

T. LIPIŃSKI*#

DOUBLE MODIFICATION OF AlSi9Mg ALLOY WITH BORON, TITANIUM AND STRONTIUM**PODWÓJNA MODYFIKACJA STOPU AlSi9Mg ZA POMOCĄ TYTANU, BORU I STRONTU**

The microstructure of an unmodified AlSi9Mg alloy comprises large primary α phase dendrites, eutectic β phase crystals and eutectic α phase. This composition is responsible for the alloy's low strength parameters, and it limits the extent of practical applications. The mechanical properties of hypoeutectic silumins can be improved through chemical modification as well as traditional or technological processing. Modification improves the mechanical properties of alloys through grain refinement. This study presents the results of double modification of an AlSi9Mg alloy with strontium, boron and titanium. The influence of the analyzed modifiers on the microstructure and mechanical properties of the processed alloy was presented in graphs. The modification 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 alloys, silumin, mechanical properties, modification, boron, titanium, strontium

Mikrostruktura niemodyfikowanego stopu AlSi9Mg składa się z dużych dendrytów pierwotnej fazy α , eutektycznych kryształów fazy β i eutektycznej fazy α . Taki skład fazowy jest przyczyną niskiej wytrzymałości stopu, co ogranicza jego praktyczne zastosowanie w praktyce. Właściwości mechaniczne podeutektycznych siluminów można poprawić poddając stop modyfikacji chemicznej, jak również poprzez zastosowanie procesów technologicznych. Modyfikacja poprawia właściwości mechaniczne stopów poprzez rozdrabnianie ziarna. W pracy przedstawiono wyniki podwójnej modyfikacji stopu AlSi9Mg przy użyciu strontu, boru i tytanu. Wpływ badanych modyfikatorów na mikrostrukturę i właściwości mechaniczne obrabianego stopu przedstawiono na wykresach. Modyfikacja podeutektycznego stopu AlSi9Mg poprawiła jego właściwości. Wyniki badań wskazują, że właściwości mechaniczne modyfikowanego stopu zależą od kolejności, w jakiej składniki są wprowadzane do stopu.

1. Introduction

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 [1,2]. Those properties can be altered by cooling, directional solidifications, modification, heat processing and improved production technology [3-11]. In practice, the properties of alloys are improved mainly through modification. Modified alloys have been widely used as structural materials ever since the first modification method was proposed by Pacz [12]. Modification treatments involv-

ing chemical elements and compounds, exothermic modifiers and homogeneous modifiers (made from the processed alloy) have been developed. The influence of chemical elements and compounds on alloys has been widely researched [13-23]. Hypoeutectic silumins have been modified with nearly all chemical elements. Industrial modifiers containing numerous components, including modifiers, grain refiners and strengthening compounds, have been developed. Most modifiers are available in the form of mixtures that are added to the alloy. The majority of casting plants, in particular small facilities, use piglets of modified alloys. Most authors present the results of studies where several modifiers were used to improve the microstructure and properties of silumins. However, they usually regard modifiers as independent variables, and they disregard the

* UNIVERSITY OF WARMIA AND MAZURY IN OLSZTYN, FACULTY OF TECHNICAL SCIENCES, DEPARTMENT OF MATERIAL AND MACHINE TECHNOLOGY, 11 OCZAPOWSKIEGO STR., 10-957 OLSZTYN, POLAND

Corresponding author: tomasz.lipinski@uwm.edu.pl

influence of the sequence in which the modifiers are introduced to the alloy [13-23].

In view of the growing popularity of modified alloys, the aim of this study was to determine the properties of hypoeutectic silumins double modified with boron, titanium and strontium, cooled to ambient temperature, heated to pouring temperature and solidified in the mold.

