

## MODIFICATION OF THE EN AC-42000 ALUMINIUM ALLOY WITH USE OF MULTICOMPONENT ELECTROLYSIS OF SODIUM SALT

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Preliminary Note - Prethodno priopćenje

The present paper discusses results of research concerning the process of continuous modification of the EN AC-42000 (AlSi7Mg) alloy with sodium, based on electrolysis of sodium salts, occurring directly in a melting pot with the liquid alloy. Sodium ions formed as a result of dissociation of the sodium salt and the electrolysis are “transferred” through walls of the retort made from solid electrolyte. Upon contact with the liquid alloy, as a cathode, sodium ions are transformed into atomic state, modifying the alloy. As a measure of the extent of the alloy modification impact strength, elongation  $A_5$  and analysis of the microstructure have been obtained, which confirmed the achievement of modification of the alloy under analysis.

*Key words:* aluminium alloy, electrolysis, modification, mechanical properties

### INTRODUCTION

Silumins belong to the most common group of casting alloys. Their size, shape and method of distribution of hard and brittle crystals of silicone  $\beta$  (Si) in plastic groundmass of solid solution  $\alpha$  (Al) are the features that have a significant influence on their mechanical properties. In order to improve (modify) the structure of these alloys, i.e. to achieve fragmentation of the structure, technological treatments are used which involve introduction of small quantities of various metallic elements, known as modifiers to these alloys, e.g. Na, Sb, Sr, P, Ti, La, Ce, Y [1-4], i.e. modification of the alloy aimed at improvement of its mechanical properties, such as elongation and impact strength [5,6].

So far, there has not been developed a single, general modification theory; instead, there exist numerous hypotheses attempting to describe phenomena connected with alloy modification. These include several groups: hypotheses connected with limitation of crystal growth rate; hypotheses describing conditions for creation of numerous, new, heterogeneous nuclei of crystallization; molecular energy hypotheses [7,8].

Historically, sodium belongs to the oldest, the most commonly used within the industry, and the most effective modifiers for hypoeutectic and peritectic alloys [2,9]. Sodium makes nucleation of silicone crystals more difficult, which results in over-cooling of eutectic crystallization and transformation of irregular lamellar eutectic mixture  $\alpha+\beta$  into eutectic mixture with a fibrous structure, which is connected with considerable

reduction of interfacial distance and a distinct transformation of eutectic crystals of the silicone [10]. This modifier is introduced into a metal bath in a metallic form, or in the form of chemical compounds containing sodium. However, regardless of the form in which the modifier is introduced to the metal bath, its action is relatively short (about 15-20 minutes), mainly due to its evaporation from the metal bath.

Application of the continuous modification technology can enable elimination of the necessity of repeated modification treatments and resulting stoppages in production cycle of components mostly ones cast in metal moulds.

The use of the phenomenon of electrolysis and a ceramic material (solid electrolyte) with high ionic conductance of sodium ions in high temperatures [11] is the basis of this process. Such materials include sodium “beta-alumina”, accessible in form of thin-walled pipes (with various dimensions), rods, discs and plates. “Beta-alumina” is produced with the use of the electrophoresis method, and it contains 90-95 % phase  $\beta$  and about 0,5 %  $\text{Na}_2\text{AlO}_2$ , and is stabilized with lithium [11]. It is also possible to stabilize the ceramics with magnesium or zirconium. Products made on the basis of „beta-alumina” are durable, semi-crystalline ceramic materials, in which movable ions of Na, K, Ag, H, Pb, Sr and Ba [12,13] can be implanted.

