Effect of Sr, Ti and B Additions as Powder and a Preliminary Alloy with Al on Microstructure and Tensile Strength AlSi9Mg Alloy

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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. This study presents the results of modification of an AlSi9Mg alloy with strontium, boron and titanium in different ranges produced as a melted modifier added as powders and as rod. The influence of the analyzed additions on the microstructure and tensile strength of the silumin was presented in graphs. The used treatments of a hypoeutectic AlSi9Mg alloy improved the alloy's properties. The results of the tests indicate that the mechanical properties of the modified alloy are determined by the sequence in which the components are introduced to the alloy.

Keywords: Al-Si alloy, Silumin, Modification, Mechanical properties

1 Introduction

Aluminium alloys have the potential for excellent castability, good weldability, good thermal conductivity, high strength at elevated temperatures and excellent corrosion resistance for these reasons, they have found wide application [1-3].

The microstructure of Al-Si alloys may be altered through modification, heat processing, etc. One of the most popular modification methods involves the use of chemical elements and compounds. Sodium and strontium are the most commonly used modifiers in subeutectic silumins. Strontium permanently modifies silumins, while sodium shapes their structure over a set period of time [1,4,5].

However, in recent years it has been established that the technological properties of aluminium-silicon alloys can be enchanced by adding modifiers and by applying suitable thermal treatmens [6]. The modification behavior of Al-Si alloy was ferst studied in 1920 by Pacz, who shows that the additions 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 [7]. In 1966 Thiele and Dunkel showed that the effects of strontium on such alloys are similar and longer-lasting than those of sodium [8].

Mechanical properties especially tensile strength, elongations and hardness are important reasons for increasing applications of this alloy system. Mechanical properties of Al-Si cast alloys depend not only on chemical composition but, more importantly, on microstructural features such as morphologies of dendritic α-Al, eutectic Si particles and other intermetallics that present in the microstructure [1,9-11]. Addition of sodium or strontium and other elements modifiers in Al-Si cast alloys have been found to improve mechanical properties considerably [12-18].

In order to improve the mechanical properties of alloys, they are subjected to modification. Properly selected chemical elements and compounds, added to alloy in the amounts not changing its chemical composition an a macroscopic scale, can considerably affect its microstructure (the so called alloy morphology) and mechanical properties. It results, among others, in changes in tensile strength.

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. Recent years have witnessed various research studies attempting to change silumin structure with the use of the temperature gradient [19-24]. 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. Despite numerous studies into the improvement of silumin properties, modification methods involving chemical elements and compounds deliver the most cost-effective results.

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 [1,14,25]. At present time strontium is the most frequently used in the aluminium alloy industry because it is easy to handle, has a good modification rate, a long incubation time and a low fading effect. The remelting is important for microstructure and mechanical properties, too [26,27]. There are a lot of control systems for testing qualiti of alloys [28-30]. However, the most reasonable for practical reasons is the study of mechanical properties.

The main aim of the present investigation was to evaluate influence of strontium, boron and titanium in different ranges produced as a melted modifier added as powders and as rod melted with Al on tensile strength of AlSi9Mg alloy.

2 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 Sr, Ti and B additions. The melting was carried out in two series applying total factoral experiment (23) for three independent variables (table 2). In the first series, the additives were introduced into the alloy in the form of a powder mix in accordance with the test plan. In the second series, in the form of a rod created by melting the amount of individual components appropriate for a given study plan point and aluminium. At each point in the research plan, the total amount of additives in the preliminary alloy accounted for about 10%. The same research plan was used to compare the effectiveness of silumin treatment in both series. For the second research series, 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 first series. The alloy was modified at a temperature of 800°C for 6 minutes. Cylindrical samples, 8 mm in diameter and 75 mm in length, were poured into a 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 standard PN-EN ISO 6892-1:2016-09 " Metallic materials. Tensile testing. Method of test at ambient temperature". The equation (1) was introduced for received plan of investigations the figure of equation of regress. The modifier was prepared by mixing its components (1) in proportions indicated in the experimental plan.

