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ARCHIVES of FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 2023
Issue 2/2023

10 – 14

2/2

10.24425/afe.2023.144289

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Influence of Defects on Deformation Behavior of High-Pressure Die-Casting Magnesium Alloys

K. Braszczyńska-Malik
Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology,
Department of Materials Engineering, 19 Armii Krajowej Ave., 42-200 Czestochowa, Poland
Corresponding address: e-mail: kacha@wip.pcz.pl

Received 13.06.2022; accepted in revised form 12.01.2023; available online 28.04.2023

Abstract

The results of investigations of defects in AME-series magnesium alloys produced by the high-pressure die-casting method are presented. The analyzed magnesium alloys contain about 5 wt% aluminum and 1-5 wt% rare earth elements introduced in the form of mischmetal. The casts were fabricated using a regular type cold-chamber high-pressure die-casting machine with a 3.2 MN locking force. The same surfaces of the casts were analyzed before and after the three-point bending test in order to determine the influence of the gas and shrinkage porosity on the deformation behavior of the alloys. The obtained results revealed that the most dangerous for the cast elements is the shrinkage porosity, especially stretched in the direction perpendicular to the that of the tensile stress action. Additionally, the influence of deformation twins arise in the dendrites of the primary α(Mg) solid solution and its interaction on the cracking process was described.

Keywords: AME-series magnesium alloy, High-pressure die-casting, Gas and shrinkage porosity, Microstructure, Deformation twins

1. Introduction

The high-pressure die-casting (hpdc) method is very attractive for the multi-serial production of thin-walled components of complicated shapes with dimensional precision. This technology is widespread especially for aluminum alloys; however, it is also used to produce magnesium elements. Although magnesium alloys require protective atmospheres during all casting processes, they offer very good castability and properties like excellent flow characteristics. On the other hand, magnesium alloys require a shorter time to fill a die than aluminum due to the low heat content. The higher flow speed of magnesium (characterized by low density) is also caused by higher the inertia of this metal vs. aluminum [1-5]. For these reasons, magnesium alloys involve different injection parameters than aluminum alloys. The main hpdc parameters like the temperature of the liquid metal and die, plunger speed in the first and second stage or intensification pressure directly influencing the solidification conditions of magnesium alloys, determine the level of microstructure refinement of the element and also the level of its porosity. Especially low intensification pressure and simultaneously high plunger speed in the first and second stage result in a high amount of gases occluded during casting. Additionally, it should be noted that other factors (which determine the manner of filling the cavity of the mold with liquid metal) also directly affect the quality of the casting. Among these factors the size of the element and die design (i.e. design of gating system, size and shape of in-gate, number, size and shape of venting channels and also volume of the pressing chamber) can be distinguished. The quality of the castings, including the level of internal porosity, is the main aspect of the line design for hpdc. Nevertheless, it is well known that hpdc parts quite often exhibit a high level of porosity. Both gas and shrinkage porosity in hpdc aluminum and magnesium alloys were intensively investigated in works [6-13]. In the present paper, investigations of the three-point bending surfaces allowed the role of individual defects during deformations of AME-series magnesium alloys to be assessed.

2. Experimental procedures

The AME-series magnesium alloys described in works [5, 10, 14-15], with 5.0 wt% aluminum and 1.0-5.0 wt% rare earth elements (in the form of cerium-rich mischmetal) were chosen for this study. Experimental casts were produced using a regular type cold-chamber high-pressure die-casting machine with a 3.2 MN locking force in the same condition. Samples with a length of 30 mm, height 5 mm and width 3 mm were deformed in a three-point bending experiment (at ambient temperature). Before the deformation, one side of samples were polished in the standard manner (non-etched). The same areas of the samples before and after the three-point bending test were investigated, which is presented schematically in Fig. 1. Observations were performed on the tension surface by means of light microscopes (Olympus GX41 and GX51 with differential interface contrast). The percentage of deformation was determined from the deflection. After the above described experiment, a standard metallographic technique was also repeated and samples were etched in a 1% solution of nitrous acid in ethyl alcohol for about 60 s.

