SYSTEM SAFETY: HUMAN - TECHNICAL FACILITY – ENVIRONMENT
6(1), 2024, pp. 384-394

CHANGES IN THE STRUCTURE OF THE AK7 ALLOY IN TERMS OF MODIFICATION

DOI: 10.2478/czoto-2024-0040
Received: 13/11/2024
Accepted: 23/12/2024

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Abstract: On this work there was decided to verify the possibility of influence of micro additives of strontium and boron on structure of AlSi7Mg (EN-AC-42000) alloy with chemical composition according to PN-EN 1706. As the modifier there were used AlSr10 (0.3%) and AlTi5B1 (0.3%) master alloy, which were added separately and together. Changes in the structure of individual samples of the AK7 alloy were examined using a metallographic microscope. The chemical composition of complex intermetallic phases formed in the structure of the tested alloy was also examined. The most beneficial effect turned out to be the effect of strontium in the form of 0.3% AlSr10, ensuring a favourable conversion of lamellar silicon into the form of fine fibres. The presence of complex phases was observed in all test samples. Most often, these were phases with various needle shapes and variable Fe and Mn contents.
Keywords: alloy, intermetallic phase, structure, modification.

1. INTRODUCTION

Aluminum -silicon alloys are used in various industrial segments due to their reduced weight combined with good mechanical properties, corrosion resistance, thermal and electrical properties. The share of aluminum and its alloys in foundry production is over 70% in the construction of means of transport and approximately 13% in the production of machine parts (Wiecheć, 2016). Regardless of their relatively low strength, their strength-to-weight ratio is superior to those of most metals (Rams et al., 2022; Lipiński et al., 2015). Hypoeutectic and near-eutectic silumins are characterized by an unfavorable structure. In addition to the plastic primary phase α (solid solution of silicon in aluminum), the structure contains an eutectic mixture α(Al)+β(Si). In eutectic, in addition to the plastic eutectic phase α, there are hard crystals of the β(Si) phase - solid solution of aluminum in silicon. The share of this form of silicon in Al-Si alloys can have a beneficial effect on mechanical properties, however, increasing its share causes the occurrence of an unfavorable lamellar form of this silicon in the structure of hypoeutectic silumins, characterized by a developed surface and high brittleness. Such a state can affect the alloys' easier cracking under load (Lipiński, 2015; Tillova et al., 2016;). The microstructure of an standard hypoeutectic Al-Si alloys is responsible for those alloy's low mechanical parameters, so it cause the limts on practical applications. The microstructure morphology can be changed for by addition of chemical elements that influence on change of unpleasant lamellar morphology of β(Si) using for this masteralloys basing on strontium with aluminum (Lipiński, 2017). Based on previous research done by researchers, it can be observed that strontium (Sr) has a very beneficial effect on the structure of the eutectic silicon β phase. However, as it results from the cited studies, not only the type of modifier used but also its amount is very important. In the case of eutectic in hypoeutectic Al-SI alloys, the addition of Sr (0.10% AlSr10) causes slight or uneven fragmentation of lamellar silicon in the eutectic. In turn, too much increase in the amount of strontium by introducing 0.4% AlSr10 into the alloy may additionally result in the formation of additional AlSr type phases of significant size and brittleness in the refined eutectic (Lipiński, 2019). Referring to the research conducted by earlier researchers on the possibility of changing the structure of hypoeutectic Al-Si alloys, it is confirmed that it is appropriate to continue research on the impact of various modifiers on the unfavorable structure of these alloys. On this work there was decided to verify the possibility of influence of micro additives of strontium and boron on structure as well as complex mododification of hypoeutectic AlSi7Mg alloy.

2. DESCRIPTION OF THE EXPERIMENTS

For the experiments there was used AlSi7Mg (EN-AC-42000) alloy with chemical composition according to PN-EN 1706.