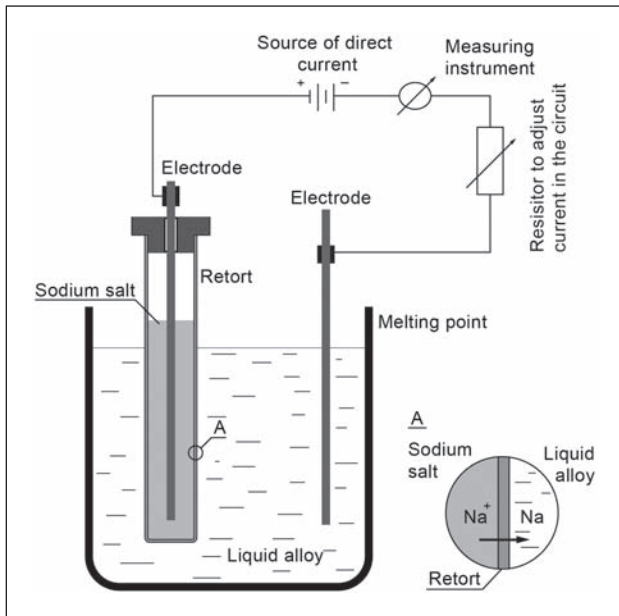
Sodium salt placed in a retort produced from a solid electrolyte, as a result of the application of DC voltage, undergoes dissociation, and next electrolysis. The sodium salt connected to a source of electric current through a graphite electrode or an electrode made from stainless steel serves as an anode. Liquid sodium salt connected to a source of electric current through a graphite elec-

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trode acts as an anode. Sodium ions generated as a result of dissociation and electrolysis are “transferred” through walls of the retort, and as a result of contact with the liquid alloy are passing to atomic state, thus modifying the alloy.

**EXPERIMENTAL METHOD**

Hypoeutectic EN AC- 42000 (AlSi7Mg) alloy was used in the tests. The alloy under analysis was melted in a ceramic melting pot placed in an electric resistance furnace. The diagram of the test stand is shown in the Figure 1.



**Figure 1** Scheme of the test stand

Sodium salt was placed in a retort produced from “beta-alumina“-based material. As a result of applied DC voltage it undergoes dissociation, and next electrolysis. Elements which provide flow of electric current are two electrodes: the first one immersed in liquid salt (anode), the second one immersed in liquid alloy (cathode). In course of the testing one used one-sided closed retort made from the “beta-alumina”, stabilized with zirconium (type B2), manufactured by Ionotec Ltd Company.

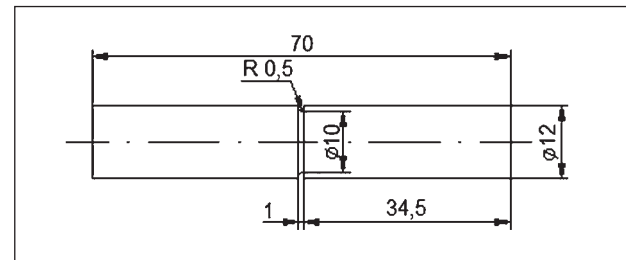
As the material of the anode (source of sodium ions) ternary and pentanary salts consisting of the following chemical compounds were used:

- salt I – NaCl, MgCl<sub>2</sub>, KCl,
- salt II – NaNO<sub>3</sub>, NaCl, KCl, Mg<sub>2</sub>Cl, Na<sub>2</sub>CO<sub>3</sub>,

After filling the retort with salt and after the installation of the feeding system to reduce the possibility of the retort cracking during its immersion in the liquid alloy, the retort was placed for several minutes directly above the metal-level overheated to a temperature of 690 °C. After immersing the retort filled with salt, and melting the salt, the electric circuit was closed, while the current intensity was fixed at the level of 5 A. The

duration of the modification treatment was depended on the quantity of the melted material (25 kg of the alloy), from which samples for impact strength and elongation tests were cast, and on the quantity of salt in the retort, connected with the rate of its consumption.

Cast samples for impact strength tests and elongation tests were produced every 20 minutes. Elongation A<sub>5</sub> of the samples was determined after a static tensile test performed on a ZD-20 tester according to the EN ISO 6892-1:2010 standard. The samples for impact strength tests were prepared according to Figure 2.

