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Impact Strength of AE-type Alloys High Pressure Die Castings

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Abstract

The results of the Charpy impact test of AE-type magnesium alloys produced by the high pressure die casting method are presented. Three alloys with different weight fractions of rare earth elements (RE; e.g. 1, 3 and 5 wt%) and the same mass fraction of aluminium (5 wt%) were prepared. The casts were fabricated using a typical cold chamber high pressure die casting machine with a 3.8 MN locking force. Microstructural analyses were performed by means of a scanning electron microscope (SEM). The impact strength (IS) was determined using a Charpy V hammer with an impact energy equal to 150 J. The microstructure of the experimental alloys consisted of an α-Mg solid solution and $Al_{11}RE_3$, $Al_{10}Ce_2Mn_7$ and Al_2RE intermetallic compounds. The obtained results show the significant influence of the rare earth elements to aluminium ratio on the impact strength of the investigated materials. Lower the RE/Al ratio in the chemical composition of the alloy results in a higher impact strength of the material.

Keywords: AE-type magnesium alloy, Aluminum, Rare earth elements, High pressure die casting, Impact strength

1. Introduction

The high pressure die casting (HPDC) method, which ensures the production of thin-walled components of complicated shapes with dimensional precision, is very attractive in such applications as the automobile, aerospace and electronic industries. In recent decades this technology has especially been developed for aluminum alloys [1-3]. Then the intensively development of magnesium alloys caused this method to be widely used to produce elements from these alloys. Magnesium alloys are currently very desirable due to their low density and unique combination of residual properties [3-5]. High pressure die casting in both cold and hot chamber die casting machines is used to cast magnesium (like aluminum) alloys. It should be noted that magnesium alloys offer very good casting properties like castability and flow characteristics but require protective atmospheres as well as injection parameters and die designs different than those for aluminum alloys.

From among the many different magnesium alloys, especially those from the AM or AZ series (based on the Mg-Al system) are widely used due to their low prices and high casting properties. On the other hand, a negative feature of those alloys is their low properties at elevated temperature (higher than 393 K) [6-9]. This behavior is caused by the presence of a γ phase (with the stoichiometric composition of $Mg_{17}Al_{12}$ at 43.95 wt% Al) in the microstructure of Mg-Al type alloys, which contributes to deformation by grain boundary sliding (especially during creep). For these reasons, many different types of alloys have been developed in which the formation of thermally stable phases along the grain boundaries could improve the properties at elevated temperatures, like with rare earth elements (RE) [8-11]. In Mg-Al-RE type alloys the γ phase is suppressed through the formation of Al-RE-type intermetallic compounds. Especially the $Al_{11}RE_3$ phase has an advantageous influence on the mechanical properties of the final components. In the last few years many different Mg-Al-RE type alloys have been investigated and developed. Some of them were designed with singular rare earth elements but a mixture of elements in the form of mischmetal was also used due to its more economical solution. In previous works [12-14], the microstructure and properties determined in uniaxial tensile tests of high pressure die cast Mg-Al-RE alloys were presented.

In the present study, the influence of the rare earth element mass fraction on the impact strength of HPDC AE series magnesium alloys with aluminum and rare earth elements was presented.

2. Experimental procedures

AE series magnesium alloys with the chemical composition given in Table 1 were used in this study. The alloys were produced on the basis of AM50 commercial magnesium alloy and rare earth elements in the form of cerium rich mischmetal (according to [13]) and called AME. Experimental casts were produced according to [14] by means of a typical cold chamber high pressure die casting machine with a 3.8 MN locking force.

Table 1.
Chemical composition of investigated AME series alloys

Chemical composition wt% (Mg - rest)			
Alloy	Al	RE*	Mn
AME501	4.9	0.73	0.37
AME503	4.9	2.86	0.34
AME505	4.9	4.92	0.35

* Rare earth elements: 54.8 wt% Ce, 23.8 wt% La, 16 wt% Nd, 5.4 wt% Pr, 0.16 wt% Fe and 0.19 wt% Mg

Microstructural analyses were performed by means of a scanning electron microscope (JOEL JSM-6610LV). A standard metallographic technique was used for sample preparation. After polishing the samples, they were etched in a 1% solution of nitrous acid in ethyl alcohol for about 60 s. Mechanical properties tests of the investigated alloys were carried out according to relevant ASTM standards. The impact strength (IS) was determined using a Charpy V hammer with an impact energy equal to 150 J. The above test was performed at room temperature. The used specimens (without a notch) had the dimensions presented in Fig. 1 (6 mm x 6 mm x 55 mm).

Fig. 1. Macrograph of HPDC AME series alloy impact test specimens with dimensions in mm.

