rapidly when the temperature is above 150 °C [5]. In this temperature the partially decomposition of $Al_{11}RE3$ had been reported [6]. This leads to the emergence of β phase, which attributes to the deterioration of creep resistance. Therefore a limitation to the use of AE42 magnesium alloys at high temperature still remains. The increase RE content can cause the improvement of creep resistance [7]. With an increasing RE/Al ratio, Al_2RE phase gradually becomes the more dominant phase relative to $Al_{11}RE_3$. A higher RE content than that of AE42, possibly producing Al_2RE phase during solidification, this unwanted phase transformation may no longer occur [8-13]. The current study has focused on the effect RE addition on the microstructure of ingots Mg alloys containing 4 wt% aluminum.

2. Experimental

Ingots for die casting of AE42 and AE44 with the chemical composition given in Table 1 were investigated. The rare earth additions were made as mischmetal with the approximate compositions: 50Ce-25La20Nd 3Pr. Specimens for microstructure studies were mechanically polished using standard methods, etched with 5% acetic acid. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). EDS analysis were performed with an accelerating voltage of 15 keV. The phase identification of these alloys was identified by X-ray diffraction (JDX-75) using Cu Kα radiation.

Table 1.
Chemical composition (wt-%) of experimental alloys.

Alloy	Al	Mn	RE	Zn	Si
AE42	3.6-4.4	0.2-0.5	2.0-3.0	0.2	0.05
AE44	3.6-4.4	0.2-0.5	3.6-4.6	0.2	0.05

3. Results

3.1. Microstructure of AE42 alloy

Microstructures of AE42 alloy under optical microscope are showed in Fig. 1. There was observed of α-Mg matrix, acicular and irregular precipitations. The XRD pattern of AE42 indicates this alloy is mainly composed of α-Mg phase and $Mg_{17}Al_{12}$ phase (Fig. 2). The intensities of α-Mg peaks are roughly proportional to data from JCPDS standard, indicating the random distribution of grain orientations. The $Mg_{17}Al_{12}$ phase was identified with four diffraction peaks, starting from (411) at 2θ of 35.7°. A further SEM observation indicates a divorced eutectic characteristic, as can be seen from Fig. 3 (point A). Moreover, EDS analysis reveals that the microstructure contains irregular Mn-rich and needle shaped RE-rich phases (points B and C respectively, Fig. 4, Tab. 2). These phases were not positively identified with XRD method. The aluminum content (point D, Tab. 2) in solid solution α-Mg is higher than its maximal solubility at ambient temperature [14]. The AE42 alloy is designated for die-casting method and supersaturating of α-Mg will be higher than in the investigated material. It is disadvantageous because during exploitation of this alloy in elevated temperature might release $Mg_{17}Al_{12}$ from primary solid solution.

