EEFFECT OF MODIFICATION TIME ON MICROSTRUCTURE AND TENSILE STRENGTH ALSI9MG ALLOY WITH SR, TI AND B ADDITIONS USING IN AGRICULTURAL MACHINERY

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Abstract. A lot of elements of agricultural machines are made of Al-Si alloys. Hypoeutectic silumins are among the most popular casting alloys. They are used in a wide range of industrial applications, but their properties are continuously studied to improve the quality of cast products. Attempts are being made to improve the casting technology, refine the microstructure of cast products and enhance their functional properties. Those properties can be altered by cooling, directional solidifications, modification, heat processing and improved production technology. In practice, the properties of alloys are improved mainly through modification. The initial structure of AlSi9Mg alloy is composed of granular and acicular β phase, with α phase as matrix. The hard, irregular, often pointed β phase is responsible for the poor mechanical properties of said alloy. This composition is responsible for the alloy's low strength parameters, and it limits the extent of practical applications. The properties of alloys may not only depend on the chemical composition, modifiers, but may also depend on the conditions of the modification process, which may include the modification time. The analysis of the influence of modifying components in connection with the parameters of the modification process can give wider possibilities of controlling the properties, and thus the use of the alloy. This study presents the results of modification time of an AlSi9Mg alloy with strontium, boron and titanium. The influence of the analyzed modification time on the tensile strength and elongation of silumin modified by Sr, Ti + B was presented in graphs. The used modification treatment time of a hypoeutectic AlSi9Mg alloy improved the alloy's properties. The results of the tests show a change in the mechanical properties of tested alloy.

Keywords: aluminium alloy, modifications, tensile strength, elongation.

Introduction

Foundry metal alloys are the basic building material. For this reason, work on improving them is ongoing and they are still valid [1; 2]. Aluminium-silicon casting alloys are used extensively in many industrial applications because of their excellent mechanical, chemical and casting characteristics. However, the coarse acicular silicon phase morphology adversely affects the used properties of these alloys [3-6].However, a serious disadvantage of those alloys is the coarse-grained structure responsible for a decrease in the mechanical properties (mainly hardness, tensile strength and unit elongation) [6-9]. Currently, the dynamically developing industry requires alloys with increasingly higher properties. The increase of alloy properties can be achieved through the process of crystallization [10-12], modification [13; 14], through the use of technological processes [15-17] and developed using numerical methods [18; 19].

The modification behaviour of Al-Si alloy was first studied in 1920 by Pacz [20], who shows that the addition of sodium or its salts to the molten alloys leads to structural modification during solidification, and hence, to a considerable improvement in its mechanical properties. In 1966 Thiele and Dunkel [21] show that strength and malleability are important reasons for increasing applications of this alloy system. Mechanical properties of Al-Si cast alloys depend not only on the chemical composition but, more importantly, on microstructural features, such as morphologies of dendritic *α*-Al, eutectic Si particles and other intermetallics that are present in the microstructure [22-26]. Addition of sodium or strontium modifiers in Al-Si cast alloys has been found to improve the mechanical properties considerably, especially the ductility [6, 27-30]. The improvement in the mechanical properties generally has been attributed to the variations of the morphology and size of the eutectic silicon phase particles. It is worth noting, however, that at the same time, when eutectic silicon particles change from acicular to fiber, the amount, morphology and size of dendritic α-Al phase are varying, too. The contribution of these to the improvement of the mechanical properties has not been paid more attention. It is well known that grain refining is beneficial to mechanical properties. However, no final conclusion has yet been reached on whether the transition of dendrite from long columnar morphology to fine equiaxed one results in improved mechanical properties in near-eutectic Al-Si alloy. From the point of view of microstructure control, it is necessary to investigate the correlation between the mechanical properties and dendritic or eutectic morphologies in near-eutectic Al-Si alloys. The effects of strontium on such alloys are similar and longer-lasting than those of sodium [10-12; 31-33].

The mechanical properties of hypoeutectic silumins are first of all affected by the shape and size of eutectic mixture ($\alpha + \beta$). Chemical elements and compounds, both added to the alloy and formed as aresult of exothermic reactions [34, 35] or homogenical modifier [36], "pass" into the alloy, changing the course of its crystallization. Selection of the mixture components allows – to a degree – to decide about the starting moment of crystallization and change the range of solidification of alloy or its individual phases. The combined effects of these structures are rather complicated. The results of modification of eutectic and hypoeutectic aluminum-silicon alloys by sodium, strontium, antimony and other additions in the metallurgic process have been already analyzed and described by numerous authors [37-42].

