Plasticity of the AlSi9Mg alloy modified with Na, F and Cl compounds

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Abstract

This paper presents the results of an experiment investigating the structure and the percent elongation of an AlSi9Mg alloy modified with NaCl, Na₃AlF₆ and NaF compounds. The alloy was modified in a crucible. The experiment had a factorial design of 2³. Strength tests were performed on specimens with a diameter of 8 mm collected from a 16x140 mm cylinder cast in a sand mould. The applied modifier improved the studied alloy's eutectic properties and changed its percent elongation. Percent elongation values are presented in graphic form.

Keywords: Al-Si Alloy, Silumin, Modification, Percentage Elongation

1. Introduction

Al-Si alloys are among the most popular casting alloys. Two-component aluminum and silicon alloys are practically unfit for use directly after melting. They have a coarse-grained eutectic, subject to their silicon content, and they exhibit large grains and primary beta phase needles when the Si content exceeds 13%. Beta phase is a hard and brittle phase. Large beta phase grains create an effective parting plane which lowers the alloy's strength properties [1–3]. The alpha phase, a solid solution of silicon in aluminum, is created in hypoeutectic, two-component alloys. A coarse-grained eutectic is crystallized against this background (α+β). The usable properties of silumins are determined by the number, type and size of phases. The properties of hypoeutectic alloys are affected mostly by the form of their eutectic. The alpha phase also influences alloy properties. The alpha phase is characterized by plasticity, and it does not contribute to the brittleness of silumins [2–4].

The structure of Al-Si alloys we can shape by modification, thermal treatment and different methods. Despite the availability of a wide range of technologies enhancing the usable properties of Al-Si alloys, modification continues to be the most popular method [5–7]. Recent years have witnessed various research studies attempting to change silumin structure with the use of the temperature gradient. A method for modifying silumin structure has been developed with the involvement of a modifier obtained by rapid silumin cooling. The chemical composition of the modifier is identical or similar to that of a processed alloy [8, 9]. Despite numerous studies into the improvement of silumin properties, modification methods involving chemical elements and compounds deliver the most cost-effective results [10–12]. Eutectic systems are modified mainly with strontium and sodium. The primary beta phase of hypereutectic alloys is modified with the use of phosphorus. The strontium gives the effect of durable modification the siluminów. Natrium however shapes the structure during definite time. Dispersion of phase α dendrites, especially eutectic (α+β)-phase, causes an increment in both alloy strength and elongation [13–15].

The aim of this study was to modify the hypoeutectic Al-Si alloy with NaCl, Na₃AlF₆ and NaF compounds.
2. Aim of the study and methods

The experimental material comprised an alloy with a 9% silicon content. In a preliminary study, the AlSi9Mg silumin was modified separately with each of the analyzed compounds. Based on the obtained results, the proportions of the investigated compounds were qualified for the main part of the experiment. Each compound altered the alloy's structure, in most cases, by modifying its eutectic. The modifier was prepared by combining its components (1). The used proportions were detailed in different points of the experimental design. The modifier was introduced into the crucible containing liquid alloy at a temperature of 1023 K. Modification time was set at 15 minutes.

Founding, that studied proprieties are continuous functions considered variables and its can be with sufficient exactitude represented in figure of polynomial in investigations planning experiences was applied active, applying total factoral experiment (2) for three independent variables $X_1, X_2, X_3$ (1). The equation (2) was introduced for received plan of investigations the figure of equation of regress [14].

$$\begin{align*}
X_1 : NaCl & \in <0,02, 0,1>[\%] \\
X_2 : Na_3AlF_6 & \in <0,02, 0,1>[\%] \\
X_3 : NaF & \in <0,02, 0,1>[\%]
\end{align*}$$

\[ f = \beta + \gamma_1 x_1 + \gamma_2 x_2 + \gamma_3 x_3 + 12 x_1 x_2 + 13 x_1 x_3 + 23 x_2 x_3 + 123 x_1 x_2 x_3 \]  

(2)

Specimens were hand molded. Each experiment produced specimens measuring $\phi 16 \times 140$ mm. The bottom section of each specimen was shortened by 10 mm. A microsection for microstructural analyses was prepared on the surface of the incision. A specimen for mechanical tests was collected from the upper part of the cast.

In hypoeutectic Al-Si alloys, plasticity is determined mainly by eutectic structure. The alpha phase has a less significant influence. Structure and percent elongation have been assumed to be the main parameters representing the effect of modification on plasticity. Structural analyses were carried out using the IX70 microscope with the DP- SofT application at 2.5x-1500x magnification. Specimens for metallographic analyses were collected from the lower part of the sample intended for mechanical tests. Specimens were etched in 10% HF.

