T6 Heat Treatment of Hypo-eutectic Silumins in Aspect of Improvement of $R_m$ Tensile Strength

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Obtained 28.06.2012; accepted in revised form 05.09.2012

Abstract

Improvement of properties of silumins in scope of classic methods is connected with changes in morphology of silicon precipitation through: process of modification of alloy, maintaining a suitable temperature of overheating and pouring into moulds, as well as perfection of heat treatment processes. Obtained structure of casting have a direct influence on mechanical and technological properties of machinery parts, and therefore, usage of knowledge on crystallization to control of crystallization’s kinetics of castings in order to optimize obtained structure and introduction of modern methods of heat treatment, enabling considerable improvement of mechanical and technological properties, becomes an important factor.

Dispersion hardening with soaking of alloy near temperature of solidus, consisting in heating of poured specimens to temperature of solutioning, keeping in such temperature, cooling down in cold water (20 $^\circ$C), and next operation of artificial ageing have effect on change of tensile strength $R_m$ of a selected hypo-eutectoid silumin. Selection of suitable parameters of dispersion hardening is condition of obtainment of positive results in terms of improvement of tensile strength $R_m$ and has effect on its economic aspects.

Keywords: Heat treatment, Modification, ATD, Tensile strength $R_m$

1. Introduction

The most common casting alloy produced on base of aluminum is silumin, i.e. alloy of Al-Ši system. It is connected with wide series of operational and technological advantages of this group of alloys [1-4].

Methods of continuous selection of alloying additives (with use of attainments of synthesis of alloys) [2, 4-8], modification of silumin structure [1-3, 7-12] or modern technologies of their heat treatment [2-3, 13-17] belong to the main areas of investigations aimed at improvement of mechanical and technological properties of silumins.

Heat treatment of aluminum alloys, aimed at growth of their strength consists mainly in dispersion hardening (precipitation hardening), i.e. on successive solutioning treatment of solid solution and ageing. The main condition, which constitutes basis to precipitation hardening is reduction of limiting solubility of alloying constituents in solid state together with reduction of temperature [2, 3].

Precipitation of a dissolved constituent from supersaturated solution $\alpha$ during cooling stage leads to change of alloy properties. Precipitation of phase from supersaturated solid solution is obtained through annealing in temperature in which solid solution has got equilibrium structure, and next cooling
down to lower temperature, in which solid solution is metastable, while mixture of two phases constitutes a stable structure.

Generally known methods of heat treatment, connected with keeping of a castings in constant temperature during predetermined period of time result in improvement of mechanical properties such as: tensile strength $R_m$ and hardness HB, with simultaneous worsening of plasticity ($A_5$, KCV). Due to fact that the most often growth of strength of alloy after heat treatment is accompanied by reduction of plasticity, optimal composition of the alloy should be selected depending on a given application of the alloy.

Solution in such case could be implementation of a new methods of heat treatment like for instance thermo-cyclic heat treatment (TCO) consisting in multiple heating and cooling of a products [15], silicon spheroidization (Silicon Spheroidization Treatment - SST) [16-17] or implementation of optimization methods to select parameters of the process (temperature and duration of solutioning and ageing treatments) based on analysis of their effect on change of mechanical and technological properties of alloys [13,14,18].

Implementation of ATD method, used for many years to registration of crystallization of metals and alloys, both in research work and to quality control of alloys within industrial environment [1-3,6,10,14,19] enables selection of temperature ranges of solutioning and ageing treatments.

2. Methodology of the research

To the tests were used the following alloys:
- EN AB-42000 (AlSi7Mg),
- EN AB-43300 (AlSi9Mg),
- EN AB-46000 (AlSi9Cu3(Fe)).

To prepare specimens to the testing one melted the alloys in electric resistance furnace in temperature of about 720°C. The next treatment consisted in refining of the investigated alloys. To the refining on used Rafal 1 preparation in quantity of 0,4% mass of charge.

Refined alloys, after removal of oxides and slag from metal-level, were modified with AlSr10 master alloy in quantity of 0,4% mass of charge (0,04% Sr) for the EN AB-42000 alloy; 0,6% mass of charge (0,06% Sr) for the EN AB-43300 alloy; 0,5% mass of charge (0,05% Sr) for the EN AB-46000 alloy.

Modified alloys were poured into metal mould, enabling obtainment of standardized specimens of alloys used to tests of mechanical properties. The metal-mould was heated to temperature of 250°C.

Poured specimens underwent treatment of dispersion hardening with soaking of the alloy in temperature near solidus. The treatment consisted in heating of the poured specimens to temperature of solutioning, keeping in such temperature, and cooling down in cold water (20 °C), and next treatment of artificial ageing. Temperature ranges of solutioning and ageing treatments were selected basing on analysis of recorded curves from ATD method. Process of solidification and melting of the alloy was recorded with use of Crystaldimat analyzer.

The ATD analysis was performed for the alloys refined and modified with strontium. Diagrams of course of crystallization of refined and modified alloys with marked temperature ranges of solutioning and ageing treatments are shown in the Figs. 1-3.
In the Table 1 are presented parameters of heat treatment parameters selected on base of values from melting curved obtained from ATD method (Figs. 1-3).