The alloy was melted in a resistance furnace using a 2 kg chamotte-graphite crucible. Maintaining the target metal temperature was ensured by a TC6 microprocessor temperature controller from METROL coupled with a thermocouple installed in the cylindrical chamber of the furnace. The temperature of the liquid metal was controlled by immersing the measuring tip of a K-type (NiCr-NiAl) sheathed thermocouple in it, which was inserted through a through-hole made in the insulating cover of the furnace. The mass of the metal charge (AlSi7Mg) for each melt was 1.2 kg. After reaching the target temperature, the liquid metal was heated for 30 min. In the next step, at a temperature of 750ºC, the modifier was introduced into the metal bath using a heated graphite plunger. The modification procedures were carried out using the addition of 0.3% of the AlTi5B1 master alloy (containing B) and 0.3% of the AlSr10 master alloy (containing Sr) in relation to the mass of the metal charge. The metal was cast into a metal mold 30 minutes after the introduction of the modifier. Both modifiers were used separately and in complex modification it means together, in accordance with the data in Table 1

Table 1
Modification conditions of alloy AK7

Melt Nr	The modification conditions	HB
1	Alloy AK7 without modification	58
2	Alloy AK7 modified with 0.3% AlTi5B1	64
3	Alloy AK7 modified with 0.3% AlSr10	62
4	Alloy AK7 modified with 0.3% AlTi5B1 and 0.3% AlS10	67

Source: own study

The table 1 contains the types and amounts of the modifying additives that were used on presented research as well as the results of Brinell hardness test.

In order to obtain a sample of the unmodified alloy, melts were carried out using the same procedure as for the modified alloy, omitting the modification procedure. A cylindrical split metal mould (with an internal diameter of 27 mm, wall thickness of 17 mm and height of 45 mm) was used in the tests, placed on a steel base (showed on Fig. 1).
In order to obtain samples for metallographic examination, after the casting had cooled, a part of it was cut off (perpendicularly to the axis of the casting) at the level of 1/3 of the height from the bottom of the mould. Metallographic microsections were made on the sample cut surface using an automatic grinder and polisher from "STRUERS". On the next step the prepared sample surfaces were etched for 10 seconds with a 0.5% HF agent with the following composition: 0.5 ml HF + 99.5 ml H_2O. The etching agent caused the precise disclosure of the structure and especially of the eutectic silicon precipitates.

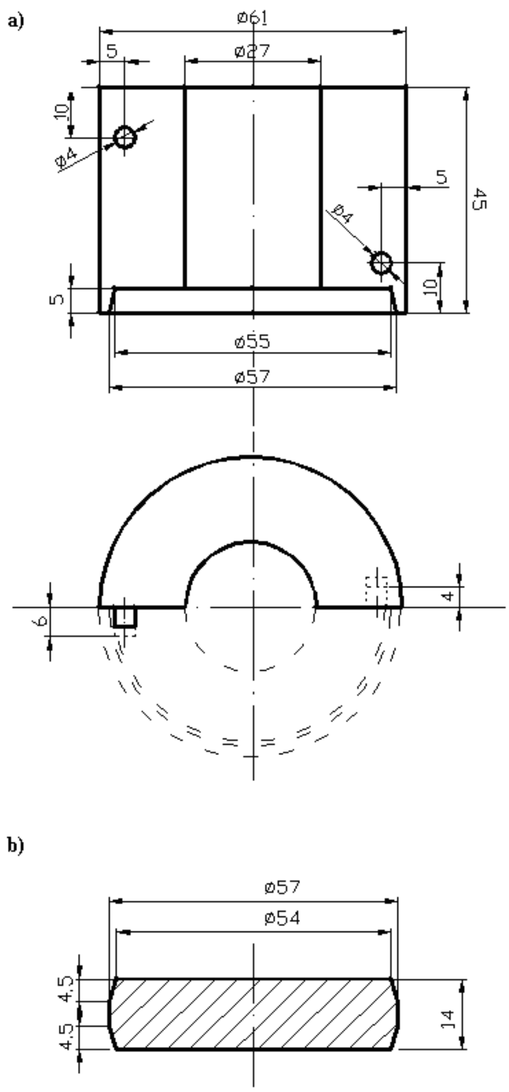


Fig. 1. Metal mould: a) divided mould, b) base

Metallographic examination of the microstructure was carried out using a ZEISS Axio Observer A.m1 (fig. 2) metallographic microscope. Microstructure images for individual melts were obtained using microscopic observation in a bright field of view at magnifications of 200x and 500x.

