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Influence of delivery state quality on microstructure and mechanical properties of as cast AZ91 Mg alloy

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Abstract

In the work evaluation of influence of porosity and microstructure on mechanical properties of AZ91 alloy coming from three suppliers was done. It was found that the structural factors influence the AZ91 alloy's strength properties are: the pores' area fraction, the area fraction of the $Mg_{17}Al_{12}$ phase of massive and lamellar morphologies, and the Mg_2Si phase's area fraction.

Keywords: metallography, metallic alloys, magnesium alloys, AZ91 microstructure

1. Introduction

The development of magnesium alloys contributed to their increasing usage in a number of technological fields, among other things, in the aircraft or automotive industries, or for the manufacture of household appliances. Magnesium alloys are currently applied for large-size sand-castings, die-castings and precision castings [1-9]. A particularly important direction of magnesium alloys' development is connected with the castings' operation temperature. At present, their maximum working temperature amounts ca. 250˚C. Endeavours are made to achieve the highest possible level of magnesium alloys' creep resistance, which should enable an increase of the working temperature for components made of these alloys to more than 300°C [2-6].

The present paper presents the testing of the AZ91 alloy in an as-cast condition and after heat treatment, including the measurement of morphological and stereological parameters of the following phases and structural factors: the shrinkage and gas porosity, the intermetallic $Mg_{17}Al_{12}$ phase (of massive morphology), the lamellar mixture $\alpha Mg + Mg_{17}Al_{12}$, the Mg_2Si phase, the α - Mg phases and other intermetallic phases from the Mn-Al system [10-13].

2. Material for examination

The AZ91 alloy in an as-cast condition coming from three different manufacturers (designated as: m, s, e, respectively) was selected for the research. The sampling places and the method of specimens' designation as well as their basic mechanical properties are shown in Table 1. Next, the specimens were solution heat treated (360°C/3h and 415°C/24h) and aged (170°C/8h) (Table 1).

In order to determine the structure, etching tests were performed for the prepared metallographic specimens in 10 chemical reagents selected on the bases of papers [3, 4]. It was found that the best etching reagent for the as-cast alloy was a reagent consisting of 10 ml HF + 90 ml H_2O. Etching with this reagent enables a correct identification of phases in the structure for automatic phases' detection and a quantitative description of the structure, whereas the alloy's structures after heat treatment are well detected by means of a reagent composed of 5 ÷ 20 ml of acetic acid and 80 ÷ 95 ml of H_2O. The detected structures differ from one another with the amount and morphology of individual phases. Example structures in an as-cast condition are presented in Fig. 1a, and after heat treatment, in Fig. 1b.

Table 1.
Method of specimens' designation and sampling places.

specimen	description	R_e [MPa]	R_m [MPa]	R_e/R_m [-]	A_5 [%]	HB
1m	m – manufacture I	127	170	0,75	1,8	56,8
1e	e – manufacture II	119	146	0,82	1,0	58,1
1s	s – manufacture III	113	136	0,83	0,9	58,1
2mHT	Heat treatment (HT)	124	156	0,79	0,8	63,9
2eHT	360°C/3h and 415°C/24h, 170°C/8h	135	228	0,59	4,5	63,9
3sHT		158	240	0,66	2,9	70,6

where: R_e – yield point, R_m – material's strength, A_5 – elongation, HB – hardness (Brinell).

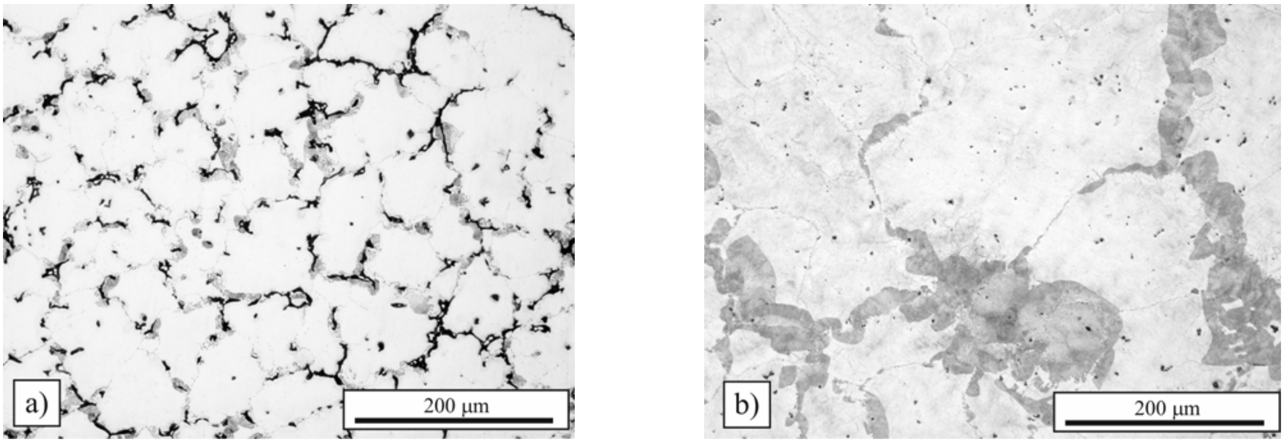

Fig. 1. AZ91 alloy's microstructure: as-cast, a) specimen 1e, b) specimen 2eHT after heat treatment