2. Materials and methods

The experimental material was AlSi9Mg alloy which was regarded as representative of hypoeutectic silumins. The alloy was obtained from industrial piglets. The alloy was melted in a 316L steel crucible in an electric furnace, and the modification process was carried out with Sr at 0.06% by weight, B at 0.03% by weight and Ti at 0.05% by weight in accordance with the variants presented in Fig. 1-9. Chemical additions were introduced separately in the order shown in the figures. The alloy was modified at a temperature of 850°C for 5 minutes. Upon the completion of each modification stage, specimens were collected for metallographic and mechanical tests. At the end of the modification process (for each samples series), the alloy was cooled to ambient temperature, reheated to 850°C and sampled. Those tests are marked as cold variants. Cylindrical samples, 8 mm in diameter and 75 mm in length, were poured into a mold made of molding sand. Casts were removed from molds, and specimens were collected for mechanical tests. Hardness was determined by the Brinell method by applying a test load of 612.9 N to a ball with a diameter of 2.5 mm. The side surface of the head of the specimen used in a static tensile test was ground to a depth of 2 mm. Three measurements were taken per sample (6 measurements per cast). The tensile stress test was performed on a specimen with a length-to-diameter ratio of 5:1 in the ZD universal tensile tester. Ultimate tensile strength and percentage elongation were determined. All measurements were carried out according to standard PN-EN 6506-1:2008 "Metallic materials. Brinell hardness test. Part 1: Testing methodology", with a standard ball, 2.5 mm in diameter, under the load of 612.9 N, in the HPO 250 hardness tester. A tensile strength test was performed on two samples, ϕ 6 mm, for each melting point, according to standard PN-EN 6892-1: 2010 "Metallic materials. Tensile testing. Part 1: Testing methodology at room temperature".

3. Results

The chemical composition of heats is presented in Table 1. The ultimate tensile strength (UTS) of the AlSi9Mg alloy after chemical treatment is presented in Figures 1, 4 and 7. Percentage elongation (A) of the AlSi9Mg alloy after chemical treatment is shown in Figures 2, 5 and 8. The Brinell hardness of the AlSi9Mg alloy after chemical treatment is presented in Figures 3, 6 and 9.

TABLE 1

Chemical composition of the AlSi9Mg alloy

Chemical composition [wt. %]								
Si	Mg	Mn	Fe	Cu	Ti	Ni	Zn	Al
9.15	0.29	0.35	0.60	0.15	0.012	0.02	0.2	all

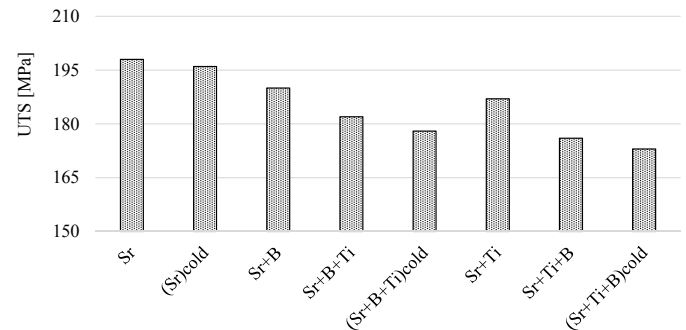


Fig. 1. Tensile strength of the AlSi9Mg alloy after chemical treatment for Sr as a first modifier

In an unmodified AlSi9Mg alloy, ultimate tensile strength UTS was determined at 151 MPa, elongation A at 1.2%, and Brinell hardness H at 54 HB. Treatment with 0.06% Sr increased all of the analyzed parameters in the resulting alloy: ultimate tensile strength increased by 47 MPa to 198 MPa, elongation increased by 5.2% to 6.4%, and Brinell hardness increased by 9 HB to 63 HB. Tensile strength decreased by 1%, percentage elongation decreased by 3%, and hardness decreased by 3% after remelting (cold variant). An increase in the B content of the modifier to 0.03% decreased tensile strength to 190 MPa, elongation to 5.6% and hardness to 58 HB. Treatment with a 0.05% Ti decreased tensile strength to 182 MPa, elongation to 5.2% and hardness to 56 HB. After remelting (cold variant), the alloy's mechanical properties decreased by approximately 1%. A similar effect was observed when Ti was used as the second element (Fig. 1-3).

