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Mg-Al-RE Magnesium Alloys for High-Pressure Die-Casting

K. N. Braszczyńska-Malik *
Czestochowa University of Technology, Institute of Materials Engineering,
Al. Armii Krajowej 19, 42-200 Czestochowa, Poland
*Corresponding author. E-mail address: kacha@wip.pcz.pl

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Abstract

Experimental Mg-Al-RE type magnesium alloys for high-pressure die-casting are presented. Alloys based on the commercial AM50 magnesium alloy with 1, 3 and 5 mass % of rare earth elements were fabricated in a foundry and cast in cold chamber die-casting machines. The obtained experimental casts have good quality surfaces and microstructure consisting of an α(Mg)-phase, $Al_{11}RE_3$, $Al_{10}RE_2Mn_7$ intermetallic compound and small amount of α+γ eutectic and Al_2RE phases.

Keywords: Mg-Al-RE magnesium alloys, High-pressure die-casting

1. Introduction

The development of the high-pressure die-casting process should have a priority over other metal casting technologies because it ensures the production of thin-walled cast details of complicated shapes with a high yield and high dimensional precision. High-pressure die-cast magnesium components are being increasingly used because of their excellent cast ability and the properties that magnesium offers. The high-pressure die-casting of thin-walled components is particularly suitable because of the excellent flow characteristics of molten magnesium alloys [1-9].

The die-casting technology for magnesium and aluminum alloys is basically similar. However, there are important differences like the handing of the molten alloy. The melting of magnesium is also different from other metals because it requires protection against surface oxidation. It should be noted that magnesium and aluminum die-casting alloys also possess different chemical and physical properties, which require modifications in the injection parameters and die design [2-4, 8]. The lower density of magnesium vs. aluminum signifies that the inertia is lower, and for the same metal pressure a higher flow speed results. It will hence take a shorter time to fill a given die with magnesium than with aluminum. However, for thin-walled products with a large flow distance, the required die filling time will be very short for magnesium due to the low heat content. Both cold chamber and hot chamber die-casting machines are used extensively for magnesium alloy high-pressure die-casting. Static casting pressures for cold chamber die-casting machines are commonly in the range of 30-70 MPa (4400-10000 psi). In the hot chamber process, static metal pressures are usually less than in cold chamber machines, typically in the range of 20-30 MPa (2900-4400 psi).

Magnesium alloys are light metallic structural materials, which have a unique combination of properties. They are very attractive in such applications as the automobile and aerospace industries. In lightweight magnesium alloys, aluminium constitutes the main alloying element, chiefly because of its low price, high availability, low density and advantageous effect on corrosion and strength properties. Aluminum improves the mechanical strength, corrosion properties and cast ability. Commercial magnesium alloys for the die-casting process are based on the Mg-Al system. The most commonly used magnesium alloys are the AZ91 and AM series [1-5,10-13]. In AM-type alloys the base alloying elements are aluminum and manganese. Manganese is added to control the iron content of the (indirectly improving corrosion resistance). The microstructure of those as-cast alloys consists of a solid solution of aluminium in magnesium (α-Mg phase with a hexagonal close-packed structure) and α+γ eutectic (fully or partially divorced depending on Al mass fraction and alloy solidification rate). The γ-phase is an intermetallic compound with a stechiometric composition of $Mg_{17}Al_{12}$ (at 43.95 mass % Al).

Unfortunately, Mg–Al-type alloys have poor high temperature strength (limited to about 120ºC), especially poor creep properties, due to presence of the γ phase in the microstructure. Several alloy systems, like Mg–Al–Si or Mg–Al–Ca/Sr, were therefore developed in order to improve the high temperature properties by suppressing the formation of γ phase. Recently a great deal of research has focused on the Mg–Al–RE system (RE = rare earth), like commercial AE42 or AE44 alloys. Although the influence of single Ce, Nd, La or Pr elements on the microstructure and properties of Mg–Al-type alloys has been investigated, RE elements were generally added to magnesium alloys in the form of Ce-rich misch metal. Rare earth elements cause the suppression of the γ phase through the formation of Al-RE intermetalic compounds, mainly $Al_{11}RE_3$ and Al_2RE. Especially the $Al_{11}RE_3$ phase has a advantageous influence on increasing creep resistance. There are several reports describing the structure and properties of the commercial AE42 alloy and different Mg–Al–RE-type alloys [10-15].