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \quad (1)$$

***Tab. 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

***Tab. 2** Level of variables*

Variable	Primary level [%]	Range of changes [%]	Higher level [%]	Lower level [%]
Sr	0.04	0.02	0.06	0.02
Ti	0.1	0.05	0.05	0.15
B	0.04	0.02	0.06	0.02

A 10 mm strip was cut off at the bottom of each sample. The face of cut served as metallographic specimen for microstructure analysis. Samples for mechanical tests were obtained from the upper part of the casting. A structural analysis was performed using an OLYMPUS IX70 microscope (magnification 25-600x), and OLYMPUS DP-SOFT. Samples for metallographic tests were taken from the lower part of the samples designed for mechanical tests.

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

3 Results

The microstructure of the basic AlSi9Mg alloy is presented in Fig. 1. The microstructure consists from coniferous eutektyki (α+β) on background the dendrytic of α-phase. The large needles of eutectic β-phase are the main reason of low tensile strength.

The microstructure of AlSi9Mg alloy after treatment a mixture contained with 0.06% Sr + 0.15% Ti + 0.06% B as a powder is presented in Fig. 2 and treatment a mixture contained with 0.06% Sr + 0.15% Ti + 0.06% B as a rod is presented in Fig. 3. On Fig. 2 and 3 visible are fine grains of eutectic mixture (α+β) in the inter-dendrite spaces of phase α. The dark Mg2Si phase is also present, similar to Fig. 1.

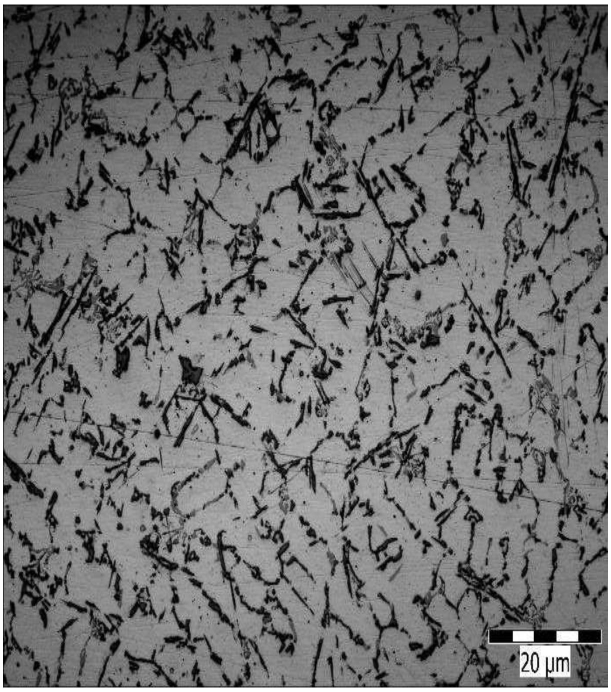

***Fig. 1** Microstructure of the raw AlSi9Mg alloy*

Comparing Fig. 2 and Fig. 3, greater refinement of eutectic (α + β) and preliminary α-phase was found for AlSi9Mg alloy with 0.06% Sr + 0.15% Ti + 0.06% B as a preliminary alloy with Al (rod).

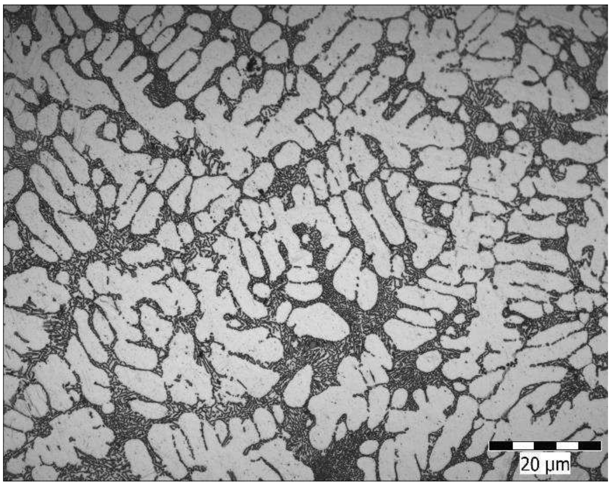

Fig. 2 *Microstructure of the AlSi9Mg alloy with 0.06% Sr + 0.15% Ti + 0.06% B as a powder*