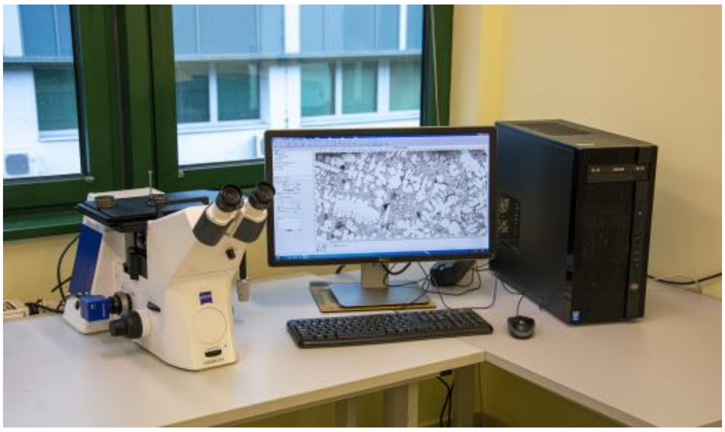


Fig. 2. Metallographic microscope Zeiss Axio Observer A.m1

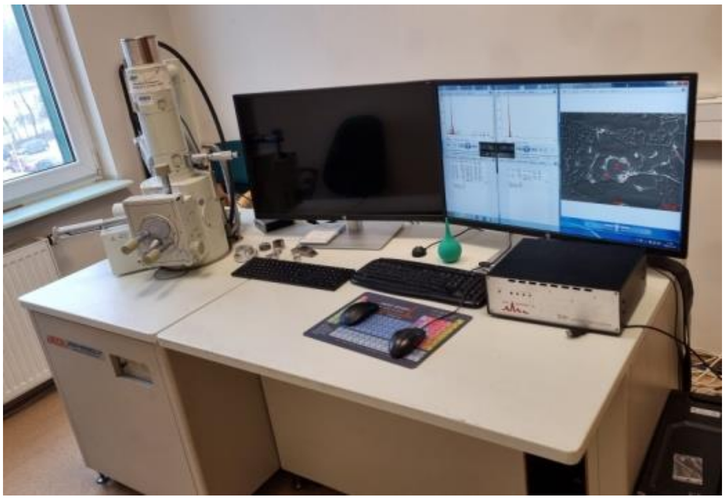


Fig. 3. Electron scanning microscope Jeol 5600LV with built in X-Ray Microanalyzer EDS 2000

Due to the complexity of the chemical composition of the tested alloy, attention was also paid to the presence of complex intermetallic phases in the structure of tested alloy. For this there was used scanning electron microscope Jeol 5600 LV with build in X-Ray Microanalyzer EDS 2000 (Fig. 3). Scanning electron microscope photographs of microstructure areas were taken at 1500x magnification.

2. RESULTS OF THE EXPERIMETS

The results of experiments have been shown on figures from 4 to 11. Figures 4, 6, 8 and 10 shows changes in the microstructure of tested samples. On the figures 5, 7, 9, and 11 are presented images of the structure area with the analysed complex phases that occurred in the tested alloy. These figures also contains the tables with chemical composition for complex intermetallic phases marked on the structure area photography's with sign and numbers near it in red colour.

In Figure 4, for the unmodified AK7 alloy, there is a microstructure composed mostly of bright-colored dendritic crystals of the primary α phase (the phase very rich on aluminum). Locally, the dendrites have long and thick arms spreading sideways surrounding eutectic mixture α(Al)+β(Si) occurred in interdendritic spaces. It is composed of bright-colored small particles aluminum α(Al) and thick dark grey beta phase plates (solid solution of aluminum on silicon) with different length and thickness (Fig. 4a and b). Such a plate-like form of the eutectic beta phase and its high hardness is very unfavorable from the point of view of the mechanical properties of the tested alloy. Such a built of the structure can cause a local increase in the hardness and brittleness of the structure, and consequently facilitate cracking. For such an unfavorable condition of the structure is also confirmed by the results of the Brinell hardness (Table 1) reached the lowest value of 58 HB for the AlSi7Mg alloy sample in the unmodified state.

a) b)