The main aim of the present investigation was to evaluate the influence of time modification in correlation with strontium, boron and titanium on the tensile strength and elongation of AlSi9Mg alloy.

Materials and methods

The experimental material was AlSi9Mg alloy (Table 1), which was regarded as representative of hypo-eutectic silumin. The alloy was obtained from industrial piglets. The alloy was melted in ceramic crucible an electric furnace, and the modification process was carried out with additions: Sr, Ti + B. The Ti + B addition was produced by mixing the two components in an equal proportion.Melting was carried out in two series applying total factoral experiment (2^3) for three independent variables (Table 2). At each point in the research plan the quantity of preliminary alloy was introduced into the alloy in an amount ensuring the addition of the same amount of individual additives as in the single Na additions. The alloy was modified at a temperature of 800 ºC for different modification time (Table 2). Cylindrical samples, 8 mm in diameter and 75 mm in length, were poured into dry sand molds. The tensile stress test was performed on a specimen with a length-to-diameter ratio of 5:1 in the ZD-30 universal tensile tester. A tensile strength test was performed on two samples, ϕ 6 mm, for each melting point, according to the standard PN-EN ISO 6892-1:2016-09 „ Metallic materials. Tensile testing. Method of test at ambient temperature". The equation (1) was introduced for the received plan of investigations of equation of regress. The modifier was prepared by mixing its components (Table 1) in proportions indicated in the experimental plan.

$$\hat{y} = b_0 + b_1 x_2 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3 \quad (1)$$

The results were analyzed mathematically, which enabled to formulate the factor equation for three variables, for the parameters studied, at the level of significance $\alpha = 0.05$. The adequacy of the above mathematical equation was verified using the Fischer criterion for $p = 0.05$.

Table 1

Real chemical composition of the tested AlSi9Mg, wt. %

Element	Si	Mg	Mn	Ni	Cr	Fe	Cu	Zn	Ti	Al
Content	9.24	0.34	< 0.005	0.003	0.05	0,15	0.03	0.007	0.001	balance

Table 2

Level of variables

Variable	**Primary level, %**	**Range of changes, %**	**Higher level, %**	**Lower level, %**
Ti + B	0.04	0.02	0.04	0.02
Sr	0.04	0.02	0.04	0.02
Modification time,min	17	15	32	2

Results and discussion

The tensile strength of the AlSi9 %Mg alloy treated with Sr, Ti + B in different modification time is shown in Figs. 1-6 and elongation in Figs. 7-12.

After modification of the AlSi9Mg alloy 0.02 % Sr + 0.02 % (Ti + B) and modification time of 2 minutes, Rm = 145 MPa and A = 2 % were obtained (Fig. 2). After extending the modification time to 32 minutes, an increase in Rm to 153 MPa and A = 2.8 % was noted. After increasing the Sr share to 0.06 %, Rm = 175 MPa (Fig. 3) and A = 5.2 % (Fig. 9) were obtained. For Sr = 0.06 %, an increase in Rm and A was noted only when the modification time was extended maximum to 24 minutes. Further extension of time did not affect Rm (Fig. 3). An intensive increase in Rm was noted for the two parameters analyzed at a higher level and the third parameter at a lower level (Table 2), respectively Figs. 2, 4, 6 and 8, 10 and 12.

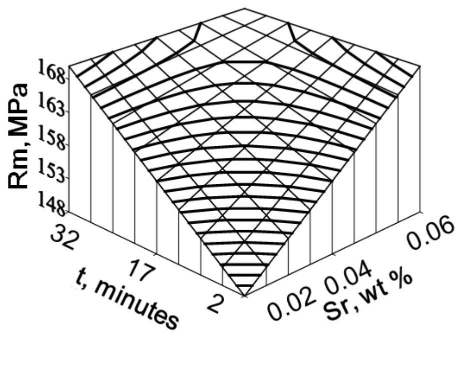

Fig. 1. **Tensile strength of AlSi9Mg alloy with Sr∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Ti + B = 0.06 %**