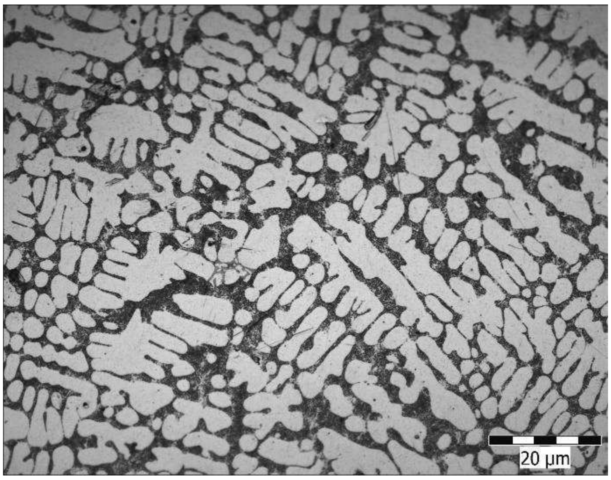

Fig. 3 *Microstructure of the AlSi9Mg alloy with 0.06% Sr + 0.15% Ti + 0.06% B as a preliminary alloy with Al (rod)*

Tensile strength of the AlSi9%Mg alloy treated with mixtute consisting of Sr, Ti and B Na, F and Cl cmpounds as a powder shows on Figs. 4-9. The analysis of tensile strength, shows that the greatest benefits were achieved after AlS9Mg alloy treatment with powder of 0.06% Sr, 0.15% Ti and 0.06% B which substantially improved alloy properties.

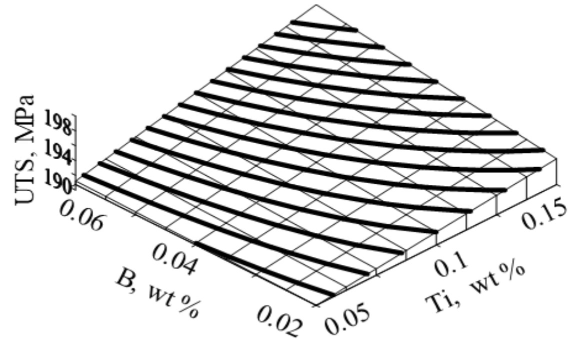

Fig. 4 *Tensile strength of AlSi9Mg alloy with B ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for Sr=0.06*

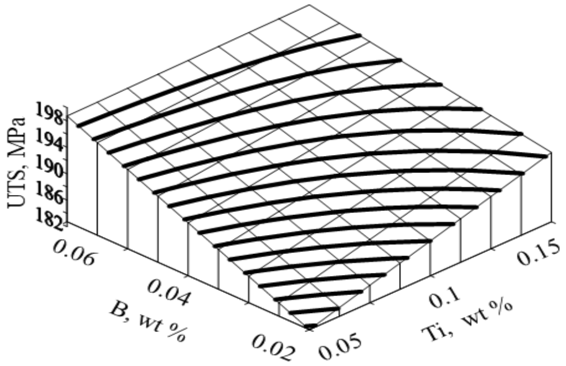

Fig. 5 *Tensile strength of AlSi9Mg alloy with B ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for Sr=0.02*