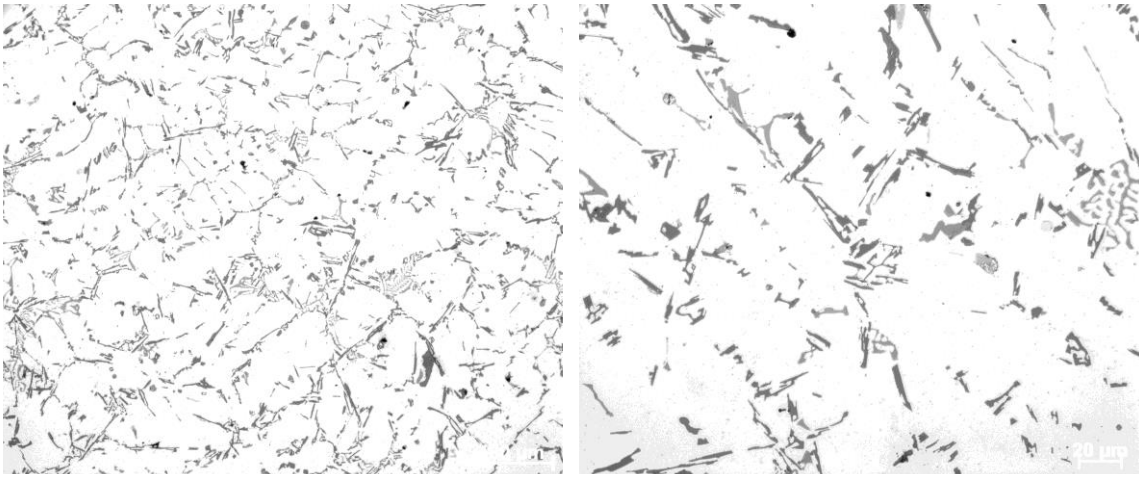
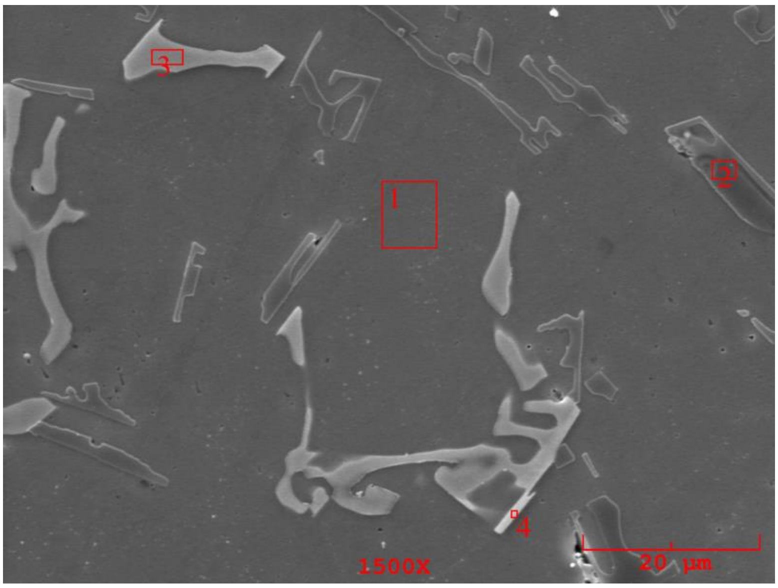


Fig. 4. Microstructure of Alloy AK7 in its unmodified state: a) mag 200x, b) mag 500x

In the examined structure, phase separations can be observed in the form of light gray skeletons (3) or in a compact form (4). These are complex intermetallic phases. Figure 5 shows a photo from an X-ray microanalyzer and the chemical composition confirms the complexity of the indicated phases. Those phases are rich on Fe(23 – 25.5%) and Cu(2.2-4.3%). Phases 1 and 2 are the corresponding primary α phase and eutectic silicon Si(β). In the examined structure, phase separations can be observed in the form of light grey skeletons (3) or in a compact form (4). These are complex intermetallic phases. Figure 4 shows a photo from an X-ray microanalyzer and the chemical composition confirms the complexity of the indicated phases. Those phases are rich on Fe(23 – 25.5%) and Cu(2.2-4.3%). Phases 1 and 2 are the corresponding primary α phase and eutectic silicon Si(β).

a)



b)

