HEAT TREATMENT OF THE AL–ALLOY DIE-CASTINGS FOR THE AUTOMOTIVE INDUSTRY

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Abstract

Furnaces for the heat treatment of the alloys of the aluminium die-castings for the automotive industry require working conditions within very narrow temperature tolerances and therefore permanent and continuous temperature control. Their thermo-technical characteristics have a great influence on the product quality and costs.

Within the framework of our investigation the control temperature measurements through the entire heat treatment process of the testing charge of the alternator and pump castings of the AlSi7Mg0,3 aluminium alloy have been performed in the electric furnaces installed in the CIMOS foundry. At the same time, the temperature measurements of the testing charge and the atmosphere in the furnace were carried out respectively.

The efficiency and quality of the heat treatment were analysed by the mechanical testing and scanning electron microscopy (SEM).

1. INTRODUCTION

In cooperation with the slovenian automotive industry the control temperature measurements through the entire heat treatment process of the testing charge of the alternator and pump castings (\textbf{Figure 1}) of the AlSi7Mg0,3 aluminium alloy were performed [1,2].

\textbf{Figure 1.} The girder of the alternator and pump.

The girder is one of the so-called safety elements and for this reason it must have secured mechanical properties. All accompanying technical and production documentation must be kept for the period of 10 years. The progress of the girder manufacturing was taking place in the three technological sequence phases:

- die-casting,
- heat treatment with quenching, and
- ageing (isothermal annealing).
2. TECHNICAL DATA

The girder of the alternator and pump (Figure 1) was made from the aluminium AlSi7Mg0,3 alloy by die-casting. Its weight was 1.95 kg. The heat treatment of the castings of the aluminium AlSi7Mg0,3 alloy is prescribed by the EN 1676 standard [3]. The specified procedure of the heat treatment is presented in Table 1.

Table 1. The completed heat treatment procedure of the aluminium AlSiMg0,3 alloy according to the EN 1676 standard [3].

<table>
<thead>
<tr>
<th>Heat treatment</th>
<th>Solution treatment</th>
<th>Artificial ageing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating</td>
<td>Quenching medium</td>
</tr>
<tr>
<td>Time (h)</td>
<td>Temperature (°C)</td>
<td>Quenching medium</td>
</tr>
<tr>
<td>6</td>
<td>540</td>
<td>Cold water</td>
</tr>
</tbody>
</table>

The heat treatment of the castings, in which the process of heating, superheating, quenching and ageing (isothermal annealing) was included [4], was carried out in the hood-type annealing furnace and in the pit furnace respectively. The preheating of each casting in the furnace was enabled by their charging into the level-bucket (Figure 2), so the optimal heat transfer by the hot air circulation from the side to the middle of the bucket was possible [5].

Figure 2. The castings loaded into the cylindrical steel level-bucket (lifting of the level-bucket from the quenching vat).

The essential purpose of the heat treatment of the castings of the aluminium alloy was to improve their mechanical properties: tensile strength (Rm), elastic limit (Rp0,2), elongation (As) and hardness (HB).

The heating of the castings on the quenching temperature (540 °C) and the preheating on that temperature was carried out in the hood-type annealing furnace. Then the quenching with the water in the vat followed. In accordance with the EN 1676 standard the process was taking place by the uniform heating of the charge by the heating rate of 180 °C/h from the surrounding temperature to 540 °C. The homogeneity of the temperature of the atmosphere
and the charge in the furnace must be in the interval of $\pm 5 \, ^\circ C$, and prescribed time of the charge preheating on the temperature of $540 \, ^\circ C$ was 6 hours. The temperature of the quenching water in the vat must be in the interval between 20 and 70 $^\circ C$. Maximal time of the transport of the bucket with the castings from the furnace to the water was 12 seconds and then 2 minutes for holding it in the water. After the quenching the charge must "stand" in the air atmosphere at the ambient temperature in the dry and in the closed room at least 6 and maximally 92 hours respectively. Then the castings and the testing specimens must be charged into the hood-type annealing furnace, where the ageing was taking place. The prescribed ageing temperature of the whole charge of the castings was 160 $^\circ C$, allowed deviation was $\pm 5 \, ^\circ C$ and the ageing time was 6 hours.