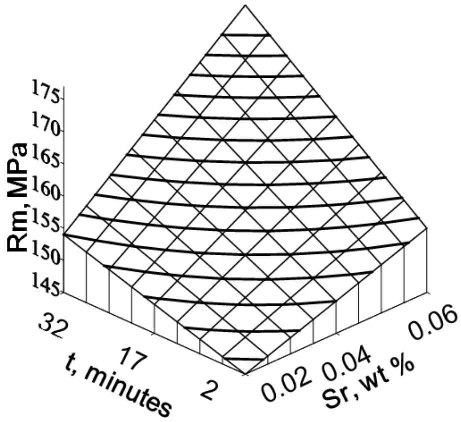

Fig. 2. **Tensile strength of AlSi9Mg alloy with Sr∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Ti + B = 0.02 %**

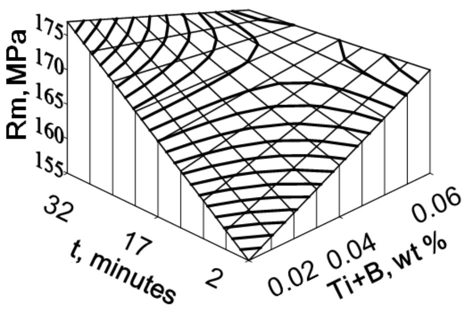

Fig. 3. **Tensile strength of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Sr = 0.06 %**

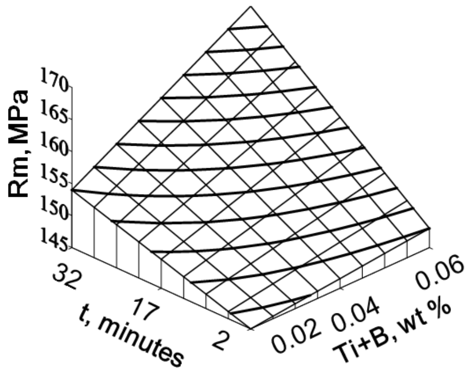

Fig. 4. **Tensile strength of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Sr = 0.02 %**

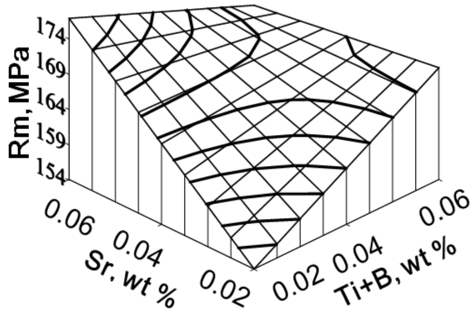

Fig. 5. **Tensile strength of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and Sr∈ < 0.02, 0.06 > % for modification time = 32 min**

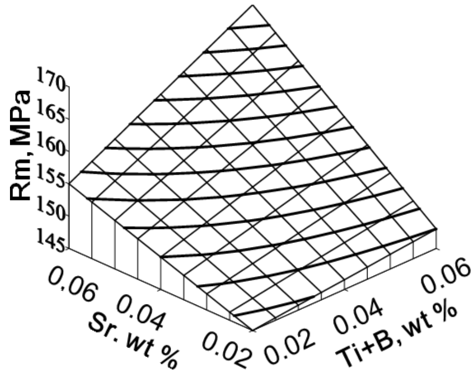

Fig. 6. **Tensile strength of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and Sr∈ < 0.02, 0.06 > % for modification time = 2 min**

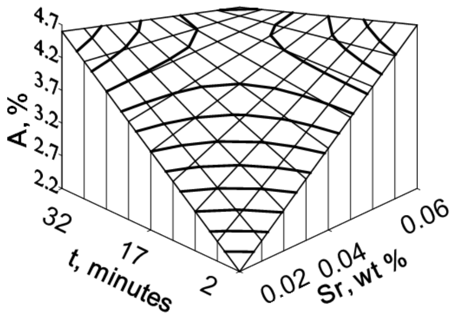

Fig. 7. **Elongation of AlSi9Mg alloy with Sr∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Ti + B = 0.06 %**

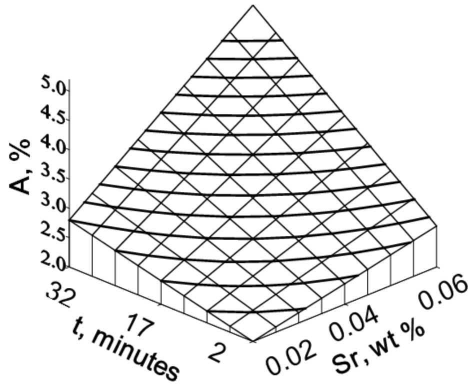

Fig. 8. **Elongation of AlSi9Mg alloy with Sr∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Ti + B = 0.02 %**