Elt.	Line	Intensity (c/s)	Conc	Units
Na	Ka	7,04	0,214	wt.%
Al	Ka	2 414,54	57,136	wt.%
Si	Ka	263,76	9,229	wt.%
Mn	Ka	62,30	5,307	wt.%
Fe	Ka	247,52	25,525	wt.%
Ni	Ka	2,26	0,377	wt.%
Cu	Ka	9,59	2,213	wt.%
			100,000	wt.%

3

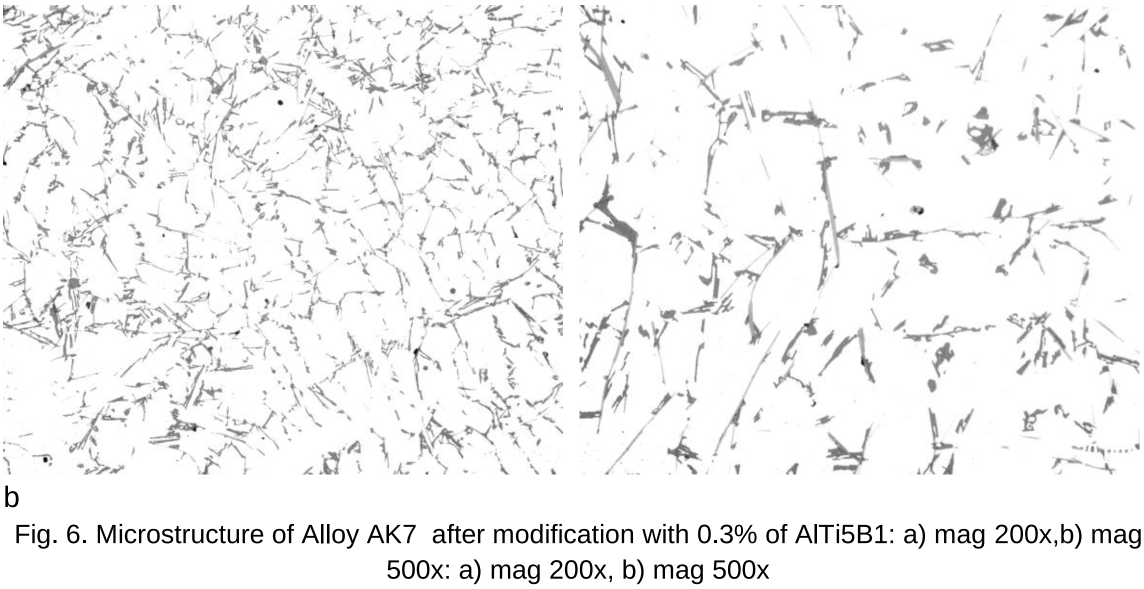
Elt.	Line	Intensity (c/s)	Conc	Units
Na	Ka	5,06	0,145	wt.%
Al	Ka	2 777,13	64,078	wt.%
Si	Ka	179,08	6,471	wt.%
Mn	Ka	11,68	0,991	wt.%
Fe	Ka	229,22	23,505	wt.%
Ni	Ka	2,94	0,488	wt.%
Cu	Ka	18,81	4,322	wt.%
			100,000	wt.%

4

Fig. 5. Image of the structure area with the analysed phases for the AK7 alloy in its unmodified state (a) and chemical compositions of complex phases (b)

Figure number 6 shows the microstructure of the AK7 alloy after modification with the addition of 0.3% AlTi5B1. Dendritic precipitates of the primary α phase became more regular and their primary arms became little thinner in comparison to the unmodified state. The form of eutectic silicon (Si) in the α(Al) + β(Si) eutectic has not changed and still has the form of dark gray plates with various thicknesses, different size or length. Their less frequent distribution is noticeable. In the eutectic area (fig. 6b and fig. 7) and on the border of the dendrites of the primary αphase, there are crystals in the form of long, bright, thin needles (4 and 5) that are rich on Fe (12%) and Mn (1.9%). There is a short dark gray needle (2) rich on Fe (12%) and Mn (2.8%). Phases 1 and 3 are the corresponding primary α phase and eutectic silicon Si(β). Despite such small changes in the alloy structure in relation to the unmodified alloy, a much higher Brinell hardness index of 62 HB was achieved. Apart from the unfavorable lamellar form of the eutectic beta phase (rich in Si), an additional factor that could have influenced the increase in hardness may be a significant number of occurrences of acicular complex phases rich in Fe due to analyzed area.