3. TEMPERATURE MEASUREMENTS

The frequently tested measuring system in the engineer practice [6] with the following three basic elements was used to achieve the temperature measurements [7]:

- six coated Ni-NiCr thermocouples (five of them for measuring the charge temperature and one for the ambient temperature),
- the data acquisition modul (ADAM – 4018), and
- the results of the measurements were registered by the PC computer in the time intervals of 5 minutes.

Temperature profile of the test charge in the hood-type annealing furnace for the quenching is presented in Figure 3, and that one in the pit furnace in Figure 4.

![Figure 3](image)

**Figure 3.** Temperature profile of the testing charge in the hood-type annealing furnace.

Descending time of the bucket to the cooling water in vat was 7.5 seconds. The temperature of the water before quenching was 20.7 $^\circ C$, and after that 26.8 $^\circ C$.

Measured temperatures of the heating and preheating of the testing charge of the castings in the hood-type annealing furnace were practically all the time within the prescribed values. According to the regulation parameters the quenching process has been performed optimally. Due to the too high heating rate of the charge in the pit furnace, the measured temperatures exceeded the upper tolerance limit of 20 $^\circ C$ and also more.
4. MECHANICAL PROPERTIES OF THE HEAT TREATED CASTINGS

According to the regulations the investigation of the mechanical properties of the alloy has been taking place after the heat treatment, the extra cast testing specimens were cast separately in the special prepared mould.

The mechanical properties of the testing specimens of the AlSi7Mg0,3 alloy after the heat treatment according to the CIMOS foundry internal standard for the automotive components are presented in Table 2.

Table 2. The prescribed mechanical properties of the alloy after the heat treatment.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>tensile strength (Rm)</td>
<td>&gt; 280 MPa</td>
</tr>
<tr>
<td>elastic limit (Rp0.2)</td>
<td>&gt; 190 MPa</td>
</tr>
<tr>
<td>elongation (A5)</td>
<td>&gt; 10 %</td>
</tr>
<tr>
<td>hardness</td>
<td>&gt; 80 HB</td>
</tr>
</tbody>
</table>

The measurements of the elastic limit, tensile strength and the elongation were carried out on the universal tensile testing machine INSTRON 1255 with the testing force range of 50 kN. On the basis of the experimental results the following mean values of the tensile strength, elastic limits and elongation were calculated: $R_m = 331.1$ MPa, $R_{p0.2} = 283.2$ MPa and $A_5 = 10.54\%$.

The values of hardness (HB) of all 12 test specimens within the range of 82 to 97 HB were measured on their surfaces, and they all were exceeding the prescribed value of 80 HB. In case of the testing charge the results of the mechanical testing were satisfying despite of the temperature deviation outside of the prescribed tolerance range.

5. METALLOGRAPHIC ANALYSIS

The metallographic analyses of the castings were done by the electron scanning microscope (SEM) JEOL 5610 under three phases of the heat treatment:

- after casting (heat untreated casting),
- after quenching, and
- after ageing (isothermal annealing), (heat treated casting).

Figure 4. Temperature profile of the testing charge during the ageing process in the pit furnace.
The micrographs of the castings on the different stages of the heat treatment with the magnification of 300 x are presented in Figure 5.

Figure 5. Microstructure of the casting of the AlSi7Mg0,3 alloy after the casting (left), and the ageing (right).

6. CONCLUSIONS
Within the investigation the temperature calibration of the furnace for the heat treatment of the die-castings (girders) of the aluminium AlSiMg0,3 alloy, which is used for the automobile industry, was performed.

The tested and reliable measuring system was applied for the temperature measurements. The results of the achieved measurements during the heating and preheating of the testing charge of the castings in the hood-type annealing furnace were all the time in accordance with the prescribed values. The quenching process was carried out optimally regarding to the prescribed parameters. During the ageing process in the pit furnace the measured temperatures exceeded the upper tolerance limit for 20 °C and also more, due to the too high heating rate of the charge.

According to the prescribed heat treatment the mechanical properties of the castings of the AlSi7Mg0,3 alloy are in good agreement. All the results of the mechanical testing performed on the testing specimens exceed the required minimal values.

7. BIBLIOGRAPHY
3. BS EN 1676: Aluminium and Aluminium Alloys – Specifications.