3. Results and discussion

The micrographs of the microstructures of the investigated AME series magnesium alloy casts obtained by means of a cold chamber die casting machine are shown in Fig. 2. The microstructure of the investigated AME series alloy consisted mainly of primary α(Mg) solid solution dendrites (impoverished in alloying elements compared to the phase diagram) and an $Al_{11}RE_3$ phase, which is an intermetallic compound analogical to the $Al_{11}Ce$ phase. The volume fraction of this main structural constituent increases with a rise in the RE/Al ratio in the alloy.

(a)
(b)
(c)

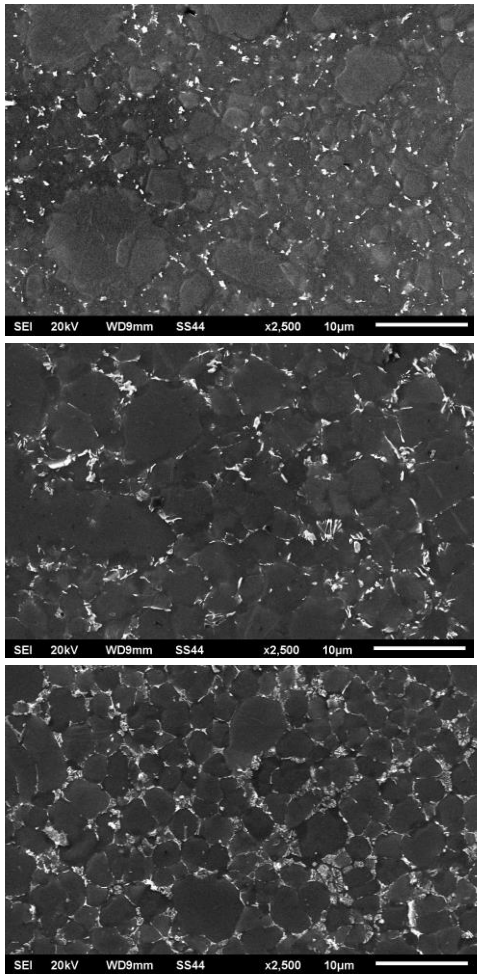

Fig. 2. Microstructure of AME501 (a), AME503 (b) and AME505 (c) magnesium alloy casts obtained using cold chamber die casting machine; scanning electron microscopy

It should be noted that intermetallic compounds like $Mg_{17}Al_{12}$ (characteristic for the Mg-Al system) or $Mg_{12}RE$ (typical for Mg-RE alloys) were not present in the investigated alloy. In the microstructure of the alloys the $Al_{10}Ce_2Mn_7$ phase was observed and for the alloys with a high RE/Al ratio the Al_2RE phase was also revealed. The microstructure of the investigated alloys was presented in works [12-14] in detail.

Fig. 3. presents macrographs of the specimens after the impact test, whereas the obtained values are shown in Table 2. Changes in the phase composition of the alloys resulted in different impact strengths of the investigated casts, with the biggest differences between the AME501 alloy and the other two. The increase in

volume fraction of the $Al_{11}RE_3$ phase contributed to a decrease in the impact strength of the alloys. This influence of phase composition of the alloys is comparable to the results obtained for the investigated materials after the gravity cast process [13], though the values obtained for the gravity cast materials were considerably lower (from 5 J for the AME501 alloy to 3 J for the AME505 alloy). On the other hand, this behaviour is contrary to the tensile strength of the alloys, described in work [14]. The HPDC AME501 alloy exhibited an ultimate tensile strength equal to 224 MPa and the tensile strength was 132 MPa, whereas for the AME505 alloy those properties were equal to 248 and 145 MPa, respectively. The $Al_{11}RE_3$ intermetallic compound caused dislocation blocking during tensile strength tests but this influence is insignificant during impact strength testing. In this case, a finer intermetallic phase in the microstructure of the AME501 alloy has a more advantageous influence on blocking crack growth.

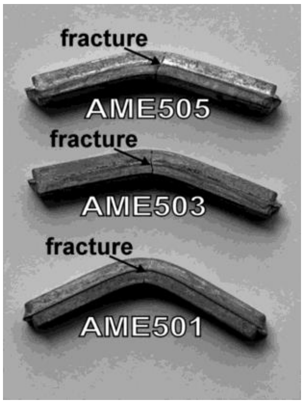

Fig. 3. Macrographs of samples after impact test

Table 2.
Results from impact test of investigated alloys

Alloy	Impact energy [J]	Impact strength [J/cm^2]
AME501	13	36.1
AME503	9	25.0
AME505	8	22.2

Figs. 4-6 show the scanning electron microscopy micrographs of typical impact fracture surfaces of the investigated alloys. The micrographs were made in areas of tensile stresses. Brittle trough cleavage or quasi-cleavage fracture of the alloys is typical because of the hexagonal closed packed structure of magnesium. In spite of this, the observed fracture surfaces were characterized by visible extension and the presence of small dimples. Secondary cracks were also visible, especially on the intermetallic phases.