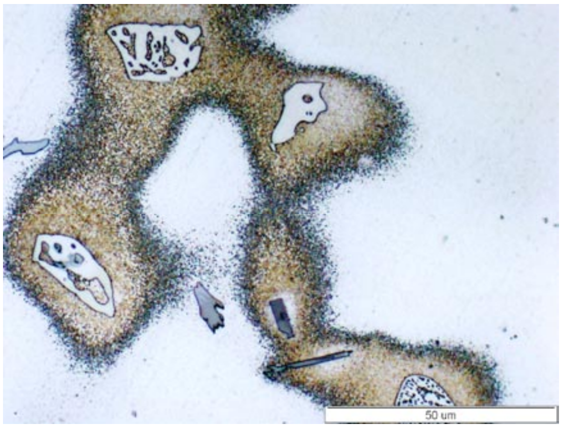

Fig. 1. LM microstructure of as-cast AE42 alloy

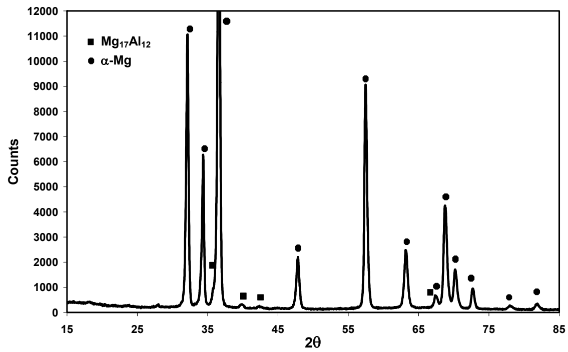

Fig. 2. X-ray diffraction pattern of AE42 alloy

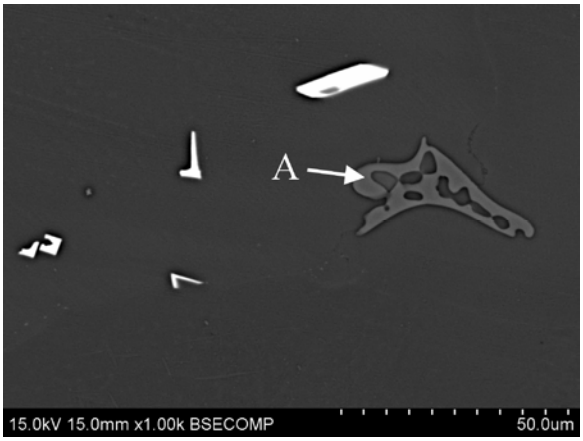

Fig. 3. BSE image of AE42 alloy

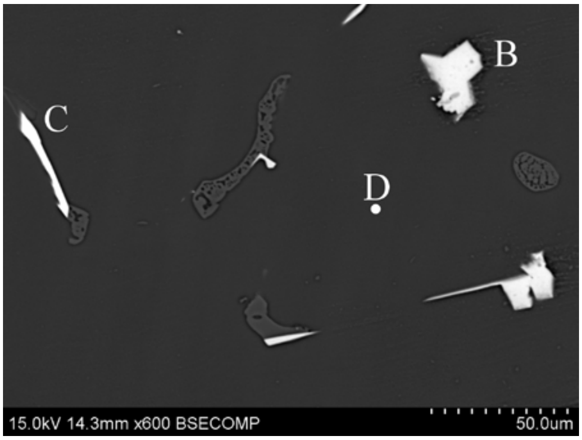

Fig. 4. BSE image of AE42 alloy

Table 2.
Element distribution in different areas of AE42 as-cast structure from Fig. 3 and 4 (at.%).

Point	Mg-K	Al-K	Ce-L	La-L	Nd-L	Mn-K
A	66.25	33.75	-	-	-	-
B	5.61	57.32	3.26	-	0.93	32.88
C	10.94	73.15	4.77	10.17	0.97	-
D	94.39	5.61	-	-	-	-

3.2. Microstructure of AE44 alloy

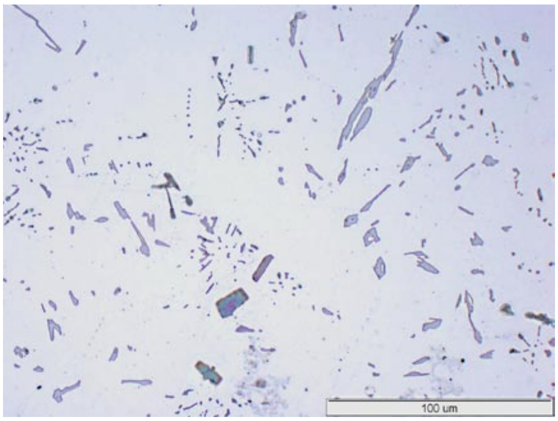

Fig. 5. LM microstructure of as-cast AE44 alloy

The increase of RE content from 2 wt% to 4 wt% leads to a change of microstructure Mg-4Al alloys (Fig. 5). Results of XRD analysis (Fig. 6) show the main intermetallic phases in AE44 alloys were $Al_{11}RE_3$ and Al_3RE. The $Al_{11}RE_3$ may be Al_4RE [15] because these phases have similar peak values. BSE images (Fig. 7) show acicular and fine globular compounds. Further investigations of the RE content of the Al-RE compounds shows that globular particles (point A, Fig. 7, Tab. 3) have higher content of cerium than other constituents of the Ce-rich mischmetal, while the acicular compounds (point B, Fig. 5, Tab. 3) have higher content lanthanum and neodymium than the others. In AE44 there was not observed a $Mg_{17}Al_{12}$ phase. Moreover, in microstructure are Mn-rich particles (point C, Fig. 8). The aluminum dissolved in α-Mg is lower than its maximal solid solubility at room temperature (point D).

