Effect of modifying process on mechanical properties of EN AC-43300 silumin cast into sand moulds

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Abstract

Significance of alloy modification in course of casting process is the most explicitly visible on example of Al-Si alloys. Broad application of these alloys in foundry industry has become possible after invention of a method which changes solidification form of Al-Si eutectic mixture. Such primarily thick, acicular shape of silicon crystals becomes changed into fine and compact structure due to introduction of a small quantity of modifier to liquid alloy. The paper presents an attempt of assessment of melting and modification with strontium effects on mechanical properties of EN AC-43300 alloy cast into sand moulds. Obtained results concern selection of optimal quantity of strontium additive in aspect of obtained mechanical properties ($R_m$, $A_5$, KCV, HB). Effect of strontium additive on change of mechanical properties of the investigated alloy was presented in graphical form. Further investigations shall be connected with determination of an effect of strontium additive on mechanical properties of the alloy after solution heat treatment and ageing treatment.

Keywords: Aluminum alloys, Mechanical properties, Crystallization

1. Introduction

Aluminum-silicon alloys are widely used in components where good strength and light weight are required or where corrosion resistance and good castability are needed. Aluminum-silicon casting alloys are essential to the automotive, aerospace and engineering sectors. Al-Si alloys allow complex shapes to be cast; however the silicon forms brittle needle-like particles which reduce impact strength in cast structures. As an additive to Al-Si casting alloys, strontium improves strength, enhances mechanical properties and disperses porosity as it modifies the eutectic structure.

Proper preparation of the liquid alloy effects significantly on quality and properties of produced alloys. Essential effect on mechanical properties can be obtained due to interaction in direction of production of fine-grained structure with uniform distribution of structural constituents [1, 2]. Fine-grained structure favors increase of tensile strength, elongation, impact strength, hardness and improved machinability of the alloy. Suitable methods of the modification are the most effective means, accessible in foundry industry, to obtain advantageous, fine-grained structure of cast materials.

Meaning of the modification can be interpreted as „introduction to liquid metal a slight additives to change structure of the casting“ [3]. Sometimes, one assumes that introduction of the modifiers differs from introduction of alloy additions with concentration of the modifiers, which are limited by max contents of 0,1% atom. [3]. The most often, presence of small quantities of elementary substances in liquid metal (in chemically free or bounded form) can be characterized by specified time of reaction on crystallization process. If after melting operation – in some cases repeated several times, or after other refinement treatments of the liquid metal, obtained result of structure’s change disappears after some time we can tell about modification; if that
effect shows some stability – it tells about introduction of alloy additions. In many cases, the term „modifier” is identified as alloying „micro-additive” or „micro-constituent” [3].

There are existing numerous hypotheses, trying to explain phenomena occurring during modifying processes [4-8] differing each other in such way that it is difficult to formulate a single, coherent theory of such process. Finally, important is positive effect of the modifying process, and hence refinement of the structure and improvement of mechanical and technological properties of the alloy, connected with such refinement.

Moreover, effect of technological conditions on modifying process can not be neglected (proper selection and batching of the modifier, time elapsed from modification to solidification of the alloy), because even the best selected modifier can not fulfill its task in not-correctly selected technological conditions.

Modifying process of the silumins, due to its importance in production a castings is a topic widely discussed by various authors [1-4, 9, 7, 11-14].

Modification with strontium has been known since 1921 /Pacz’s patent/ and spread out only by W. Thiele in 1966 [10]. Thiele showed that effect of modification with strontium is similar to modification with sodium, but is more long-lasting. Comparing to sodium, strontium can be characterized by better stability – drop of its contents in modified, liquid alloy proceeds more slowly.

Strontium is the preferred modifier in current use. Addition of strontium in the near-eutectic Al–Si alloy not only results in a modification of the eutectic silicon, but also an obvious increase in the amount of α-Al dendrites and promotion of columnar growth of these dendrites, increasing both the strength and ductility of the alloy considerably.

Structure of Al–Si eutectic mixture after correct modification is typical of minimal interfacial spacing of eutectic mixture, rounding of their outlines and higher portion of dendritic crystals of plastic phase α.

One from the main issues connected with casting of aluminum-silicon alloys is determination of a suitable quantity of the modifier, necessary to required mechanical and physical properties.