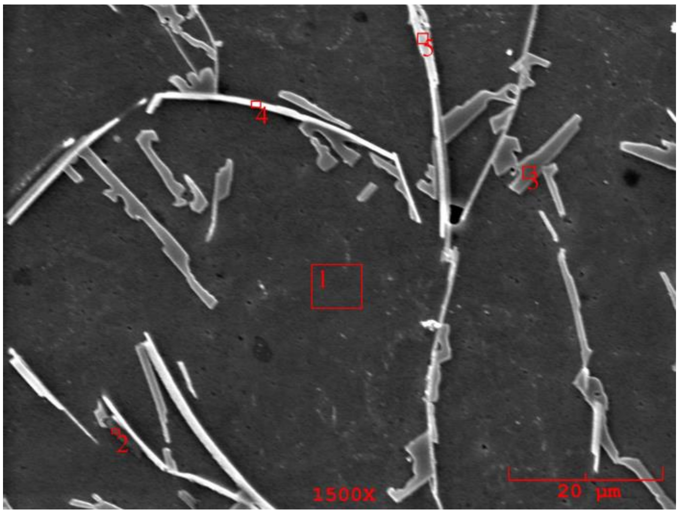
a) b)



b

Fig. 6. Microstructure of Alloy AK7 after modification with 0.3% of AlTi5B1: a) mag 200x,b) mag 500x: a) mag 200x, b) mag 500x

a)



b)

2

Elt.	Line	Intensity (c/s)	Conc	Units
Mg	Ka	15,21	0,318	wt.%
Al	Ka	2 993,68	69,075	wt.%
Si	Ka	367,83	14,780	wt.%
Mn	Ka	28,56	2,801	wt.%
Fe	Ka	101,74	12,014	wt.%
Ni	Ka	1,70	0,321	wt.%
Cu	Ka	2,65	0,692	wt.%
			100,000	wt.%

4, 5

Elt.	Line	Intensity (c/s)	Conc	Units
Mg	Ka	32,95	0,603	wt.%
Al	Ka	3 462,25	69,524	wt.%
Si	Ka	414,82	14,550	wt.%
Mn	Ka	22,45	1,915	wt.%
Fe	Ka	119,01	12,225	wt.%
Ni	Ka	0,92	0,150	wt.%
Cu	Ka	4,54	1,032	wt.%
			100,000	wt.%

Fig. 7. Image of the structure area with the analysed phases for the AK7 alloy after modification with 0.3% of AlTi5B1 (a) and chemical compositions of complex phases (b)

The microstructure of the AK7 alloy modified with the addition of 0.3% AlSr10, shown in Figure 8, showed significant changes in structure. Strontium present in the AlSr10 master alloy caused a change in the form of eutectic silicon from the form of large plates to the form of very fine fibres comparing to unmodified state. This also resulted in a general fragmentation of the components in the eutectic α(Al) + β(Si) area.

a) b)