(a)
(b)

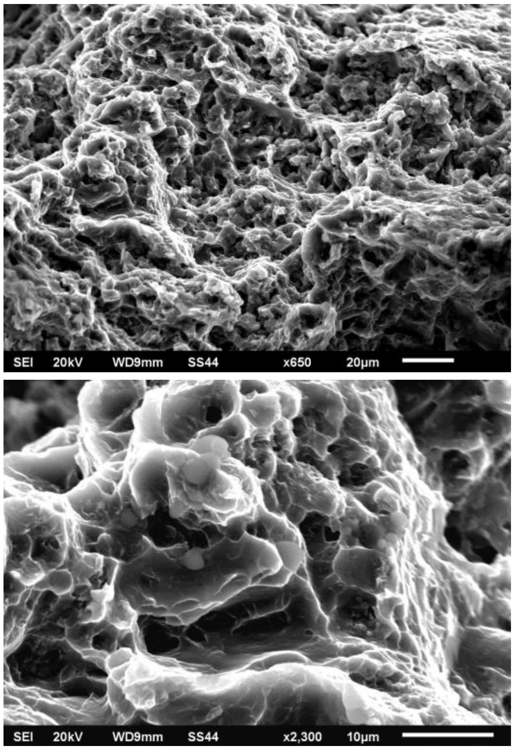

Fig. 4. SEM micrographs of fracture surface of HPDC AME501 alloy (after impact test)

(a)
(b)

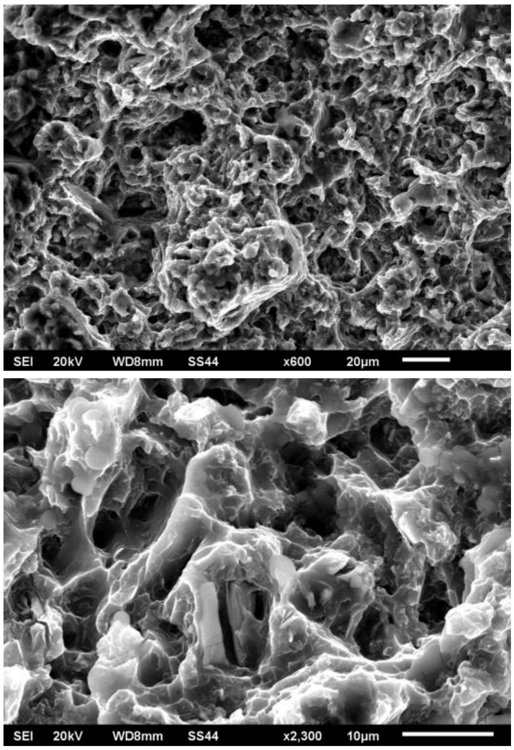

Fig. 5. SEM micrographs of fracture surface of HPDC AME503 alloy (after impact test)

(a)

(b)

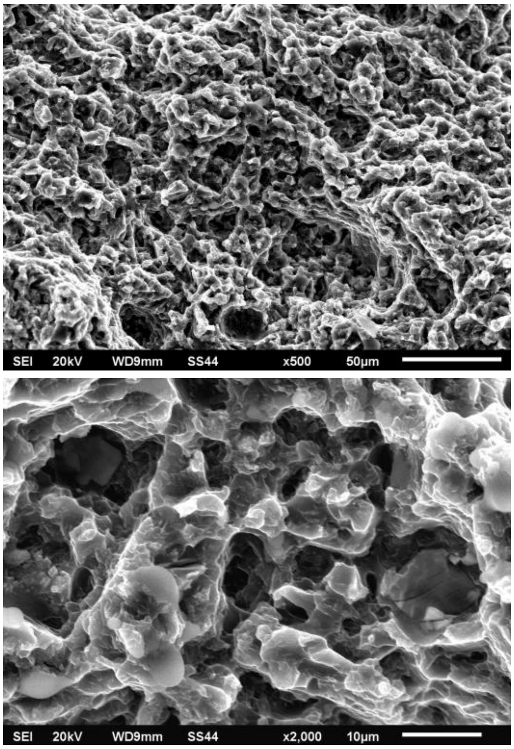

Fig. 6. SEM micrographs of fracture surface of HPDC AME505 alloy (after impact test)

4. Conclusions

High pressure die cast technology allowed final components to be obtained from the AE series magnesium alloy, which is characterized by the α(Mg) solid solution and Al-RE-type intermetallic compounds. The low RE/Al ratio in the chemical composition of the alloy contributed to a high level of impact strength. Increasing the RE/Al ratio contributes to a decrease in the plasticity of the alloy and results in a lower impact strength of the material.

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