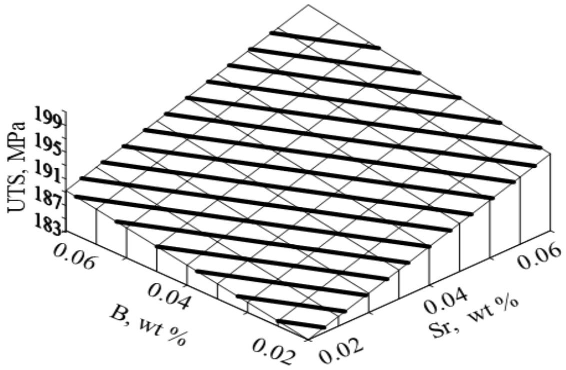

Fig. 6 *Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and B ∈<0.02, 0.06> [%] for Ti=0.15*

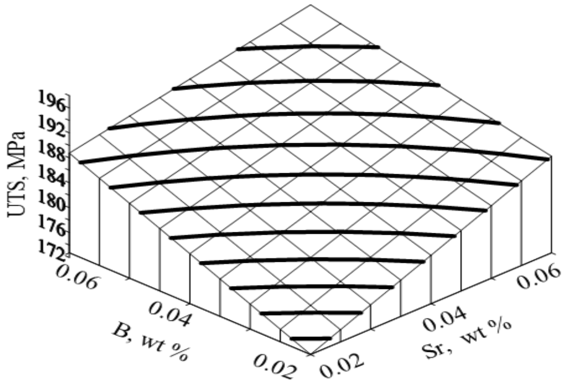

Fig. 7 *Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and B ∈<0.02, 0.06> [%] for Ti=0.05*

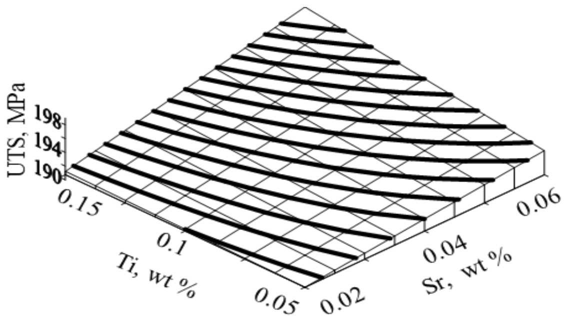

Fig. 8 *Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for B=0.06*

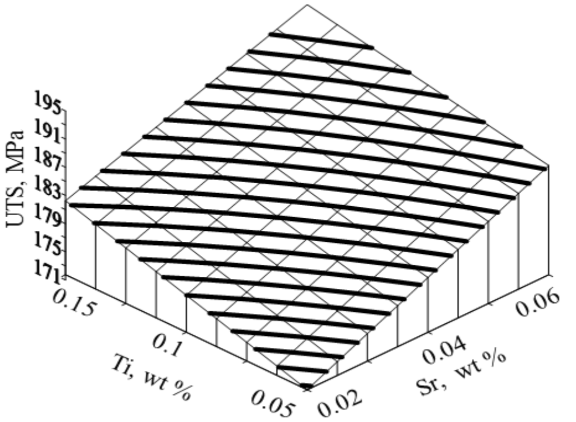

***Fig. 9** Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for B=0.02*

With a constant content of B = 0.02%, or B = 0.06%, Sr has a greater effect on the increase in tensile strength then Ti. However, the effect of titanium on strength increased with increasing boron content (Fig. 8 and Fig. 9).

Tensile strength of the AlSi9%Mg alloy treated with mixtute consisting of Sr, Ti and B Na, F and Cl cmpounds melted with Al as a rod shows on Figs. 10-15.