Table 1. Heat treatments parameters of the investigated alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>solutioning temperature [°C]</th>
<th>solutioning time [h]</th>
<th>ageing temperature [°C]</th>
<th>ageing time [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN AB-42000</td>
<td>t₁₁ = 465</td>
<td>0,5</td>
<td>t₁₁ = 165</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>t₁₂ = 520</td>
<td>1,5</td>
<td>t₁₂ = 235</td>
<td>5</td>
</tr>
<tr>
<td>EN AB-43300</td>
<td>t₃₁ = 550</td>
<td>3</td>
<td>t₃₁ = 325</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>t₃₂ = 545</td>
<td>1,5</td>
<td>t₃₂ = 235</td>
<td>5</td>
</tr>
<tr>
<td>EN AB-46000</td>
<td>t₈₁ = 485</td>
<td>0,5</td>
<td>t₈₁ = 174</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>t₈₂ = 510</td>
<td>1,5</td>
<td>t₈₂ = 240</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>t₈₃ = 545</td>
<td>3</td>
<td>t₈₃ = 320</td>
<td>8</td>
</tr>
</tbody>
</table>

After performed heat treatment, specimens to the strength tests were prepared according to PN-88/H-88002 standard, while static strength tests were performed with used of ZD-20 tester.

3. Description of obtained results

3.1. EN AB-42000 alloy

Average value of the tensile strength Rₘ obtained for raw alloy (from pig sows) amounted to 190 MPa. A slight change of tensile strength Rₘ (199 MPa) occurred after the refining. Performed treatment of modification of the investigated alloy enabled obtainment of average tensile strength Rₘ having value of 203 MPa. After performed heat treatment, tensile strength amounted to from 156 to 328 MPa.

In the Fig. 4 are shown average values of the tensile strength Rₘ for the EN AB-AlSi17Mg alloy after the heat treatment.

Making comparison of obtained average parameters from the test for the alloy after heat treatment, and the alloy without heat treatment, one confirmed growth of the tensile strength Rₘ up to 65% (configuration no. 25, Fig. 4) comparing to modified alloy without heat treatment. The highest value of tensile strength Rₘ = 328 MPa was obtained for: solutioning temperature of 550 °C, solutioning time of 3 h, ageing temperature of 165 °C and ageing time of 8 h.

The highest values of the tensile strength Rₘ were obtained for the following parameters of heat treatment process:
- solutioning temperature: 520 – 550°C,
- solutioning time: 1,5 – 3 h,
- ageing temperature: 165°C,
- ageing time: 5-8 h.

3.2. EN AB-43300 alloy

Tensile strength Rₘ obtained for the refined alloy amounted to from 159 to 190 MPa. Performed modification of the investigated alloy enabled obtainment of the tensile strength Rₘ having value of 196 - 230 MPa. After performed heat treatment, the tensile strength amounted to from 220 to 326 MPa.

In the Fig. 5 are shown average values of the tensile strength Rₘ for the EN AB-AlSi9Mg alloy after the heat treatment.

Making comparison of obtained average parameters from the test for the alloy after heat treatment, and the alloy without heat treatment, one confirmed growth of the tensile strength Rₘ up to 60% (configuration no. 25, Fig. 5) comparing to modified alloy without heat treatment. The highest value of tensile strength Rₘ = 326 MPa was obtained for: solutioning temperature of 560 °C, solutioning time of 3 h, ageing temperature of 180 °C and ageing time of 8 h. The highest values of the tensile strength Rₘ were obtained for the following parameters of heat treatment process:
- solutioning temperature: 545 ÷ 560°C,
- solutioning time: 0.5 do 1.5 h,
- ageing temperature below 200 °C,
- ageing time: 5 to 8 h.

Fig. 4. Change of Rₘ tensile strength of the investigated alloy for individual configurations of the testing plan

Fig. 5. Change of Rₘ tensile strength of the investigated alloy for individual configurations of the testing plan
3.3. EN AB-460000 alloy

Tensile strength obtained in case of raw alloy (from pig sows) amounted to from 213 to 243 MPa. After refining there was observed a slight change of tensile strength $R_m$ (246-249 MPa). Performed treatment of modification of the alloy has enabled obtaining of the tensile strength $R_m$ in limits of 248-272 MPa.

Obtained results show at distinct growth of the tensile strength after refining and modification, comparing with mechanical properties of the raw alloy (from pig sows) and refined alloy. After performed heat treatment, tensile strength amounted to from 114 to 408 MPa. The highest value of tensile strength $R_m=408$ MPa was obtained for: solutioning temperature of 510 °C, solutioning time of 1.5 h, ageing temperature of 175 °C and ageing time of 2 h (configuration no. 4, Fig. 6).

In the Fig. 6 are shown average values of the $R_m$ tensile strength for the EN AC-AlSi9Cu3(Fe) alloy after the heat treatment.

![Fig. 6. Change of $R_m$ tensile strength of the investigated alloy for individual configurations of the testing plan](image)

The highest values of the tensile strength $R_m$ were obtained for the following parameters:
- solutioning temperature: 485, 510 °C,
- solutioning time: 1.5 h,
- ageing temperature 175 °C,
- ageing time to 2 h.

4. Conclusions

The substance of performed investigations concerned determination of an effect of temperature and duration of solutioning and ageing treatments of selected hypo-eutectic silumins in aspect of improvement of tensile strength $R_m$.

Performed heat treatment, with soaking of the alloy in temperature near solidus, followed by cooling in cold water (20 °C), artificial ageing with air-cooling resulted in growth of tensile strength $R_m$ of the investigated alloys.

Selection of suitable parameters of solutioning and ageing treatments constitutes condition necessary to improvement of the tensile strength $R_m$.

References