Influence of technological factors on eutectic silicon morphology in Al-Si alloys

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Abstract
From the background about Al-Si alloys modifying from eutectic silicon morphology and mechanical properties relation point of view is at solving of chosen technological problems used structural analysis and Si morphology quantification. There were solved two concrete problems: parameters of solution annealing AlSi9Cu3 alloy and confirming of laser treatment influence on AlSi7Mg0.3 alloy structure. In both cases have material heating caused spheroidization of eutectic silicon. Optimal regime of AlSi9Cu3 alloy (515 °C/4 hrs.) solution annealing was confirmed based on structural analysis, which have achieved fine globular silicon particles segregation and structural changes study at AlSi7Mg0.3 alloy after laser treatment showed improving of mechanical properties, proved also with metallography analysis. Modern methods of structure analysis application enable to spread present knowledge’s in area of technological research.

Key words: metallography, Al-Si alloys, silicon morphology, heat treatment, laser treatment

1. Introduction
Mechanical properties of cast Al-Si alloys are significant affected by eutectic silicon shape in structure. From these reason are alloys modified with proper elements (e.g. Na, Sr, Sb, and so) [1, 2, 3, 4, 5]. The melt is then solidifying with higher undercooling and is created fine eutectic with shape positive endings of single silicon particles [6, 7]. The eutectic silicon particles shape is possible to study with SEM using of so called deep etching and to quantify it’s with shape factor. Shape factor usually characterize globularity grade (circle cross section has higher value and rest of shapes have lower value, depended on drive factor). In cases when with decreasing phase globularity is increasing its negative influence on mechanical properties from reason of stress concentration (e.g. graphite in cast iron, also silicon in Al-Si alloys) are very good experience, especially with using of shape factor $M = 4\pi A/P^2$, where $A$ is area and $P$ is particle circuit. Particles with almost perfect circle shape have shape factor $M = 1$, for other shapes is $M<1$ [8, 9].

The article is consider with structural background study of properties of chosen Al-Si alloys, with accent on eutectic silicon morphology changing at solution heat treatment [10, 11] and at surface laser treatment [12, 13]. There are presented results achieved during solving project VEGA 1/0208/08, focused on „Properties optimizing of hardened Al – alloys on casts for automotive industry, made of secondary aluminium.“

2. Experimental methods
Hardened aluminium cast alloys AlSi9Cu3 and AlSi7Mg0.3 (tab.1) were used as an experimental material, produced from so called secondary aluminium, which is achieved by recycling of Al-scrap metal and treated Al-waste. Both alloys were gravity cast into mold. Before casting (at temperature 680°C) were casts refined of refine salt AlCu4B6.
### Tab. 1. Chemical composition of experimental Al-Si alloys

<table>
<thead>
<tr>
<th></th>
<th>Wt. % Si</th>
<th>Mg</th>
<th>Ti</th>
<th>Mn</th>
<th>Cu</th>
<th>Sr</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSi9Cu3</td>
<td>10.7</td>
<td>0.27</td>
<td>0.03</td>
<td>0.22</td>
<td>2.4</td>
<td>0.01</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>AlSi7Mg0.3</td>
<td>7.1</td>
<td>0.35</td>
<td>0.10</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.11</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Fig. 1 Influence of temperature and holding time of solution annealing on quantitative structural characteristics of AlSi9Cu3**

AlSi9Cu3 alloy was none modified and also none inoculated. There were cast semi products, which were machine treated for tensile test specimens. The bars were heat treated at temperatures of solution annealing 505, 515 a 525 °C ± 3 °C with holding time 0, 2, 4, 8, 16 and 32 hrs. Solution annealing was followed quick cooling in water with temperature 40 °C and natural ageing for 24 hrs. On heat treated specimens were microstructure evaluated and chosen mechanical properties were confirmed.

From AlSi7Mg0.3 alloy were cast bars and machined to specimens 10 x 10 x 50 mm. These bars were treated with CO2 laser beam TRUMPF TLF 6000 with specimens cooling on air. The laser parameters were as follows: performance 1900 W, diameter of laser beam 6 mm, step 500 mm/min. Laser treatment were done in Centrum Laserowych Technologii Metali, Politechniki Świętokrzyskiej, Kielce.

Microstructures of both experimental alloys were quantified on metallographic specimens etched with 0.5 % HF or Dix-Keller, with using of software for quantitative analysis NIS Elements. Eutectic silicon morphology was observed in scanning electron microscope (SEM) after deep etching 36 % HCl/120 s. [7, 11].

### 3. Experimental results

#### 3.1. Influence of solution treatment on structure and properties of AlSi9Cu3

Structure of none heat treated alloy AlSi9Cu3 is created with dendrites of α-phase, eutectic (crystals Si in α-phase) and intermetallic phases of various chemical composition. Standard microstructure analysis was completed about dendrite evaluation; DAS factor and quantitative evaluation of silicon particles average area. Results for DAS factor evaluation are showed on fig. 1a. From achieved relation results that applying of heat treatment comes to decreasing of DAS factor, which is highest at temperature of solution annealing 515°C and holding time 2 hrs. The highest value of DAS factor were measured at temperature 525°C, where diffusion is easier and cause whole structure coarsening. With heat treatment application is area of silicon particles significantly decreasing (fig. 1b).