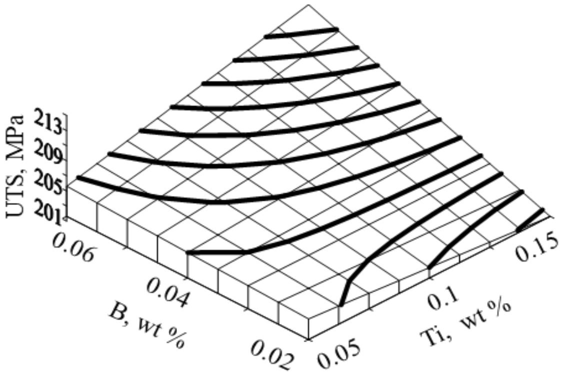

***Fig. 10** Tensile strength of AlSi9Mg alloy with B ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for Sr=0.06*

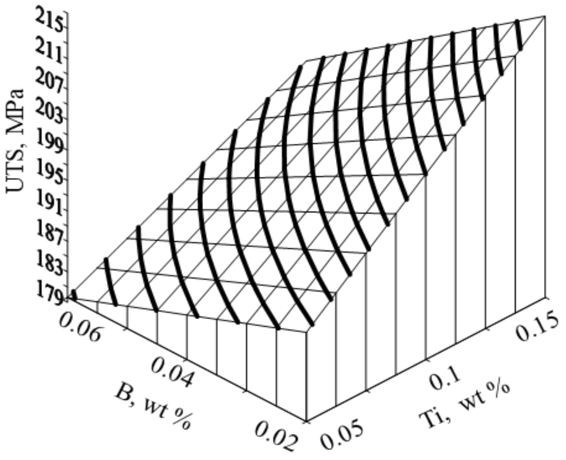

***Fig. 11** Tensile strength of AlSi9Mg alloy with B ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for Sr=0.02*

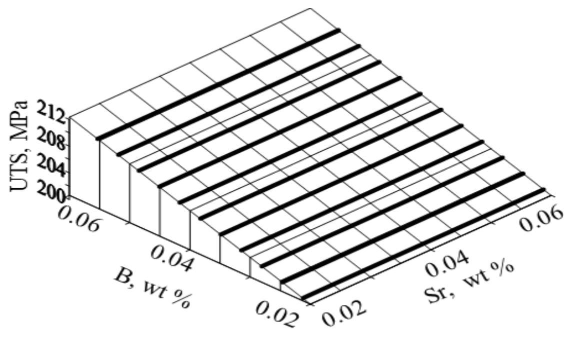

***Fig. 12** Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and B ∈<0.02, 0.06> [%] for Ti=0.15*

The analysis Fig. 12 permits to affirm, that near 0.15% Ti and B ∈<0.02, 0.06> [%] the change of quantity the Sr from 0.02 to 0.06% does not cause the change of tensile strength.