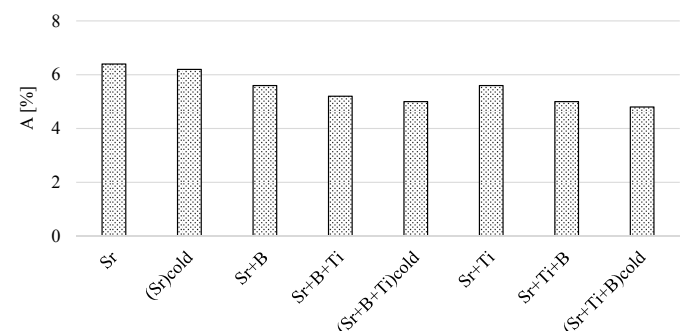


Fig. 2. Percentage elongation of the AlSi9Mg alloy after chemical treatment for Sr as a first modifier

When the original AlSi9Mg alloy was treated with 0.03% B (Fig. 4-6) as the first element, its ultimate tensile strength increased by 25 MPa to 176 MPa, percentage elongation increased by 2.4% to 3.6%, and Brinell hardness increased by 3 HB to

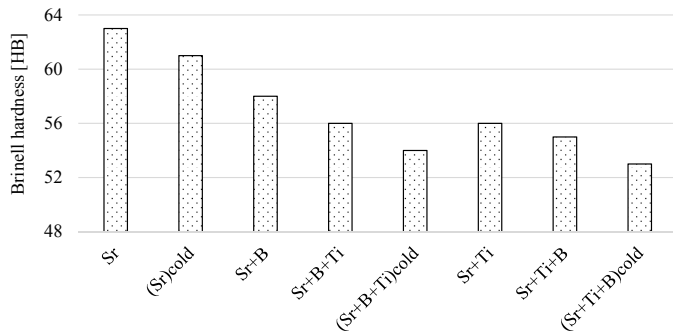


Fig. 3. Brinell hardness of the AlSi9Mg alloy after chemical treatment for Sr as a first modifier

57 HB. Tensile strength decreased by 8%, percentage elongation decreased by 36%, and hardness decreased by 4%. When the boron-modified AlSi9Mg alloy was treated with 0.05% Ti as the second element, tensile strength increased to 190 MPa, percentage elongation increased to 5.6%, and Brinell hardness increased to 58 HB (Fig. 4-6). The result was similar to those shown in Figures 1-3. The addition of 0.06% Sr as the third element (Ti+B+Sr) increased tensile strength to 205 MPa, percent elongation to 6.8% and hardness to 62 HB. After remelting (cold variant), tensile strength and elongation decreased by approximately 4%, whereas hardness did not change (Fig. 6). The analyzed parameters in the AlSi9Mg alloy modified with B as the first element and Sr as the second were determined at: UTS = 197 MPa, A = 6.2% and H = 62 HB. After treatment with Ti (B+Sr+Ti), tensile strength increased to 192 MPa, elongation increased to 5.8%, whereas hardness decreased to 59 HB. In the cold variant (B+Sr+Ti), an increase was noted in the values of UTS and A, whereas HB decreased by approximately 1% (Fig. 4-6). The mechanical properties of the AlSi9Mg alloy modified with (B+Sr), (B+Sr+Ti) and with (B+Sr+Ti) in the cold variant (Fig. 4-6) are similar to those noted in silumins treated with (Ti+Sr), (Ti+Sr+B) and with (Ti+Sr+B) in the cold variant (Fig. 7-9).

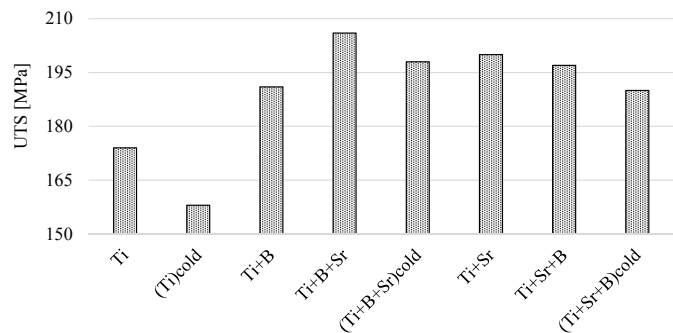


Fig. 4. Tensile strength of the AlSi9Mg alloy after chemical treatment for Ti as a first modifier

When the original AlSi9Mg alloy was treated with 0.05% Ti (Fig. 7-9) as the first element, its ultimate tensile strength increased by 23 MPa to 174 MPa, percentage elongation in-