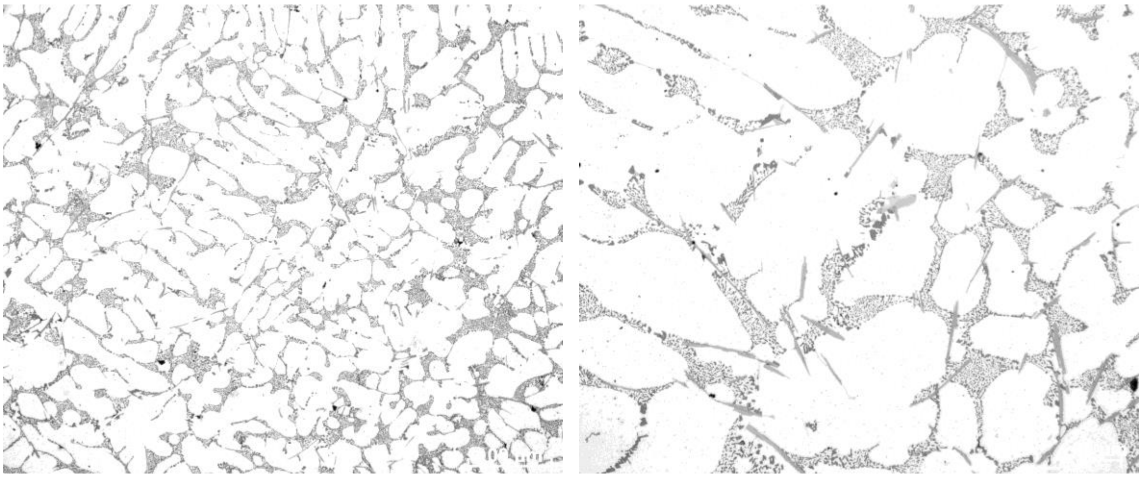
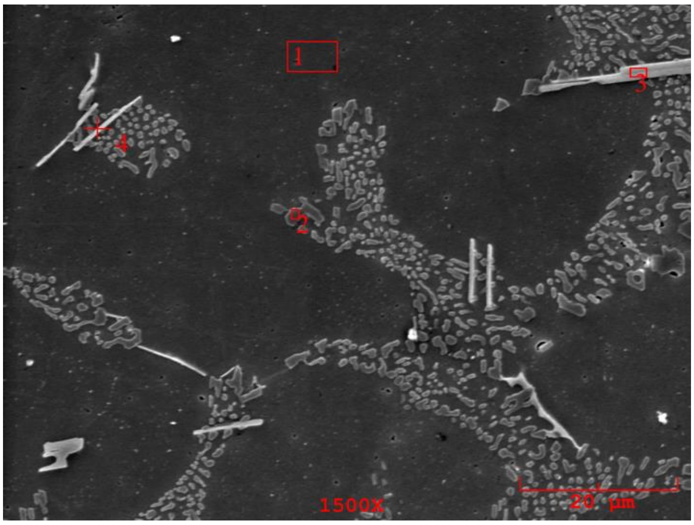


Fig. 8. Microstructure of Alloy AK7 after modification with 0.3% of AlSr10: a) mag 200x,b) mag 500x: a) mag 200x, b) mag 500x

As Figure 9 confirms, in the structure of the alloy, especially in the eutectic area, there are short, very bright needle precipitates (4) rich in Fe (10.8%) and Mn (1.8%). It can also notice the occurrence of darker, much thicker and longer needles, which are much richer in Fe (18%) and Mn (3.9%) than the thinner ones. Phases 1 and 2 are the corresponding primary α phase and eutectic silicon Si(β). In the case of the alloy sample modified with the addition of 0.3% of the AlSr10 master alloy (containing Sr), a Brinell hardness of 62 HB was achieved, which is a higher value compared to the unmodified alloy. The participation of a significant amount of iron acicular phases could also have had an influence on the increase in the hardness of the alloy, however in this case they are much shorter and thinner than after modification with 0.3% of AlSr10.

a)



b)

3

Elt.	Line	Intensity (c/s)	Conc	Units
Mg	Ka	15,04	0,383	wt.%
Al	Ka	2 039,73	54,090	wt.%
Si	Ka	554,59	22,289	wt.%
Mn	Ka	37,14	3,901	wt.%
Fe	Ka	143,63	18,207	wt.%
Ni	Ka	1,36	0,277	wt.%
Cu	Ka	3,02	0,852	wt.%
			100,000	wt.%

4

Elt.	Line	Intensity (c/s)	Conc	Units
Mg	Ka	24,40	0,533	wt.%
Al	Ka	2 704,62	64,823	wt.%
Si	Ka	506,41	20,696	wt.%
Mn	Ka	18,08	1,868	wt.%
Fe	Ka	87,37	10,863	wt.%
Ni	Ka	1,50	0,297	wt.%
Cu	Ka	3,34	0,919	wt.%
			100,000	wt.%

Fig. 9. Image of the structure area with the analysed phases for the AK7 alloy after modification with 0.3% of AlSr10 (a) and chemical compositions of complex phases (b)