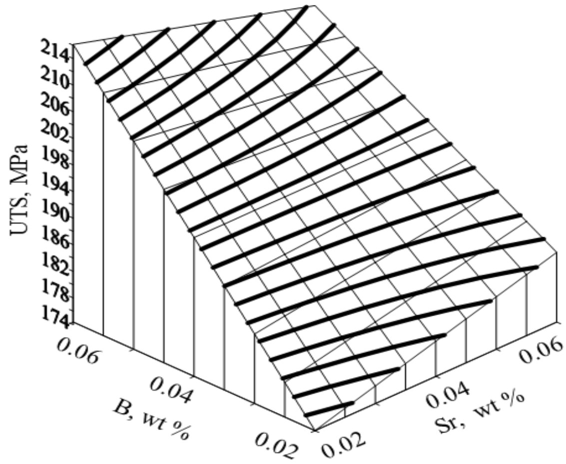

***Fig. 13** Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and B ∈<0.02, 0.06> [%] for Ti=0.05*

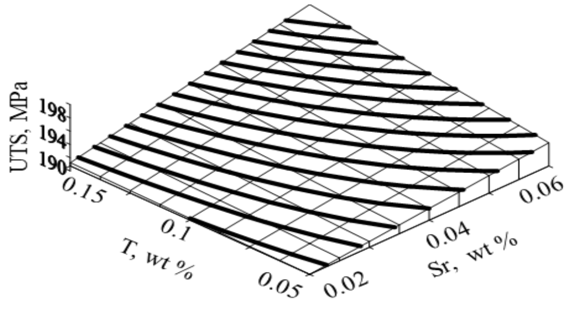

***Fig. 14** Tensile strength of AlSi9Mg alloy with Sr ∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for B=0.06*

Generally, comparing the tensile strength after treatment AlSi9Mg alloy with the same amounts of Sr, Ti and B introduced into the alloy in the form of powder (series I) and in the form of a preliminary alloy Sr, Ti and B with Al (rod) (series II) makeed by melting the componen mixturets and aluminum in a proportion about 1:10, a higher strength was found after treatment Al-Si alloy with preliminary alloy.

After treatment AlSi9Mg alloy with Sr + Ti + B with powder for a low content of Sr = 0.02%, B has a greater effect on the increase in tensile strength, whereas with a high content of Sr = 0.06%, Ti has a greater impact on the increase in tensile strength (Fig. 4 and Fig. 5). However, after treatment AlSi9Mg alloy with Sr + Ti + B as a preliminary alloy with Al (rod) for a high content of Sr = 0.06%, titanium and boron has similar effect on the increase the tensile strength. Whereas with a low content of Sr = 0.02%, titan has a greater impact then bor. This effect increases with an increase in the share of boron in the preliminary alloy (Fig. 10 and Fig. 11).

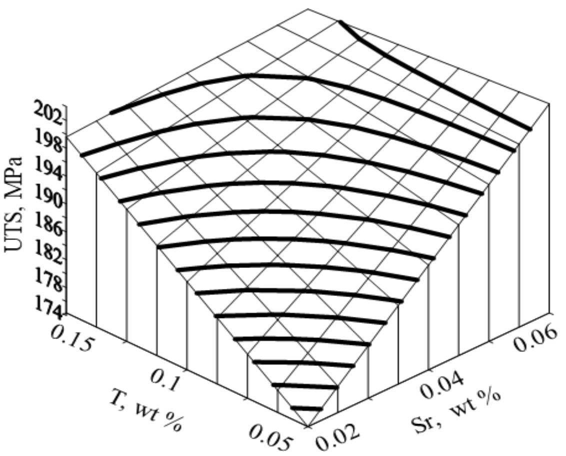

Fig. 15 *Tensile strength of AlSi9Mg alloy with Sr∈<0.02, 0.06> [%] and Ti ∈<0.05, 0.15> [%] for B=0.02*

The components of the mixture introduced into the AlSi9Mg alloy in powder form have a similar effect on strength (Fig. 4 - Fig. 9). After melting these components with aluminum, there was an approx. 10% increase in intensity in their impact on treated alloy strength (Fig. 11- Fig. 15), it was especially when one of the ingredients is at the lower level of the research plan (Fig. 11, 13 and 15).

The finer microstructure and higher strength after treatment with AlSi9Mg mortar is most likely caused by easier absorption of the aluminum-based alloy (the main component of the alloy), followed by nucleation of the priminary phases than absorbing the individual components of the mixture. This confirms the obtained test results for modification with a preliminary alloy based on Al-Si who a chemical composition similar to the processed alloy [4,14].

4 Conclusions

The main conclusion can be written as follows: the use of modifying components (Sr, Ti, B) after initial melting with the main component of the processed alloy (Al) increases tensile strength more than using the same modifying components (Sr, Ti, B) in an unmelted form (powder mix).

In addition, it was found that:

- the analysis of the process of hypo-eutectic Al-Si alloy treatment with Sr, Ti and B additions shows that this modifying addition increased mechanical properties of AlSi9Mg alloy;
- all tested modifiers altered the parameters of the analysed alloy. The β-phase was characterized by a finer-grained eutectic, and α-phase grains assumed a round shape. The analysed parameters were most significantly modified by borax and natrium with aluminium as a alloy. The analysed alloy was characterized by more satisfactory mechanical properties when Sr or B were added at 0.06% and 0.15% Ti.

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