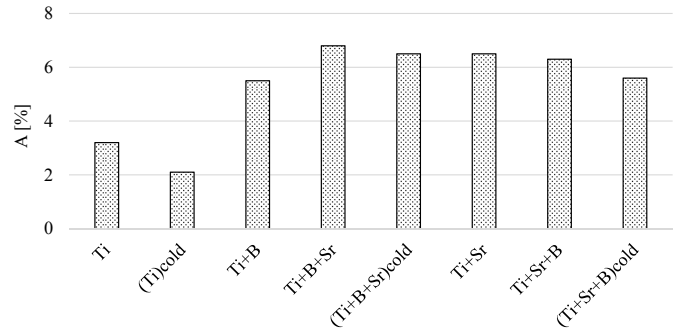


Fig. 5. Percentage elongation of the AlSi9Mg alloy after chemical treatment for Ti as a first modifier

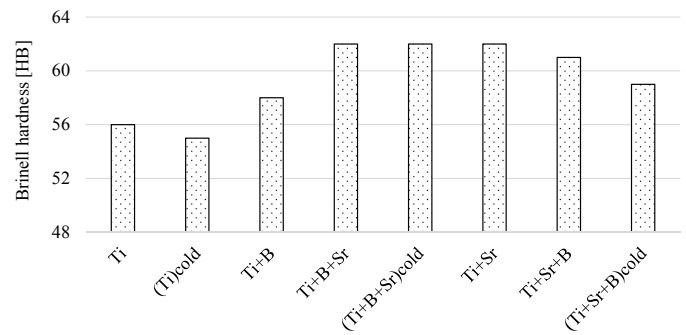


Fig. 6. Brinell hardness of the AlSi9Mg alloy after chemical treatment for Ti as a first modifier

creased by 2.0% to 3.2%, and Brinell hardness increased by 2 HB to 56 HB. Tensile strength decreased by approximately 9%, percentage elongation decreased by 34%, and hardness decreased by 2% after remelting (cold variant). When the titanium-modified AlSi9Mg alloy was treated with 0.03% B as the second element, tensile strength increased to 191 MPa, percentage elongation increased to 5.5%, and Brinell hardness increased to 58 HB (Fig. 7-9). The addition of 0.06% Sr as the third element (Ti+B+Sr) increased tensile strength to 206 MPa, percent elongation to 6.8% and hardness to 62 HB. Similar results were noted when B was added as the first element. After remelting (cold variant), tensile strength and elongation decreased by approximately 4%, whereas hardness did not change (Fig. 9).

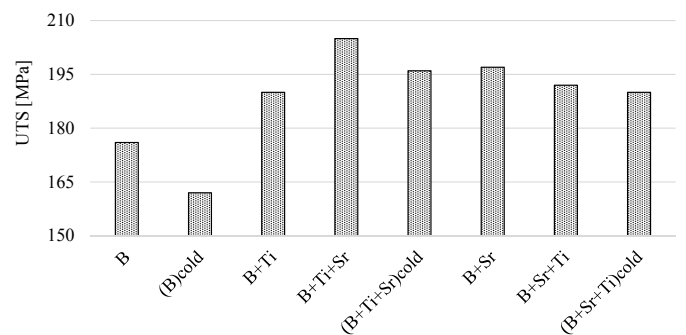


Fig. 7. Tensile strength of the AlSi9Mg alloy after chemical treatment for B as a first modifier

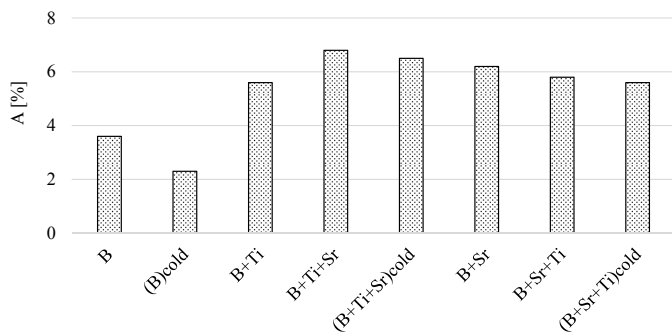


Fig. 8. Percentage elongation of the AlSi9Mg alloy after chemical treatment for B as a first modifier