3. Methodology and research results

3.1. Porosity evaluation

Porosity of as-cast alloy specimens was evaluated on unetched metallographic specimens observed in a bright field on a light microscope at 200x magnification. Evaluation was performed on a Metilo automatic image analyzer with applying the image transformation procedure developed by the Department of Materials Science, Silesian University of Technology. Example images of pores and image transformations required for the porosity evaluation are shown in Fig. 2. The results are juxtaposed in Table 2.

Table 2.
Results of porosity quantitative evaluation.

specimen	A_A [%]	$v(A_A)$ [%]
1m	1,28	75,5
2e	0,16	35,2
3s	0,12	34,4

where: A_A – area fraction of pores, $v(A_A)$ - variability ratio of area fraction

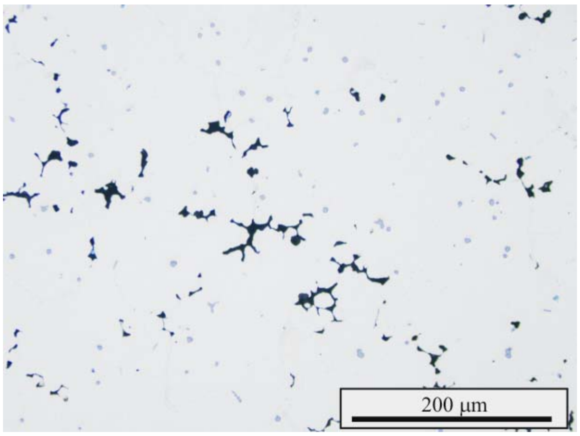

Fig. 2. Shrinkage porosity, unetched metallographic specimen, light microscope, bright field, magnification 200x

3.2. Structure evaluation in the as-cast condition and after heat treatment

Based on metallographic investigations carried out on a light microscope, the phases present in the AZ91 as-cast alloy's microstructure were identified. Presence of a solid solution of aluminium was found in magnesium (Mg-α) as well as the $Mg_{17}Al_{12}$phase of massive and lamellar morphologies, and precipitations of the Mg_2Si phase. Precipitations from the Mn-Al system were also observed (Fig. 3a).

After heat treatment, small amounts of the $Mg_{17}Al_{12}$ phase of massive morphology were found in the material, which morphology is untypical of the AZ91 alloy structure after full heat treatment. In the other specimens, only the $Mg_{17}Al_{12}$ phase of lamellar morphology is present (Fig. 3b). All specimens contain small amounts of the Mg_2Si phase and intermetallic phases from the Mn-Al system.

A quantitative evaluation of the phases was performed on a stand consisting of a light microscope *OLYMPUS GX-71* and the *AnalySIS Pro*® program. Area fractions were measured for the following phases: the $Mg_{17}Al_{12}$ of massive morphology, the lamellar $Mg_{17}Al_{12}$ phase along with the aluminum-enriched area, the Mg_2Si and the area occupied by solid solution α. The respective measurement conditions for the as-cast alloy are presented in Fig. 3c, and for the alloy after heat treatment, in Fig. 3d. Results of the quantitative evaluation for the phases measured are shown in Table 3.

4. Analysis of results

Examination was carried out of the AZ91 alloy structure in the as-cast condition and after heat treatment. The heat treatment consisted of two-stage solution heat treatment at 360°C/3h (415°C/24h) and ageing at 170°C/8h. Specimens from three different manufacturers of magnesium alloys were used.

To detect the alloys' structures, a procedure of cutting, grinding and polishing was developed, and the best structure detecting chemical reagents were chosen.

Based on the observations, it was found that in all cases, the alloy structure in the as-cast condition consisted of a solid solution of aluminium in magnesium (Mg(α)), phase $Mg_{17}Al_{12}$ of massive morphology, distributed at Mg(α) crystals' boundaries and a phase of lamellar morphology distributed mainly in the regions close to the massive phase (Fig.1a). Insignificant amounts of the Mg_2Si phase and phases from the Al-Mn system were observed as well.

After solution heat treatment, it was found that the $Mg_{17}Al_{12}$ phase of massive and lamellar morphology dissolved and next, as a result of the ageing process, phase $Mg_{17}Al_{12}$ of lamellar morphology precipitated within the grain boundaries' regions (Fig. 1b).

An analysis of the specimens' porosity showed the highest area fraction of pores (1.28%) in the specimen marked as 1m (table 2). This specimen is also characterized by the lowest mechanical properties after heat treatment, which indicated the decisive influence of porosity on the material's strength properties in both as-cast condition and after heat treatment (table 1).

