Microstructure of AM50 die casting magnesium alloy

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ABSTRACT

Purpose: AM50 magnesium alloy allows high-energy absorption and elongation at high strength and has good castability. It contains aluminum and manganese. Typically, it is used in automotive industry for steering wheels, dashboards and seat frames. The aim of this paper is to present the results of investigations on the microstructure of the AM50 magnesium alloy in an ingot condition and after hot chamber die casting.

Design/methodology/approach: Die casting was carried out on 280 tone locking force hot-chamber die casting machine. For the microstructure observation, an Olympus GX+70 metallographic microscope and a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS spectrometer equipped with SYSTEM SIX were used.

Findings: Based on the investigation carried out it was found that the AM50 magnesium alloy in as ingot condition is characterized by a solid solution structure with partially divorced eutectic ($\alpha + Mg_17Al_12$) and precipitates of $Mn_5Al_8$ phase. After hot chamber die casting is characterized by a solid solution structure with fully divorced eutectic $\alpha + Mg_17Al_12$. Moreover, the occurrence of $Mn_5Al_8$ phase and some shrinkage porosity has been proved.

Research limitations/implications: Future researches should contain investigations of the influence of the die casting process parameters on the microstructure and mechanical properties of AM50 magnesium.

Practical implications: AM50 magnesium alloy can be cast with cold- and hot-chamber die casting machine. Results of investigation may be useful for preparing die casting technology of this alloy.

Originality/value: The results of the researches make up a basis for the investigations of new magnesium alloys for hot chamber die casting with addition of RE elements designed to exploitation in temperature to 175°C.

Keywords: Metallic alloys; Methodology of research; Electron microscopy; AM50 magnesium alloy

1. Introduction

Magnesium and its alloys are often used for many technical applications, including the aerospace, automobile and motor vehicle, metallurgical, chemical and electronical industries [1,2]. Magnesium alloys are not only very attractive materials for producing very lightweight automobile components but offer the designer many unique properties not found in other alloys [3]. They are characterised by low density: ~1,8 g/cm$^3$, tensile strength $R_m$=300–350 MPa, elongation $A_5$=20% and hardness ~100HB [4].

Most commercial magnesium alloys (AM50, AZ91) are based on the magnesium-aluminium system. They contain aluminium, manganese (AM50, AM60), and zinc, which allow obtaining suitable properties. Aluminium enhances both tensile strength and
hardness, and improves casting properties of an alloy. The best ratio of mechanical to plastic properties is obtained with a 6% Al content. Manganese does not cause any increase of tensile strength, however, it does slightly increase the yield point. It also brings about an increase of resistance to the action of sea water. The quantity of manganese in magnesium alloys is limited by its relatively low solubility in magnesium. Manganese content in alloys with an Al addition does not exceed 0.3% and 1.5% in alloys without Al addition. An addition of zinc in combination with Al aims at improving tensile strength, however 1% of Zn with a 7÷10% Al content in an alloy enhances hot cracking [4, 5].

The castability of magnesium alloys of the AM-series using the die-casting process is excellent. The good flow properties allow the casting of thin-walled parts and costs are reduces due to the fact that less material is needed. High pressure die casting is the dominant process for the mass production of magnesium components [6].

Hot chamber die casting means that the molten alloy is transported directly from the furnace to the die via heated casting equipment (transfer tube, gooseneck, nozzle). The melting and gasting furnaces are directly adjoining parts of the hot chamber die casting machine (Fig.1) [4,7,8].

![Fig. 1. Schematic of the hot chamber die-casting process](image)

The maximum solubility of aluminium in magnesium at an eutectic temperature (437°C) is 14%, whereas an eutectic mixture (α + Mg17Al12 intermetallic phase) occurs at ca. 33% Al content. The content of aluminium in all industrial alloys of the AM series is not higher than the boundary solubility of Al in Mg. The equilibrium structure of these alloys is characterised by 100% presence of a solid solution, whereas the unbalanced structure, additionally metastable in casting alloys, shows the presence of an eutectic already at a 2% Al content [9,10]. During die-casting solidification, the following sequence occurs. Primary solid solution a fine grains are nucleated at liquidus temperature. As the temperature is lowered, the time for diffusion is too short to allow equilibrium solidification. This caused a core structure, with an increasing concentration of aluminium towards grain boundaries. Next, along the grain boundaries, a divorced eutectic is formed [11-14].