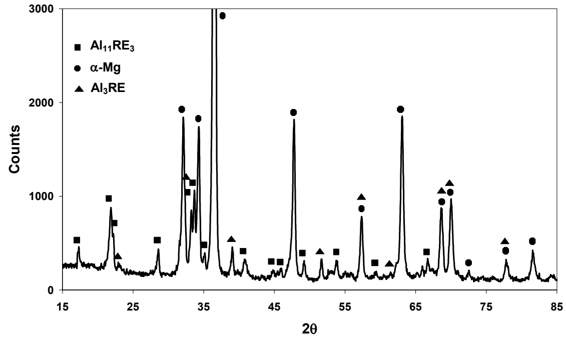

Fig. 6. X-ray diffraction pattern of AE44 alloy.

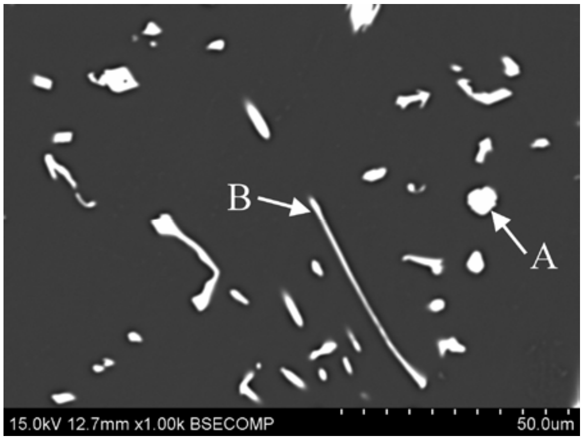

Fig. 7. BSE image of AE44

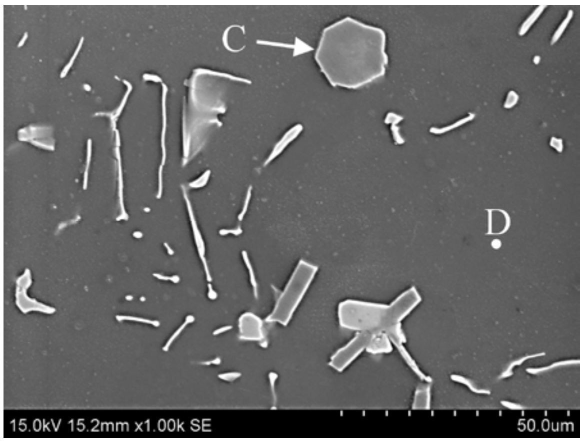

Fig. 8. SE image of AE44 alloy

Table 3.
Element distribution in different areas of AE44 as-cast structure from Fig. 7 and 8 (at.%).

Point	Mg-K	Al-K	Ce-L	La-L	Nd-L	Mn-K
A	11.12	71.26	15.54	2.08	-	-
B	32.63	49.27	11.91	3.19	2.99	-
C	5.65	55.22	4.16	-	-	34.97
D	99.57	0.43	-	-	-	-

3.3. Effect of RE on the microstructure

The increase of RE addition from 2 wt% to 4 wt% caused decreasing volume fraction of the β-$Mg_{17}Al_{12}$ phase and emergency $Al_{11}RE_3$ and Al_3RE phase, which were not identified in as-cast AE42 alloy. Solid solubility of RE in magnesium is very low, which is further reduced by the presence of Al [14]. Because of the high chemical stability of $Al_{11}RE_3$ and Al_3RE phases, rare earths are combined with Al and form $Al_{11}RE_3$ until all the available rare earths are used without any formation of pseudo-binary Mg-RE or Mg-Al phase or pseudo-ternary Mg-Al-RE phase [16]. In AE44 alloy more aluminum atoms were consumed by the formation of $Al_{11}RE_3$ and Al_3RE phases. It leads additionally to decreasing of aluminum content in solid solution α-Mg and this alloy probably will be better to work at elevated temperature.