Percent elongation $A$ was determined in accordance with the standard PN-EN 10002-1+AC1: 1998 Metals: Tensile test – Testing methodology at ambient temperature in a general-purpose strength testing machine manufactured by W.P.M. GERMANY.

3. The results of investigations and their analysis

The structure of the modified AlSi9Mg alloy is presented in Figures 1-5. The structure after modification with 0.02% NaCl + 0.02% Na$_3$AlF$_6$ + 0.02% NaF is presented in Figure 1. Alloy structure has been insignificantly modified. The eutectic beta phase comprises needles. The lowest percent elongation was reported for this alloy. When the content of NaF was increased to 0.1%, the resulting structure was a fine-grained and evenly distributed eutectic beta phase (Fig. 2) which increased the alloy's plasticity, i.e. its percent elongation. The structure of the eutectic beta phase was similar at 0.1% NaCl and 0.02% content of the remaining components (Fig. 3). The resulting structure contains randomly oriented needles which resemble the primary beta phase. Despite a similar degree of eutectic modification, the needles are the cause of less satisfactory mechanical properties in comparison with the previously discussed structure.
sporadically observed. Figure 5 shows the alloy structure after modification with 0.02% NaCl, + 0.1% Na₃AlF₆ + 0.02% NaF. This modifier composition resulted in the finest-grained eutectic which significantly contributed to alloy plasticity.

An analysis of Figures 6, 8 and 10 validates the modification results yielded by the preliminary test. The course of change functions is similar at 0.1% content of the third component, and the main differences are observed in respect of percent elongation. Low percent elongation values were reported for 0.02% NaCl, 0.02% NaF at 0.1% Na₃AlF₆ (Fig. 8). For this modifier composition, A=3.3%. Figures 6, 8 and 10 show an increase in elongation with an increase in the content of each of the two modifier components and a higher share of the third component (0.1%). The slope of elongation gradient planes points to the highest effectiveness of Na₃AlF₆ with NaF content of 0.1%.

The results of percent elongation measurements are presented in Figures 6-11. Due to difficulties with representing functions for three independent variables, figure drawings for the obtained function were developed from the experimental design (2) on the assumption that each of the analyzed modifier components was present at a stable higher (0.1%) or lower (0.2%) level while the share of the remaining two components varied. Based on this approach, six graphic forms were developed for three modifier components.

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Fig. 4. Structure of AlSi9Mg alloy with 0.1% NaCl, 0.02% Na₃AlF₆, 0.1% NaF

Fig. 5. Structure of AlSi9Mg alloy with 0.02% NaCl, 0.1% Na₃AlF₆, 0.1% NaF

Fig. 6. Elongation (A) of AlSi9Mg alloy with Na₃AlF₆<0.02, 0.1> [%], NaF<0.02, 0.1> [%], NaCl=0.1%

Fig. 7. Elongation (A) of AlSi9Mg alloy with Na₃AlF₆<0.02, 0.1> [%], NaF<0.02, 0.1> [%], NaCl=0.02%

Fig. 8. Elongation (A) of AlSi9Mg alloy with NaCl<0.02, 0.1> [%], NaF<0.02, 0.1> [%], Na₃AlF₆=0.1%

Fig. 9. Elongation (A) of AlSi9Mg alloy with NaCl<0.02, 0.1> [%], NaF<0.02, 0.1> [%], Na₃AlF₆=0.02%
The above findings are validated by Figure 11. At 0.02% NaF and 0.1% Na$_3$AlF$_6$, elongation was not dependent on the share of NaCl. Elongation was constant at A = 6.5% throughout the entire change interval, i.e. between 0.02% and 0.1% NaCl. A similar correlation was noted in respect of NaCl for the modifier composition illustrated in Figure 9 (0.1% NaF and 0.02% Na$_3$AlF$_6$). For 0.02% NaCl and 0.85% Na$_3$AlF$_6$, changes in NaF content did not affect alloy elongation (Fig. 7).

4. Conclusions

An analysis of the effect of modifier components on the investigated parameters indicates that their influence on alloy plasticity, represented by percent elongation, is determined by the individual share of each component. The results of this study justify the use of modifiers with the composition of 0.02% NaCl, 0.02% NaF and 0.1% Na$_3$AlF$_6$ (Fig. 7). Their combined contribution to an improvement in alloy parameters is manifested at low levels of Na$_3$AlF$_6$. A higher share of all three components (0.1%) introduces redundant chemical components to the alloy with only a minor improvement in the modified alloy's plasticity.

Changes in the value and the distribution of the alpha phase were not reported in the proposed modifier composition.

References