In the present paper, magnesium alloys based on a commercial Mg-Al alloy with rare earth elements in high-pressure die-casting conditions was presented. The main objective of the study was to develop technology for the production of alloys of the Mg-Al-RE system directly in high-pressure die-casting conditions. For this purpose, one of the cheapest and most widely used alloys, AM50 alloys, was selected. Rare earth elements were introduced in the form of cerum rich misch metal.

2. Experimental procedures

Experimental casts were produced in the “SILUM” Foundry (Poland) by the high-pressure die-casting method and tested “as cast” (without treatment). The main technological problems taken into account during magnesium alloys casting were: (i) gas protection throughout the whole casting cycle which required a closed system for molten magnesium alloy, (ii) a system metering molten metal from the crucible to the casting machine and also (iii) appropriate selection of materials which are in contact with molten magnesium alloys.

Due to the strong tendency of molten magnesium to be oxidized, it was a prerequisite to use a protective gas atmosphere over the molten metal throughout the whole casting cycle. For that purpose, a special molten metal gas protection system was established. In this preliminary work, IDRA-380 cold chamber die-casting machines were used.

The commercial as-cast AM50 magnesium alloy with a nominal chemical composition of 5 mass.% Al, 0.4 mass.% Mn was used in this study. Rare earth elements in the form of cerium rich mish metal were used as an addition. The composition according to attestation was: 54.8 mass.% Ce, 23.8 mass.% La, 16 mass.% Nd, 5.4 mass.% Pr, 0.16 mass.% Fe and 0.19 mass.% Mg. Alloys with 1, 3 and 5 mass.% of rare earth elements were made by introducing the RE elements into the molten AM50 alloy. The chemical compositions of the fabricated experimental alloys were determined by wet analyses and the results are listed in Table 1, in which the compositions of the alloys named AME501, AME503 and AME505 were given.

The casting temperature of the alloy was in the range of 660-690ºC. Other casting parameters, for example the injection rate, plunger speeds in particular phase, casting pressure, die temperature, etc. were selected experimentally.

Table 1.
Chemical composition of experimental alloys

Chemical composition mas.%*							
Alloy	Al	Mn	RE	Si max	Fe max	Cu max	Zn max
AME501	5	0.4	1	0.05	0.004	0.08	0.002
AME503	5	0.4	3	0.05	0.004	0.08	0.002
AME505	5	0.4	5	0.05	0.004	0.08	0.002
* Mg rest							

3. Results

Fig.1 presents a macrograph of an experimental cast obtained from the AME505 alloy. Casts obtained from the experimental alloys by cold chamber high–pressure die-casting are characterised by correct representation of the die without visible casting defects (like incomplete filling of die cavity, cold flows or cold shuts, hot cracking, deformation, distortion or fracture, etc.) and as well as satisfactory quality of the surfaces.

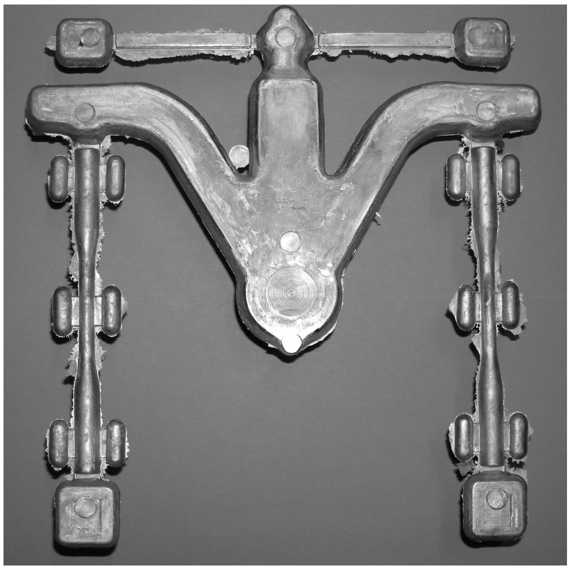


Fig. 1. Macrograph of AME505 experimental magnesium alloy cast fabricated by IDRA-380 cold-chamber die-casting