4. Conclusions

Based on the research results obtained, it has been found that:
1) The as-cast microstructure of AE42 alloy is mainly composed of α-Mg matrix and $Mg_{17}Al_{12}$. Additionally there was found presence of Mn-rich and Al-RE type phases.
2) The increasing RE content from 2 wt.% to 4 wt.% leads to appear $Al_{11}RE_3$ and Al_3RE phases.
3) No $Mg_{17}Al_{12}$ phase is detected when RE is increased to 4 wt.%
4) The concentration of Al in the Mg matrix of AE42 alloy is higher than its maximal solubility at ambient temperature. The aluminum content in solid solution of α-Mg in AE44 alloy is much lower.

Acknowledgements

The present work was supported by the Polish Ministry of Education and Science under the research project No PBZ-KBN-114/T08/2004.

References

[1] B.L. Mordike, Development of highly creep resistant magnesium alloys, Journal of Material Processing Technology, 117, (2001), 391-394.
[2] Z. Xiaoquin, W. Quodong, L. Yizhen, Z. Yanping, D. Wenjiang, Z. Yunhu, Influence of beryllium and rare earth additions on ignition-proof magnesium alloys, Journal of Material Processing Technology, 112, (2001), 17-23.
[3] H. Friedrich, S. Schumann, Research for a "new age of magnesium" in the automotive industry, Journal of Material Processing Technology, 117, (2001), 276-281.
[4] A. Kiełbus, T. Rzychoń, Microstructural characterization of Mg-Al magnesium alloys, Proceedings of the 13th scientific conference "New Technologies and Materials in Metallurgy and Materials Science and Engineering", Katowice, 2005, 117-122 (in Polish)
[5] M.O. Pekguleryuz, E. Baril, Creep resistant Magnesium Diecasting Alloys Based on Alkaline Earth Elements, Materials Transactions, Vol. 42, No. 7 (2001) 1258-1267.
[6] S. Xue, Y.S. Sun, S.S. Ding, Q. Bai, J. Bai, Effects of calcium additions on microstructure and creep behavior of AE42 alloy, Materials Science and Technology, Vol. 21, No. 7, 2005, 847-853.
[7] B.R. Powell, V. Rezhets, M.P. Balogh, R.A. Waldo, Microstructure and Creep Behavior in AE42 Magnesium Die-Casting Alloy, JOM, August 2002, 34-38.
[8] AE alloys – the new family of creep resistant die casting alloys, Diecaster Bulletin, No. 11, October 2004.
[9] P. Bakke, H. Westengen, The role of rare earth elements in structure and property control of magnesium die casting alloys, TMS, Magnesium Technology 2005, 291-296.
[10] T. Rzychoń, A. Kiełbus: Microstructure of the die cast Mg-4Al with rare earth addition, Proceedings of the 23rd Conference "Materials Science and Engineering School", Krakow-Ustron, 2005, 149-154.
[11] A.A. Luo, Recent magnesium alloy development for elevated temperature applications, International Materials Reviews, Vol. 49, No. 1, 2004, 13-32.
[12] N.A. El-Mahallawy, M.A. Taha, E. Pokora, F. Klein, On the influence of process variables on the thermal conditions and properties of high pressure die-cast magnesium alloys, Journal of Material Processing Technology, 73, (1998), 125-138.
[13] K. Davey, S. Bounds, Modelling the Pressure Die Casting Process using Boundary and Finite Elements Methods, Journal of Material Processing Technology, 63 (1997), 696-700.
[14] M.M. Avedesian, H. Baker, ASM Spiecalty Handbook, Magnesium and Magnesium Alloys, 1999.
[15] Y. Lü, Q. Wang, X. Zeng, W. Ding, C. Zhai, Y. Zhu, Effects of rare earths on the microstructure, properties and fracture behavior of Mg-Al alloys, Materials Science and Engineering A278 (2000) 66-76.
[16] L.Y. Wei, G.L. Dunlop, H. Westengen, Development of microstructure in cast Mg-Al-rare earth alloys, Materials Science and Technology, Vol. 12, 1996, 741-750.