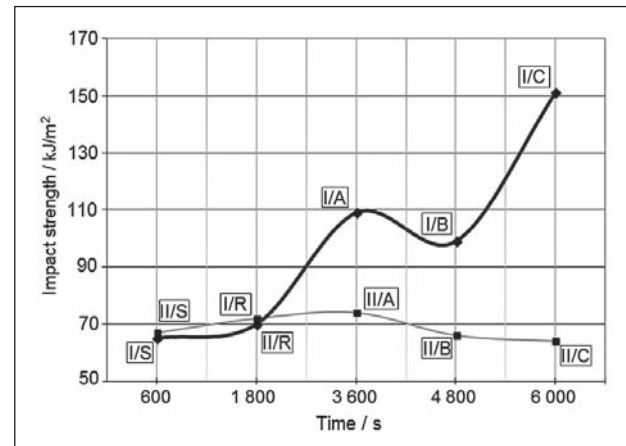


**Figure 2** Test piece to impact strength test

Impact strength tests were performed on Charpy pendulum tester. Photos of metallographic structures were taken using a Neophot 32 microscope with a MultiScan computerized system of picture analysis.

**RESULTS**

Figure 3 presents a change in the impact strength of the investigated alloy in the course of the process of continuous modification with sodium salts.



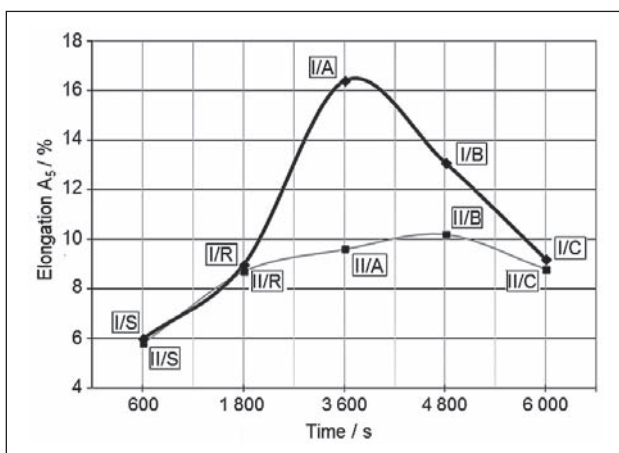
**Figure 3** Course of impact strength during modification of the alloy I – ternary salt, II – pentanary salt

In the case of raw samples (I/S, II/S) the impact strength amounted to 65 - 67 kJ/m<sup>2</sup>. Fragmentation of the alloys (samples I/R, II/R) resulted in an increase in the impact strength by 5 kJ/m<sup>2</sup>. A distinct change in the tensile strength was observed in the case of the samples modified with salt I (I/A - 109 kJ/m<sup>2</sup>; I/B - 99 kJ/m<sup>2</sup>; I/C - 151 kJ/m<sup>2</sup>). Modification with salt II did not have any effect on the change in the impact strength of the sam-

ples, reaching the level of raw test pieces (sample II/C - 64 kJ/m<sup>2</sup>) after 80 minutes from the beginning of the modification.

Figure 4 presents a change in the elongation  $A_5$  of the investigated alloy in the course of continuous modification with sodium salts.

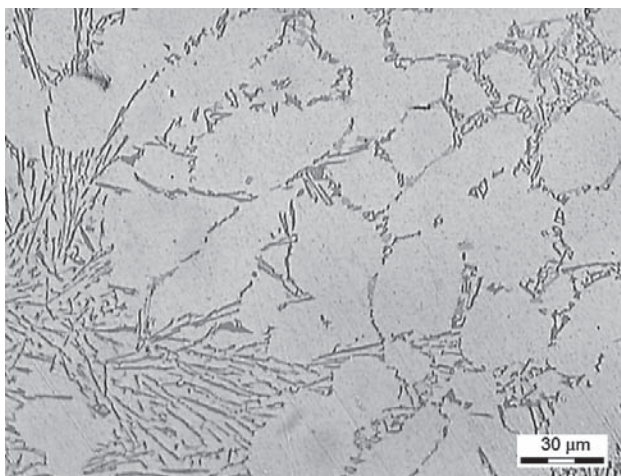
In the case of the raw samples (I/S, II/S) elongation of the alloy amounted to 6 %. After fragmentation (samples I/R, II/R) one observed an increase in elongation of the alloy by 3 %, as compared with the raw alloy. A distinct increase in the elongation was observed after 30 minutes from the beginning of the modification with salt I for sample I/A ( $A_5 = 16\%$ ) and I/B ( $A_5 = 13\%$ ).