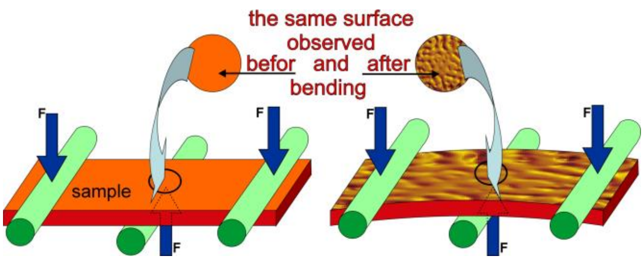

Fig. 1. A scheme of experiment

3. Results and discussion

Fig. 2 presents a typical microstructure of the AME-series magnesium alloys casts obtained by means of the cold-chamber die casting machine. A visible dendritic structure with a bimodal primary dendrite size distribution is typical for a high-pressure die-cast of these alloys. The microstructure of the investigated AME-series alloys consisted mainly of primary α(Mg) solid solution dendrites (impoverished in alloying elements compared to the phase diagram) and the $Al_{11}RE_3$ intermetallic phase. The microstructure and mechanical properties of hpdc AME-series magnesium alloys were described in detail in previous works [5, 10, 14-15].

Fig. 3 shows the changes due to the tensile stresses on the surface of the AME501 alloy. The initial surface of sample visible in Fig. 2a was characterized by the presence of gas and shrinkage porosity. After 6% deformation the main crack began to spread from the shrinkage pore marked as “y” (purple rectangle) in Fig. 3. It should be noted that this defect in the material was extended in the direction perpendicular to the direction of the tensile stress. During deformation, the visible porosity "opened" and then the crack expanded. Contrary to this, the shrinkage pore marked as “x” in Fig. 3 (navy blue rectangle) was arranged in a direction parallel to the direction of the tensile stress. After deformation, no changes in the shape or size of this defect were observed. Similarly, no significant changes in the size or shape of the gas pores were observed on the surface of the sample (some of them were marked with red ovals). Additionally, the appearance of slip bands in the form of characteristic lines was observed on the surface of the sample. Some of them are marked with green arrows.

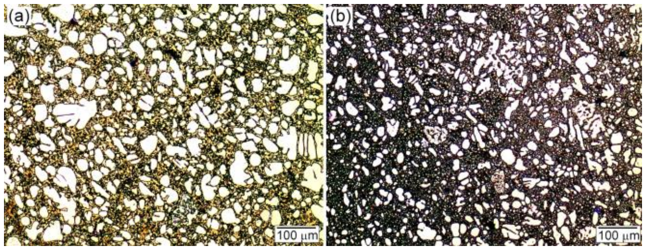

Fig. 2. Microstructure of cold-chamber die-cast AME501 (a) and AME505 (b) magnesium alloys; light microscopy

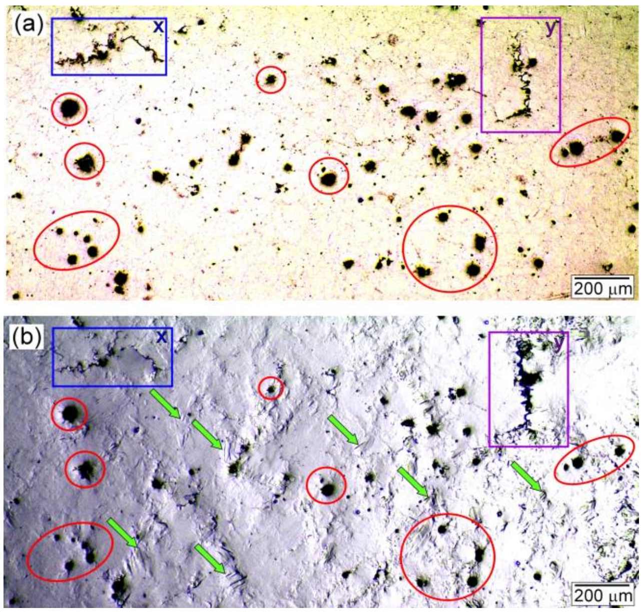

Fig. 3. Same hpdc AME501 alloy sample surface before (a) and after 6% deformation (b); light microscopy

Similar phenomena were observed after 8% deformation. Fig. 4 illustrates changes on the sample surface caused by tensile stresses. The main cracks were developed from the shrinkage porosity arranged perpendicular to the direction of the tensile stresses. Also in this case, the distribution and shape of the gas pores did not significant change (some of them were marked with red circles). The presented micrographs (Fig. 3 and 4) show that the main places of crack initiation in the casting are shrinkage pores, especially perpendicular to the direction of the tensile stresses. Similar conclusions were formulated by Li at al. [13] after *in situ* observation of the tensile deformation of the hpdc AM60B magnesium alloy. On the other hand, an analogical hpdc AE44 magnesium alloy was investigated by Lee et al. [12]. They concluded that the fraction path preferentially went through the regions of both highly localized gas clusters and shrinkage pores. The results presented in this study unequivocally indicate that shrinkage porosity, which is very often less visible than gas porosity during standard cast investigations, is more dangerous and may be the main sites of fracture development.