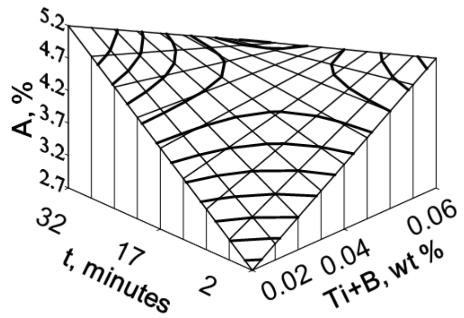

Fig. 9. **Elongation of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Sr = 0.06 %**

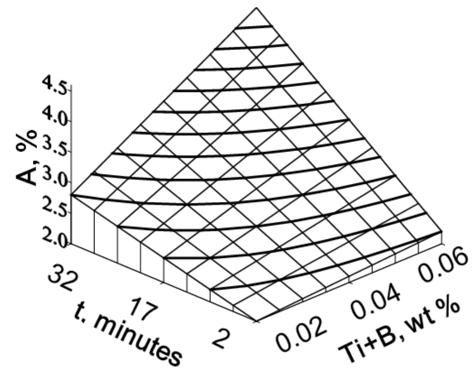

Fig. 10. **Elongation of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and modification time ∈ < 2, 32 > min for Sr = 0.02 %**

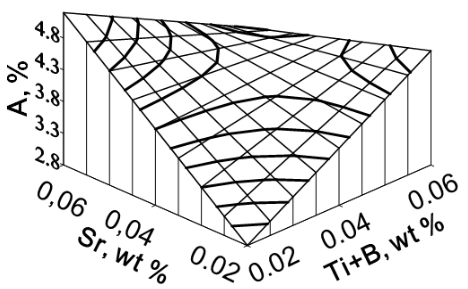

Fig. 11. **Elongation of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and Sr∈ < 0.02, 0.06 > % for modification time = 32 min**

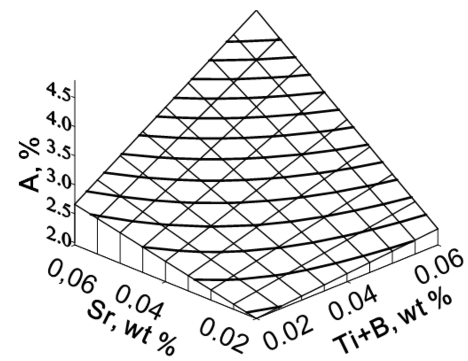

Fig. 12. **Elongation of AlSi9Mg alloy with Ti + B∈ < 0.02, 0.06 > % and Sr∈ < 0.02, 0.06 > % for modification time = 2 min**

This proves that there is no need to enter all ingredients at a higher level. Such dependence may result from the impact on the analyzed parameters of each of the factors in correlation with another factor.

The analysis of the tensile strength and elongation shows that the greatest benefits were achieved for AlSi9Mg alloy first of all for Sr and modification time. The two factors mainly changed the alloy properties. Based on the conducted research, strontium was found to be more intense than Ti + B (Figs. 5, 6, 11 and 12). For factors causing small changes in the size of Rm and A (small modification effect of the alloy) to obtain more favourable mechanical properties (for example, for low content of Ti + B), a longer modification time should be used. With an intensively working modifier, higher mechanical properties were obtained for the modification time at the basic level (about 17 minutes), Figs. 1-12. For Sr, along with an increase in exposure time above 20 minutes, a gradual decrease in the mechanical properties was noted (Figs. 1 and 7). For Ti + B, as the modification time increased (in the analyzed range), an increase in the mechanical properties was noted (Figs. 2 and 8).

Conclusions

The components (Sr and Ti + B) used for the modification of the AlSi9Mg silumin and the modification time showed a significant effect on the tensile strength and elongation.

The modification time needed to obtain the highest possible mechanical properties depends on the intensity of the modifier's impact. As the intensity of the Ti + B effect decreases, it is recommended to extend the modification time by up to 50 %, while for Sr, as the impact time increases, the alloy modification may decrease, resulting in a decrease in the mechanical properties.

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