### 2. Description of the work methodology, and material for research

#### 2.1. Material for research

The material for the research was a AM50 alloy in ingot condition and after hot chamber die casting. The chemical composition of the AM50 alloy is provided in Table 1.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>4.9</td>
</tr>
<tr>
<td>Mn</td>
<td>0.45</td>
</tr>
<tr>
<td>Zn</td>
<td>0.2</td>
</tr>
<tr>
<td>Si</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;0.008</td>
</tr>
<tr>
<td>Fe</td>
<td>&lt;0.004</td>
</tr>
<tr>
<td>Be</td>
<td>0.001</td>
</tr>
<tr>
<td>Mg</td>
<td>balance</td>
</tr>
</tbody>
</table>

#### 2.2. Research methodology

Die casting was carried out on 280 tone locking force hot-chamber die casting machine. Table 2 lists the process parameters used for this work. Casting was undertaken at the NTP firm in Kędzierzyn-Koźle, Poland.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piston speed</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>Pressure</td>
<td>100 bar</td>
</tr>
<tr>
<td>Casting temperature</td>
<td>680 °C</td>
</tr>
<tr>
<td>Die temperature</td>
<td>170 °C</td>
</tr>
</tbody>
</table>

The samples for structural examination were ground, mechanically polished and finally etched in a reagent containing 2g of oxalic acid and 100 ml of H2O.

For the microstructure observation, a Olympus GX+70 metallographic microscope and a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS spectrometer equipped with SYSTEM SIX were used.

### 3. Description of achieved results of own researches

#### 3.1. Microstructure of the AM50 ingot

The AM50 magnesium alloy in as ingot condition is characterized by a solid solution structure α with partially divorced eutectic α + Mg17Al12 and precipitates of Mn5Al8 phase (Fig.2,3). The partially divorced eutectic is characterized by “islands” of the α-Mg solid solution occur inside Mg17Al12 phase precipitations (Fig.3) [9,15]. The divorced eutectic areas are placed inside or on the grain boundaries.

The analysis of the chemical composition have shown a change of the aluminum content from 5.69 at.-% in the solid
solution grain core, through 13.85 at.-% in an area located near divorced eutectic regions, to 32.29 at.-% in the Mg₁₇Al₁₂ phase.

Fig. 2. LM microstructure of AM50 ingot

Fig. 3. SEM microstructure of AM50 ingot. Partially divorced eutectic (α+Mg₁₇Al₁₂)

The precipitates containing manganese and aluminium (Mn₅Al₈ phase) are characterised by a polygonal or an irregular shape, they very often take the form of spines (Fig.4,5).

The microanalysis results of the chemical composition of individual phases in AM50 alloy are shown in Table 3.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>95,80</td>
<td>4,20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mg₁₇Al₁₂</td>
<td>64,88</td>
<td>34,59</td>
<td>0,53</td>
<td>-</td>
</tr>
<tr>
<td>Mn₅Al₈</td>
<td>24,75</td>
<td>46,25</td>
<td>0,71</td>
<td>28,28</td>
</tr>
</tbody>
</table>

The mapping of Mg, Al, Mn in the areas of partially divorced eutectic and Mn-Al precipitates surrounded by the α solid solution visible in the SE image can be seen in Figure 5.

Fig. 4. Mn₅Al₈ precipitates in ingot of AM50 alloy

Fig.5. The SE image and the distribution of Mg, Al, Mn in microareas of AM50 alloy by means of SEM + EDS analysis

3.2. Microstructure of the AM50 alloy after hot chamber die casting

The AM50 magnesium alloy after hot chamber die casting is characterized by a solid solution structure α with fully divorced eutectic α + Mg₁₇Al₁₂. The solid solution is characterized by very small grains. They have almost spherical shape divided by fully divorced eutectic regions (Fig.6). The fully divorced eutectic is where the two eutectic phases are completely separate in the microstructure [1]. In AM50 alloy after die casting precipitations of Mg₁₇Al₁₂ phase are surrounded by α-Mg solid solution (Fig.7).
4. Conclusions

Based on the research results obtained, it has been found that:

1. The AM50 magnesium alloy in as ingot condition is characterized by a solid solution structure with partially divorced eutectic ($\alpha + \text{Mg}_{12}\text{Al}_1$) and precipitates of $\text{Mn}_5\text{Al}_6$ phase. The divorced eutectic areas and $\text{Mn}_5\text{Al}_6$ precipitates are placed both inside and on the grain boundaries.

2. The AM50 magnesium alloy after hot chamber die casting is characterized by a solid solution structure with fully divorced eutectic $\alpha + \text{Mg}_{12}\text{Al}_1$. Moreover, the occurrence of $\text{Mn}_5\text{Al}_6$ phase and some shrinkage porosity has been proved. The particles of $\text{Mg}_{12}\text{Al}_1$ phase are always much larger than $\text{Mn}_5\text{Al}_6$ precipitates and are located only on grain boundaries. The $\text{Mn}_5\text{Al}_6$ precipitates are distributed both inside and on the $\alpha$ solid solution grain boundaries.

Acknowledgements

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References