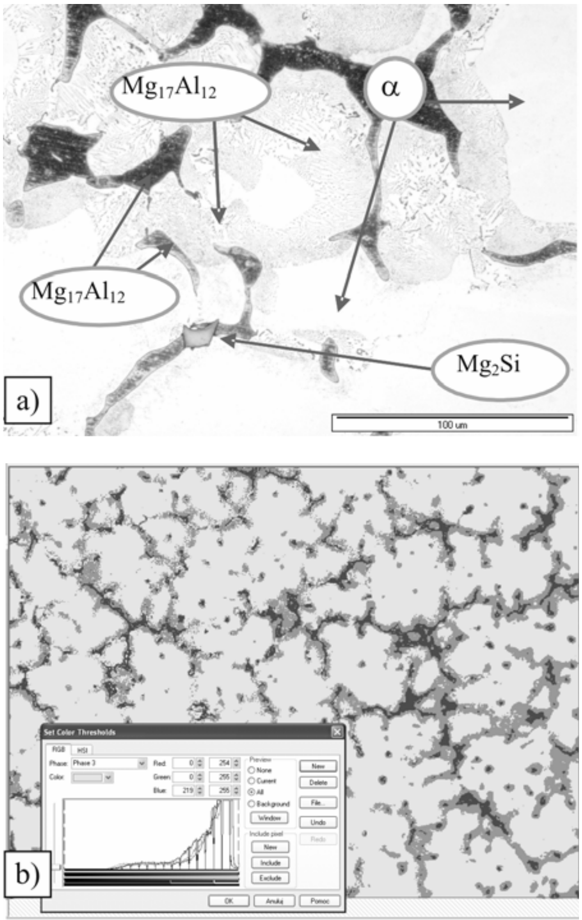

Fig. 3. AZ91 alloy microstructure: a) input specimen – after casting, b) phases detection in as-cast condition

A quantitative analysis of the as-cast alloy showed that in specimen 1m, a greater amount of the $Mg_{17}Al_{12}$ phase of massive morphology (7.73%) was detected than in specimens 1e (4.25%) and 1s (4.61%). A reverse dependence was observed regarding the amount of the lamellar phase, i.e. specimen 1m – 2.15%, and specimens 1e and 1s: 12.69% and 8.90%, respectively (Fig. 4).

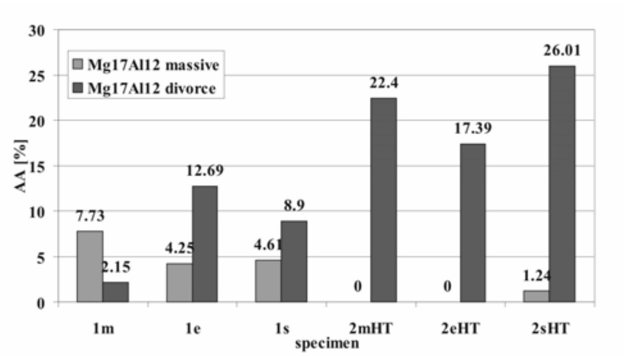

Fig. 4. Juxtaposition of the quantitative evaluation results for phase $Mg_{17}Al_{12}$ in the AZ91 alloy before and after heat treatment

In specimens 2mHT and 2eHT after heat treatment, no massive phase $Mg_{17}Al_{12}$, was detected, which testifies to its complete dissolution during the solution heat treatment process and its new precipitation in a lamellar form (22.40% and 17.39%, respectively) during ageing. In the case of specimen 2sHT, non-complete dissolution of the massive phase (1.24%) and lamellar phase precipitation within the largest area (26.01%) took place (Fig. 4).

An analysis of the investigated specimens' mechanical properties and structural changes during heat treatment shows that as regards specimen 2mHT, its material's strength was affected by alloy's porosity, whereas in the case of specimens 2eHT and 2sHT, the strength increased by ca. 50%.

5. Conclusions

1. The as-cast AZ91 alloy's structure is composed of a solid solution Mg(α), phase $Mg_{17}Al_{12}$ of massive and lamellar morphologies, distributed within crystal boundaries' regions, and not numerous precipitations of phases Mg_2Si and $MnAl_8$. As a result of the alloy's heat treatment, the massive $Mg_{17}Al_{12}$ phase dissolves and precipitates in the form of a lamellar phase.
2. The structural factors that significantly influence the AZ91 alloy's strength properties when in as-cast condition and after heat treatment, are (in the priority order): the pores' area fraction, the area fraction of the $Mg_{17}Al_{12}$ phase of massive and lamellar morphologies, and the Mg_2Si phase's area fraction.
3. Reserves for potential enhancement of the AZ91 alloy's mechanical properties lie in those elements of the technological process that are conducive to a reduction of the pores' and the Mg_2Si phase's volume, with a simultaneously increased volume fraction of the $Mg_{17}Al_{12}$ phase of lamellar morphology in the range of 10 – 40%.

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