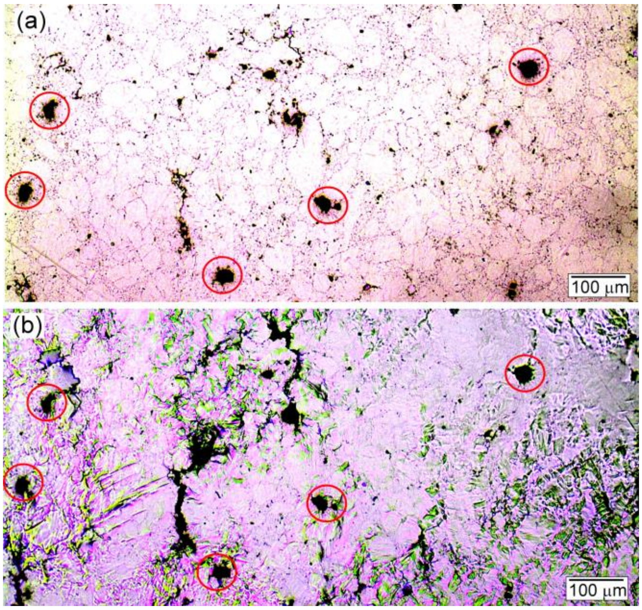

Fig. 4. Same hpdc AME501 alloy sample surface before (a) and after 8% deformation (b); light microscopy

It should also be noted that after the 8% deformation on the surface devoid of porosity, the presence of such visible cracks was not observed. Fig. 5 shows the surface without porosity in its initial state and after 8% deformation. The action of stresses caused plastic deformation of the surface without the formation of distinct cracking paths, which were formed on the surface containing shrinkage porosity at the same degree of deformation (Fig. 4).

Detailed analyses of the surfaces of the samples after deformation also revealed the presence of microcracks caused by stress concentration in the places of the intersection of deformation twins. It is well known that magnesium and its alloys have a hexagonal closed packed crystallographic structure, which due to the lack of a sufficient number of independent slip systems, undergoes strong twinning during deformation at room temperature. Twins are also the main microstructure defects of magnesium alloys. Fig. 6 shows the relief on the deformed surface resulting from the clearly visible deformation twins with the lenticular shape characteristic of magnesium. The appearance of cracks was observed at the intersection of the deformation twins. Some of the cracks thus formed on the tension surface are marked with black arrows. Deformation twins are formed in dendrites of primary α(Mg) solid solution and can extend through the entire crystals. Their intersection points are favorable places for the nucleation of cracks due to the accumulation of stresses.

Figs. 7 and 8 show the microstructure of the alloys after 8% deformation (metallographic specimens made on tension surfaces). For the investigated alloys, the presence of deformation twins inside the primary α(Mg) solid solution crystals was revealed; however, especially large intersections of twins were visible in the case of the alloy characterized by large α(Mg) solid solution dendrites (Fig. 7).

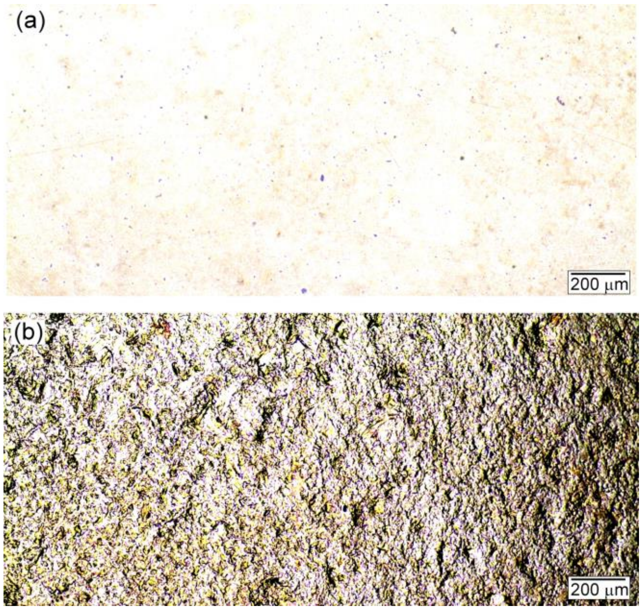

Fig. 5. Same hpdc AME505 alloy sample surface before (a) and after 8% deformation (b); light microscopy