Figures 2-4 show the microstructure of the high-pressure die-casting experimental alloys. The obtained microstructure of the experimental alloys are characterized by very strong refinement in comparison to gravity casts described in previous papers [15]. Additionally, in comparison to gravity cast alloys the same phases were observed.

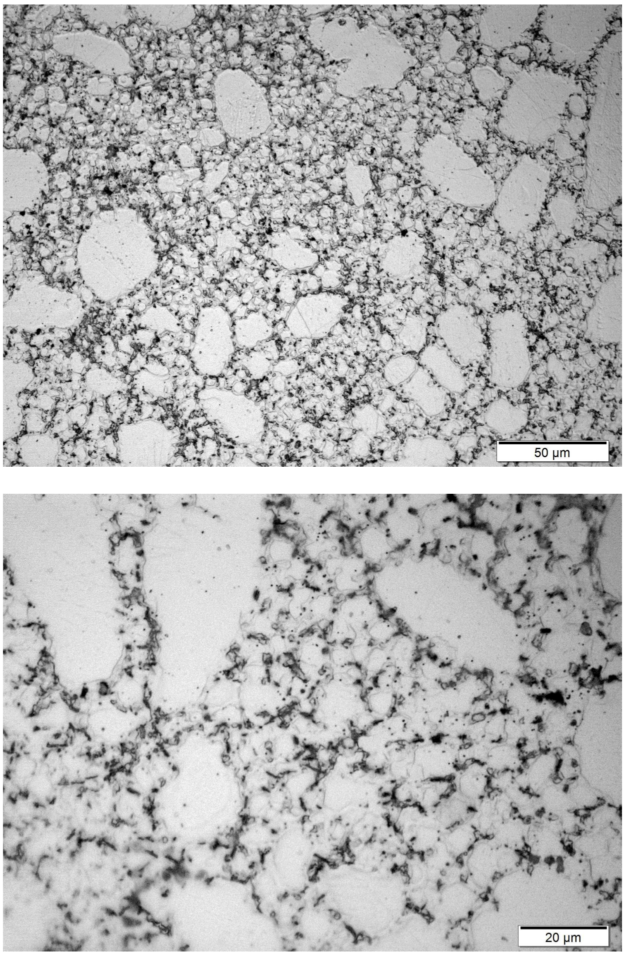


Fig. 2. Microstructure of high-pressure die-casting AME501 magnesium alloy

A non-equilibrium solidification condition caused the formation of an α(Mg)-phase depleted in alloying elements and pushed them away into interdendritical spaces. Due to the reaction between the aluminum and rare earth elements $Al_{11}RE_3$ and Al_2RE phases were formed. Additionally, owing to the non-uniform distribution of aluminum in liquid, some volume fraction of α+γ divorced eutectic formed at the last stage of solidification. Due to the small mass fraction of manganese in the chemical composition of the alloys, the $Al_{10}RE_2Mn_7$ intermetallic compound was also observed in the microstructure of the experimental alloys. Because of the rare earth elements mass fraction, different amounts of particular structural constituents were observed, i.e. α+γ eutectic, $Al_{11}RE_3$ and Al_2RE phases. The structural constituents also had a morphology analogical to that observed in gravity casts. For example, the $Al_{11}RE_3$ phases had acicular morphology, whereas $Al_{10}RE_2Mn_7$ intermetallic had polygonal morphology.