The alloys are rather sensitive to small changes in chemical composition, and the modifying process must be carried out in a very particular manner to obtain the best results. It was necessary to learn how to control the modifying process.

In practice, quantity of introduced Sr amounts to about 0.04-0.07% [2]. However, there are existing different opinions concerning optimal additives of strontium introduced to silumins, which should assure complete and stable effect of structure modification, and owing to it – high mechanical properties.

Too high contents of strontium in the modified silumin is not required, because except intensive susceptibility of the alloy to gassing, in its structure can appear releases of brittle Al₁SrSi₃ phase, confirmed during metallographic tests as early as above 0.06% of Sr contents, what deteriorates mechanical properties of the castings [11].

2. Methodology of the research

The EN AC-43300 (AK9) alloy is characterized by very good casting properties and good machinability, workability and corrosion resistance. Is used for big, heavy loaded castings having complicated shapes and high strength.

Alloy with chemical constitution shown in the Table 1 was used to the tests.

Table 1. Chemical composition of the EN AC-43300 alloy

<table>
<thead>
<tr>
<th>Si</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Zn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6 %</td>
<td>0.46%</td>
<td>0.38%</td>
<td>0.02%</td>
<td>0.08%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Ti</td>
<td>Pb</td>
<td>Cu</td>
<td>Mg</td>
<td>Al</td>
<td></td>
</tr>
<tr>
<td>0.014%</td>
<td>0.013%</td>
<td>0.015%</td>
<td>0.023</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first stage of the tests consisted in determination of the most advantageous, with respect to mechanical properties, temperature of pouring into mould.

The alloy was melted in electric resistance. Treatments of the refinement were performed with use of Rafal in quantity of 0.3% of metallic charge mass. Tested alloy was poured into sand mould. The Fig. 1 shows shape and dimensions of the casting with marked specimens used in course of the strength tests.

Fig. 1. Casting with specimens used in the testing: 1) specimens to strength test, 2) specimens to impact strength

Pouring into moulds temperature for the investigated alloy changed in range from 680°C to 820°C.

In Figs 2-5 is presented an effect of change of pouring into moulds temperature on mechanical properties of AK9 alloy.

Fig. 1. Casting with specimens used in the testing: 1) specimens to strength test, 2) specimens to impact strength
After determination of optimal pouring temperature (760°C) for the tested alloy one commenced the tests aimed at determination of optimal, with respect to mechanical properties, quantity of the strontium.

Quantity of the strontium introduced in form of master alloy amounted from 0,02 to 0,5%.

3. Description of achieved results of own researches

In the Table 2 are shown mechanical properties obtained during performed tests.

<table>
<thead>
<tr>
<th>( R_m ) [MPa]</th>
<th>KCV [kJ/m(^2)]</th>
<th>( A_5 ) [%]</th>
<th>HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 - 175</td>
<td>15,1 - 36,5</td>
<td>2,7 – 3,4</td>
<td>57,5 – 60,5</td>
</tr>
</tbody>
</table>

Additive of strontium in range of 0,02 – 0,04 % resulted in growth of the strength up to 175 MPa. In case of 0,5% of strontium, growth of modifier’s quantity added to the alloy resulted in reduction of the strength up to 155 MPa (Fig 6).
Maximal elongation, $A_5 = 3.4\%$, of the tested alloy was obtained after modification with additive of strontium of 0.04 to 0.06%. Further growth of modifier contents resulted in reduction of the elongation (Fig. 7).

The highest hardness (60.5) of the alloy was obtained after modification with additive of 0.02% of strontium. Growth of strontium additive did not result in a considerable change of alloy’s hardness.

Additive 0.02% of strontium resulted in growth of impact strength up to 32.4 kJ/m². Further growth of strontium additive did not have any considerable effect on change of the impact strength. Only 0.5% of strontium additive caused reduction of the impact strength (Fig. 8).

4. Conclusions

Performed tests have enabled specification of the most advantageous, with respect to obtained mechanical properties, additive of strontium (0.02 – 0.04%) for the EN AC-43300 alloy, cast into sand moulds.

Continuance of the test shall be connected with determination of an optimal, with respect to mechanical properties, additive of strontium for a heat treated alloy.

References