The presented results also indicate that in case of the investigated magnesium alloys, an intensive reduction in the size of primary α(Mg) solid solution dendrites is also an important factor influencing the properties of hpdc elements. This factor can be influenced by both the chemical composition of the alloy and the parameters of the casting process.

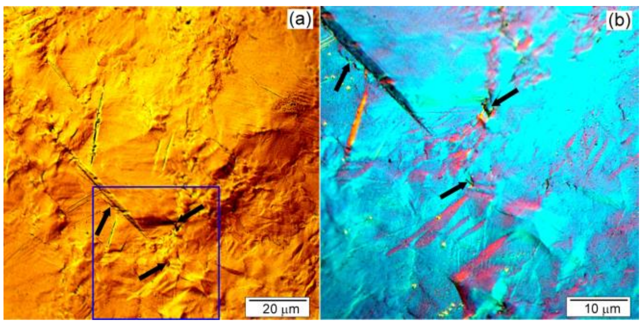

Fig. 6. Hpdc AME501 alloys sample surface after 8% deformation (a) and higher magnification of area marked by navy blue square (b); light microscopy with differential interference contrast

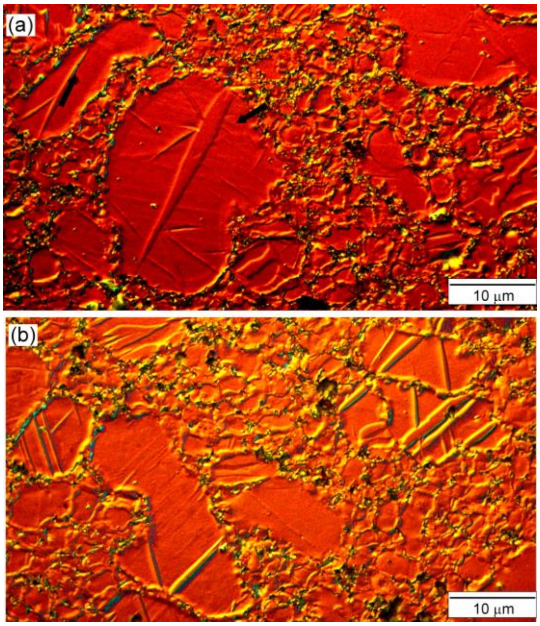

Fig. 7. Microstructure of hpdc AME503 alloys sample after 8% deformation; light microscopy with differential interference contrast

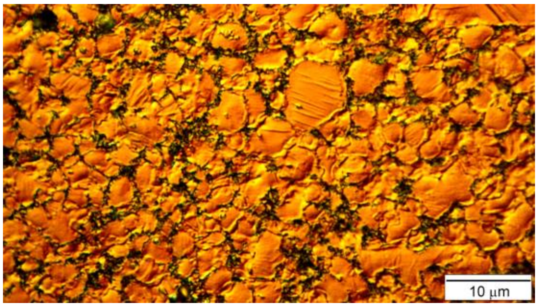

Fig. 8. Microstructure of hpdc AME505 alloys sample after 8% deformation; light microscopy with differential interference contrast

4. Conclusions

In the presented paper, high-pressure die-cast AME-series magnesium alloys after deformation by the three-point bending method was studied. The main conclusions drawn are as follows:

1. Shrinkage porosity is more dangerous for hpdc elements put into commission than gas porosity and can be the main sites of fracture development during operation under stresses.
2. Shrinkage pores stretched in a direction perpendicular to the direction of the tensile stress action are especially dangerous for cast elements.
3. For magnesium alloys, a strong reduction in the size of crystals of the primary α(Mg) solid solution is especially important due to the formation (inside them) of deformation twins, the interaction of which are privileged places for the nucleation of cracks.

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