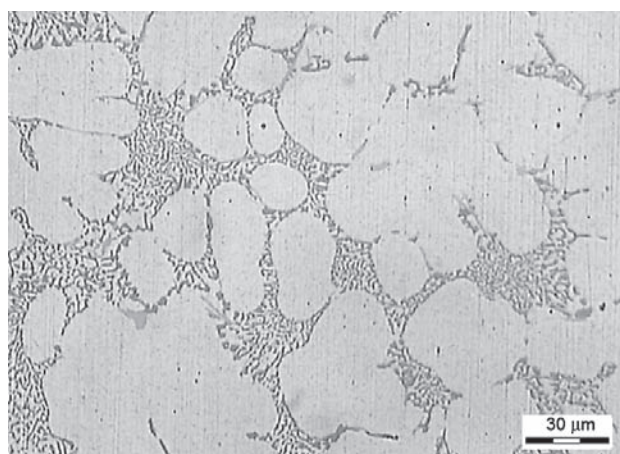
**Figure 4** Course of elongation  $A_5$  change during modification of the alloy: I – ternary salt, II – pentanary salt

Modification with salt II did not have any effect on the change of elongation  $A_5$  of the investigated alloy, which after 30 minutes since commencing the process of the modification amounted to 9 % (sample II/A), and next it decreased, reaching the value of the impact strength at the level of fragmented samples (sample II/C -  $A_5 = 8,8\%$ ) after 80 minutes from the beginning of the modification.

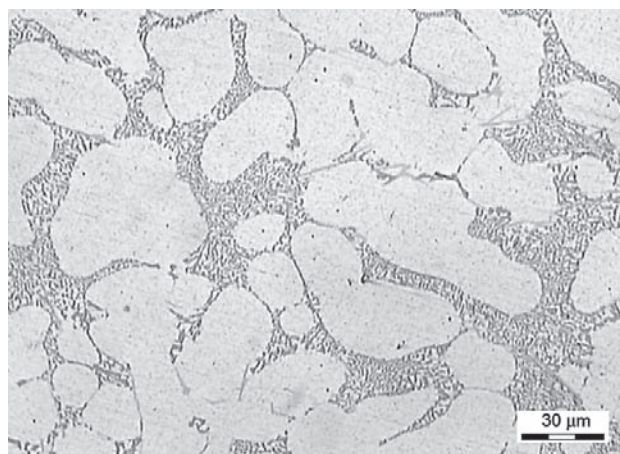
Figure 5 presents photographs of the microstructure of fragmented alloy before commencing the electrolysis of sodium salt.



**Figure 5** Microstructure of EN AC-44200 alloy after refinement



**Figure 6** Microstructure of EN AC-44200 alloy after 30 minutes of modification



**Figure 7** Microstructure of EN AC-44200 alloy after 70 minutes of modification

The structure of the initial alloy (Figure 5) before the beginning of the electrolysis can be characterized by explicit precipitations of phase  $\beta$  in the form of lamellar silicone, which are characteristic of unmodified alloys.

Figures 6 - 7 present microstructures of the alloy after 50 (sample I/A) and 70 (sample I/C) minutes of electrolysis of the salt I.

The modification of the eutectic mixture  $\alpha(\text{Al}) + \beta(\text{Si})$  is connected with a change of the shape of eutectic silicone precipitations (from lamellar to fibrous) and refinement of dendritic crystals of phase  $\alpha$ . A positive effect of performed modification treatment can be confirmed by the obtained structures of the investigated alloy after 30 and 70 minutes of the electrolysis process with use of salt I (Figures 6-7).

As no changes in the impact strength and elongation were found for modification with salt II, no metallographic specimens were produced after such modification.

## CONCLUSIONS

The test results obtained concerning elongation  $A_5$ , impact strength, and analysis of metallographic struc-

tures confirm the obtained effect of modification, which was maintained permanently in the course of the electrolysis of the salt I. It indicates conductivity of sodium ions through a solid electrolyte under conditions occurring at the time of the performed process of modification. Salt II does not meet the requirements concerning the possibility of its application in the process of continuous modification due to the lack of influence on a change in the elongation  $A_5$ , and impact strength. After the completion of the continuous modification and removing the retort from the liquid alloy, no cracks on its surface were noticed, which suggests a possibility of its reuse.

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**Note:** The responsible translator for English language is mLingua Worldwide Translations, Poznan, Poland