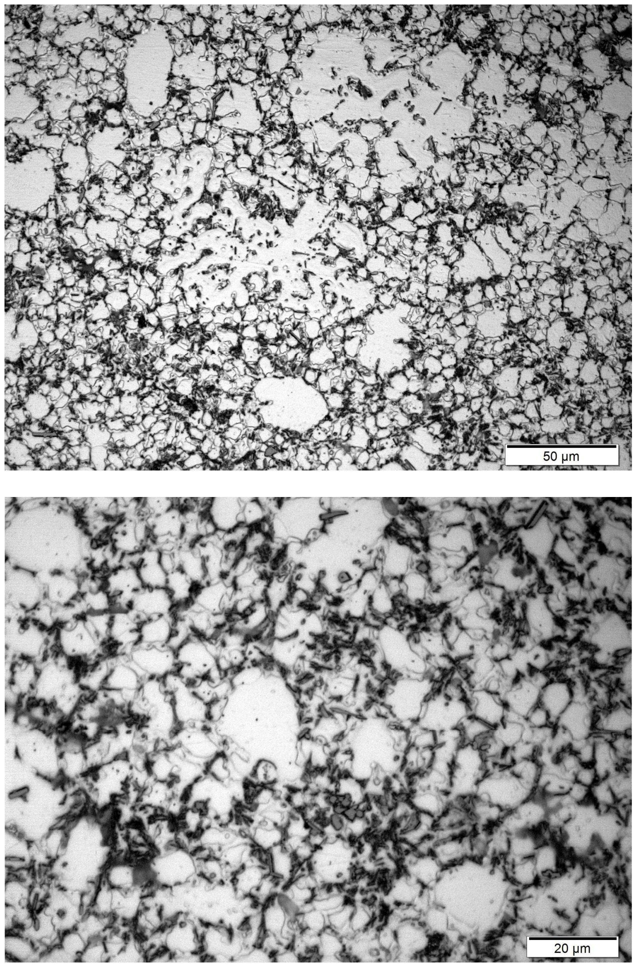
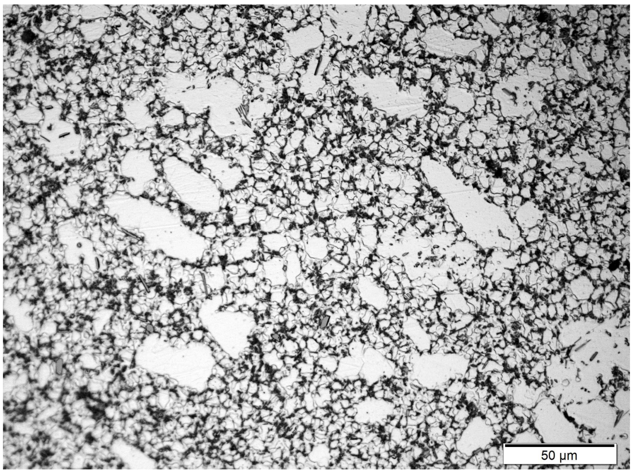


Fig. 3. Microstructure of high-pressure die-casting AME503 magnesium alloy

4. Summary

Thanks to the applied technology of direct introduction of rare earth elements to inexpensive commercial magnesium alloys, it was possible to produce castings of a given chemical composition. The conducted work has shown the ease of transfering the proposed technology as well as materials to industrial conditions. Obtaining alloys with the designed composition directly in foundry conditions or fabricating selected parts using cold-chamber high-pressure machines posed no difficulties. The obtained casts possessed the required level of quality. No oxide pollution of the alloys (thanks suitable atmosphere and batch melting technique), or excessive porosity of the castings (suitably selected parameters thanks to die-casting process) was observed, and the structure of the obtained parts was as expected.



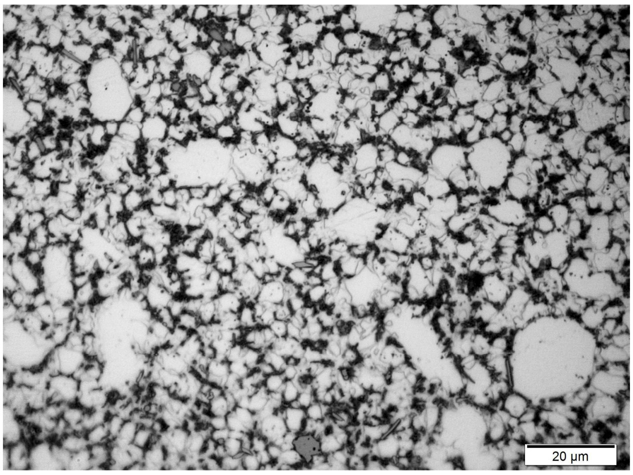


Fig. 4. Microstructure of high-pressure die-casting AME505 magnesium alloy

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References

[1] Mordike, B.L. & Ebert, T. (2001). Magnesium properties-applications-potential. *Materials Science and Engineering A*. 302, 37÷45.