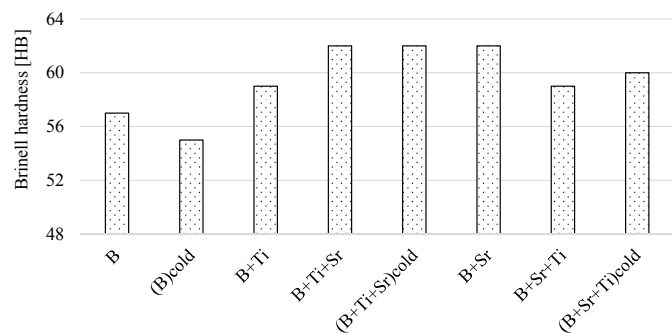


Fig. 9. Brinell hardness of the AlSi9Mg alloy after chemical treatment for B as a first modifier

The presence of modifying elements in the alloy was confirmed by quantitative X-ray analysis (Fig. 10).

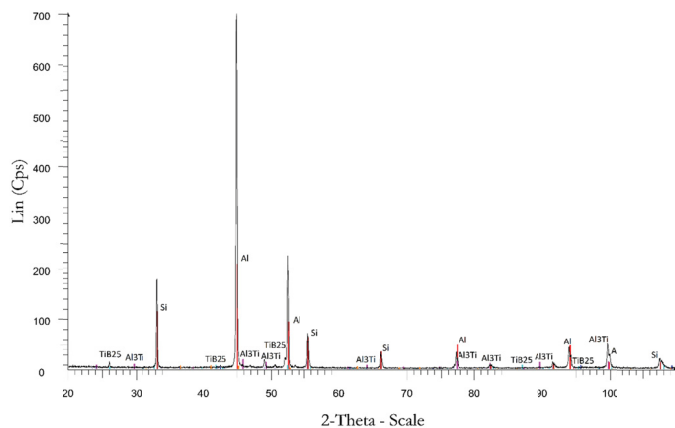


Fig. 10. Quantitative X-ray analysis of the AlSi9Mg alloy after chemical treatment for Ti + B point

The microstructure of the AlSi9Mg alloy modified with the tested elements is presented in Figure 11. The modification with Sr, followed by B and Ti (Sr+B+Ti) (Fig. 1-3) is presented in Figure 11a, and the modification with Sr, followed by Ti and B – in Figure 11b. Treatment with B, Ti and Sr (Fig. 11c) and with Ti, B and Sr (Fig. 11d) led to significant refinement of microstructure, mainly the eutectic ($\alpha + \beta$), which improved the alloy's mechanical properties (Fig. 4-9). An analysis of the microstructures shown in Fig. 11 and mechanical properties of

the modified silumin indicates that the application of strontium as the last element produced the most satisfactory results. The above confirms the suspected negative influence of both Ti and B on a strontium-modified alloy. The mechanical properties of a remelted alloy deteriorated in all cases. Those observations indicate that the modifying effects of the analyzed elements are weakened with time, most probably when the alloy is stored in liquid form.

4. Conclusions

The results of the tests indicate that the mechanical properties of the modified alloy are determined by the sequence in which the modifier is introduced to the alloy. This sequence may determine the main properties of the alloy. Hypoeutectic silumins AlSi9Mg treated with titanium and boron after the addition of strontium were characterized by lower mechanical properties, which can probably be attributed to the fact that the titanium and boron mixture reduces the modifying effects of strontium. Titanium and boron had a similar effect on alloy microstructures tested by other authors [15,16].

Strontium modification after the addition of titanium and boron resulted in improved mechanical properties in comparison with Sr modification only. The mechanical properties of the tested alloy were not degraded after double modification and repeated melting. The alloy was characterized by optimal mechanical properties when modifiers were added in the following order: (Ti+B+Sr) or (B+Ti+Sr). The use of titanium or boron as the first element did not significantly alter the results. Remelting of a modified alloy deteriorated its mechanical properties and increased the size of needles in its microstructure. The above can be explained by the fact that the effectiveness of modifiers is weakened over time in alloys that are stored at high temperatures.