The eutectic silicon morphology, which was in relation to temperature and holding time of solution annealing changed, was studied with SEM on deep etched specimens (fig. 2). In none heat treated starting stage has silicon shape of various direction formed hexagonal plates, typical for none modified structures (fig. 2a). Heat treatment at temperature 505 °C is not sufficient for spheroidizing of eutectic silicon, which can be observed in partially rounded, shorter segment plate shape with local appearing of bars. Optimal solution annealing temperature for secondary AlSi9Cu3 cast alloys is 515 °C, when has eutectic Si fine, perfectly rounded shape and bars of eutectic Si are obvious partially (fig. 2b). The temperature of solution annealing about 525°C cause perfect spheroidization of eutectic Si, but after 4 hrs. leads to globular Si particles significant coarsening (fig. 2c).

After annealing at 515°C/4 hrs, which has represents a regime where optimal structural factors are achieved even the best mechanical properties were achieved (fracture limit has increased from 211 MPa in starting stage, to 273 MPa and hardness from 98 to 122 HBS [10, 11]).

#### 3.2. Influence of laser treatment on structure of AlSi7Mg0.3

For experimental verifying of laser treatment influence there were cast none modified and modified (up to 0.04 % Sr) specimens. Modifying with Sr has positively affected of eutectic silicon morphology and reason of that also mechanical properties were better on laser none treated specimens.
Tab. 2. Results of eutectic silicon morphology evaluation after laser treatment

<table>
<thead>
<tr>
<th>% Sr</th>
<th>Size (area) of silicon particles, μm²</th>
<th>Shape factor of silicon, M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TN</td>
<td>PV</td>
</tr>
<tr>
<td>0.00</td>
<td>1.023</td>
<td>0.252</td>
</tr>
<tr>
<td>0.04</td>
<td>0.918</td>
<td>0.370</td>
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</table>

TN – structure non effected by heat, PV – transfer layer, LV – surface layer remelted by laser.
None modified alloy has tensile strength $R_m=180$ MPa and ductility $A_5=6.9\%$; after modifying with 0.04 $\%$ Sr were mechanical properties increased, tensile strength to 198 MPa and ductility to 20.1 $\%$.

In the layer treated with laser comes in stage none modified even modified to significant refinement of $\alpha$-phase because of laser remelt and high under cooling in reason of intensive heat transfer. In both alloys, modified and none modified, is possible to see eutectic silicon divarication (i.e. shaving of originally coarse Si crystal plates with following cleavage and gradual creation of separated twigs) and followed spheroiding of such these created eutectic silicon twigs (fig. 3).

Measuring of shape factor $M$ with using of software NIS Elements has confirmed and specified structure evaluation, mentioned above (tab. 2). Laser treatment in modified and none modified alloy has positively affected eutectic silicon shape (refinement of particles and its higher globularity), whereby this effect was more significant in heated layer than in layer remelted, however, with refinement of $\alpha$-phase.

From fracture areas of laser treated specimens, broken at impact bending test, were prepared specimens for microfractography analysis. On the area of none modified specimens at heat none affected area are major transcristaline cleavage facets of eutectic silicon (fig. 4a). Breaking of $\alpha$-phase is at braking area less significant, but there are partially visible parts of transcristaline ductile breaking in form of hole at plastically transformed ridges. In layer, which was treated by laser is visible refinement of $\alpha$-phase and partial spheroiding of eutectic silicon because of remelt and quick cooling. In comparing with heat none affected area, the size of cleavage facets is decreasing and ratio of ductile braking with hole has increased (fig. 4b). Fracture areas of modified with 0.01 a 0.04 $\%$ Sr are characterized by transcristaline ductile breaking with significant ratio of small shallow holes and plastically transformed ridges of $\alpha$-phase (fig. 4c). Fracture areas of modified alloys in laser treated layers (fig. 4d) are almost the same as in fracture areas in heat none affected areas.

4. Conclusion

In this article were presented results of chosen physical-metallurgical problems of materials for high quality casts with accent to using of quantitative description eutectic silicon morphology in Al-Si alloys.

There was given an optimal regime of AlSi9Cu3 alloy solution annealing: temperature 515 °C, holding time 4 hrs. Presented regime caused optimal structure changes from monitored alternates: eutectic silicon spheroidizing (without particles growth) and lowest value of DAS-factor. These changes have brought important increasing of mechanical properties.

Based on achieved facts about laser treatment influence on eutectic silicon morphology and microfractographic analysis is possible to suppose that in none modified alloys AlSi7Mg0.3 is in laser treated layer increasing toughness in comparing with heat none affected stage because of eutectic silicon globularity increasing and reason of that even ratio of ductile braking in fracture area. There is not higher toughness in modified alloys achieved with modifying.

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References