[2] Wu, D.H. & Chang, M.S. (2004). Use of Taguchi method to develop a robust design for the magnesium alloy die casting process. *Mater. Sc. Eng.*, A379 366-371.

[3] El-Mahallawy, N.A, Taha, M.A., Pokora, E. & Klein F. (1998). On the influence of the process variables on the thermal conditions and properties of high pressure die-cast magnesium alloys. *Journal of Mater. Pro. Tech.* 73 125-138.

[4] Dahle, A.K., Sannes, S., John, D.H. & Westengen, H. (2001). Formation of defect bands in high pressure die cast magnesium alloys. *Journal Light Met*. 1, 99-103.

[5] Vogel, M., Kraft, O., Dehm, G. & Arzt, E. (2001). Quasi-crystalline grain-boundry phase in the magnesium die-cast alloy ZA85. *Scrip. Mater*. 45, 517-524.

[6] Unigovski, Y.B. & Butman, E.M. (1999). Surface morphology of a die-cast Mg alloy. *App. Sur. Sc*. 153, 47-52.

[7] Tong, K.S., Hu, B.H., Niu, X.P. & Pinwill I. (2002). Cavity pressure measurements and process monitoring for magnesium die casting of a thin-wall hand-phone component to improve quality. *Journal of Material Proc. Technology*. 127, 238-241.

[8] Balasundaram, A. & Gokhale, A.M. (2001). Quantitative characterization of spatial arrangement of shrinkage and gas (air) pores in cast magnesium alloys. *Mater. Char*. 46, 419-426.

[9] Zhang, J., Yu, P., Fang, D., Tang, D. & Meng J. (2009). Effect of substituting cerium-rich mischmetal with lanthanum on microstructure and mechanical properties of die-cast Mg-Al-RE alloys. *Materials and Design.* 30, 2372-2378.

[10] Zhang, J., Liu, K., Fang, D., Qiu, X., Tang, D. & Meng J. (2009). Microstructure, tensile properties, and creep behavior of high-pressure die-cast Mg-4Al-4RE-0.4Mn (RE=La, Ce) alloys. *Journal of Material Science.* 44, 2046-2054.

[11] Asl, K.M., Tari, A. & Khomamizadeh, F. (2009). The effect of different content of Al, RE and Si element on the microstructure, mechanical and creep properties of Mg-Al alloys. *Materials Science and Engineering A*. 523, 1-6.

[12] Zhang, J., Wang, J., Qiu, X., Zhang, D., Tian, Z., Niu, X., Tang, D. & Meng, J. (2008). Effect of Nd on the microstructure, mechanical properties and corrosion behavior of die-cast Mg-4Al-based alloy. *Journal of Alloys and Compounds.* 464, 556-564.

[13] Braszczyńska-Malik, K.N. & Żydek, A. (2008). Microstructure of Mg-Al alloy with rare earth addition. *Archives of Foundry Engineering.* 10, 23-26.

[14] Zhang, J., Leng, Z., Zhang, M., Meng, J. & Wu, R. (2011). Effect of Ce on the microstructure, mechanical properties and corrosion behavior of high-pressure die-cast Mg-4Al-based alloy. *Journal of Alloys and Compounds.* 509, 1069-1078.

[15] Żydek, A., Kamieniak, J. & Braszczyńska-Malik, K.N. (2010). The effect of rare earth elements on the microstructure of as-cast AM50 alloy. *Archives of Foundry Engineering.* 10, 147-150.