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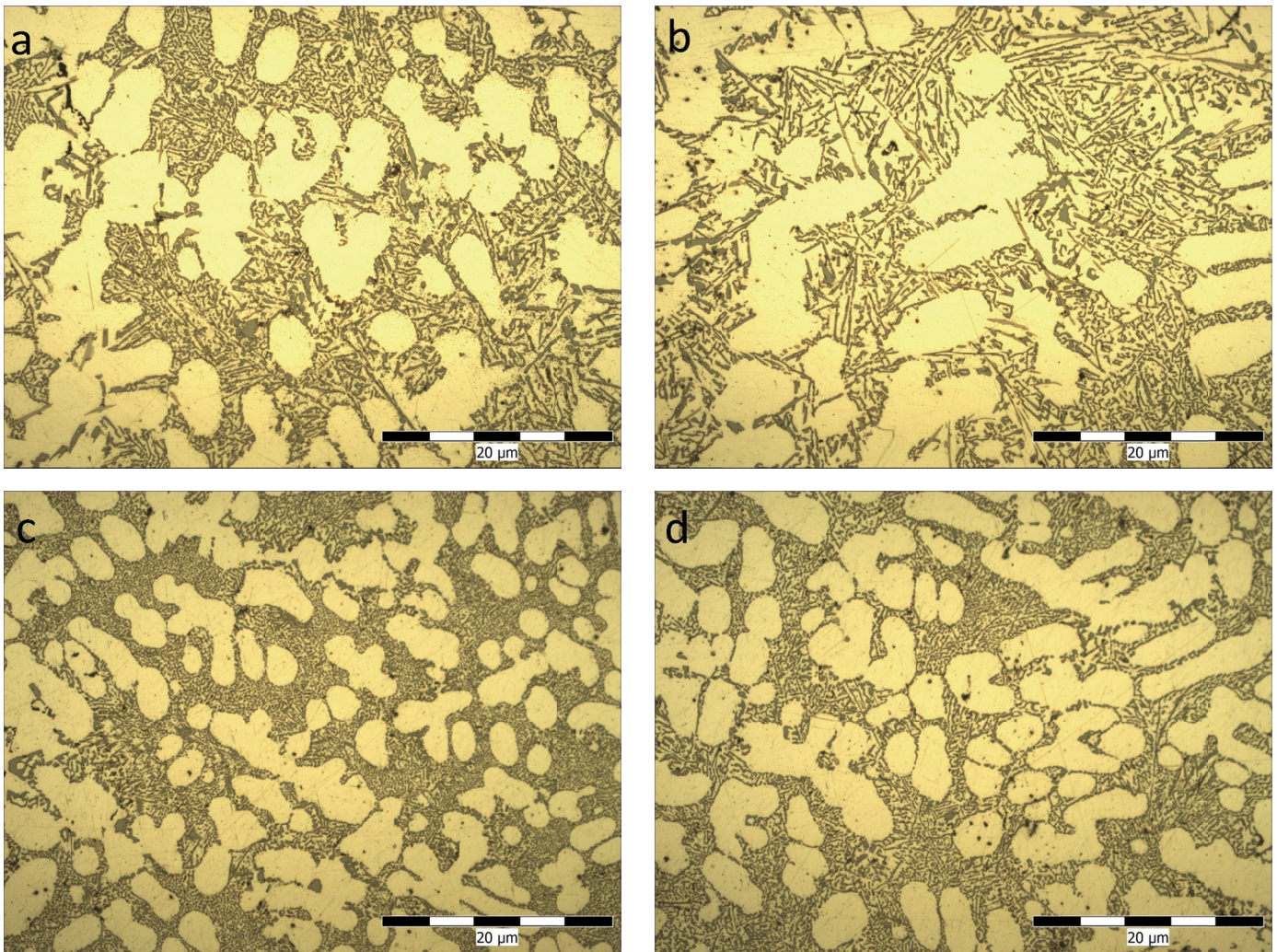


Fig. 11. Microstructure of the AlSi9Mg where modifiers were introduced in the following sequence: a. Sr+B+Ti, b. Sr+Ti+B, c. B+Ti+Sr, d. Ti+B+Sr

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