Figure no. 10 shows an image of the microstructure of the AK7 alloy after modification with the addition of 0.3% AlSr10 and 0.3% AlTi5B1. Comparing to the initial state, the greatest change occurred in the area of the α(Al) + β(Si) eutectic mixture. Strontium (in master alloy AlSr10) caused a change in the unfavourable lamellar morphology of silicon into a finer form, namely fibres. This also caused significant compaction in the eutectic. The addition of boron in the AlTi5B1 aster alloy resulted in finer and more compact dendritic crystals of the primary alpha phase in comparison to initial state. Figure 10 confirms that in addition to the basic phases, there are also complex phases in the structure.

a) b)

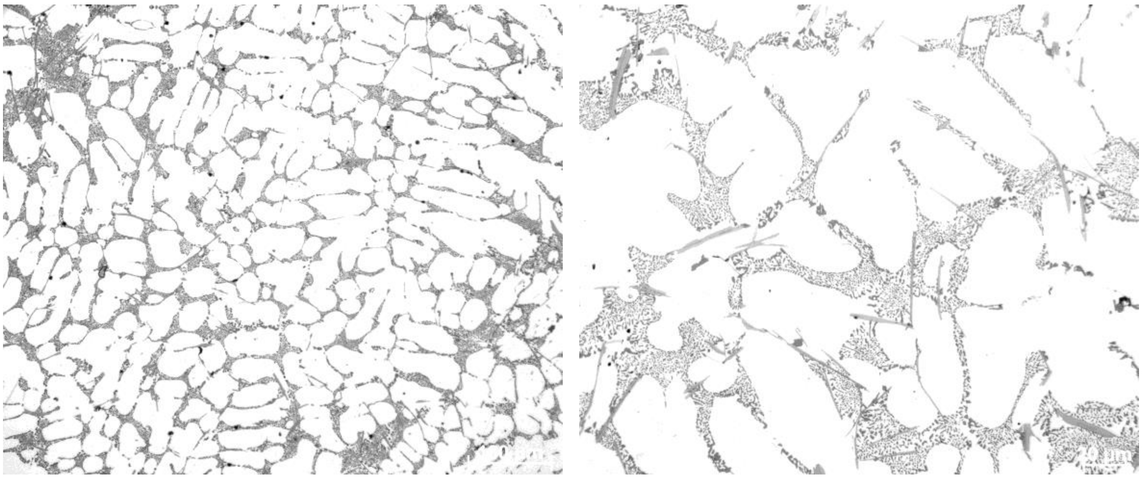
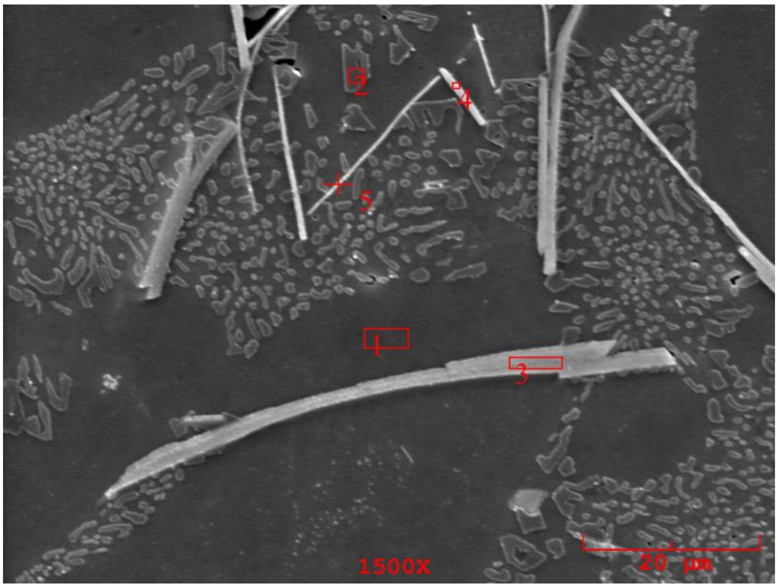


Fig. 10. Microstructure of Alloy AK7 after modification with 0.3% of AlTi5B1 and 0.3% AlSr10: a) mag 200x,b) mag 500x: a) mag 200x, b) mag 500x

Precipitations in the form of long (3) or short thickened needles (4) and long thin needles (5) were observed. All three types of needle shape phases are very rich in iron (1.8-21.4% Fe) and manganese (0.6-3.6% Mn), and this condition is related to the percentage of these two elements in them. The thicker the needle, the greater the proportion of mainly iron. In phases 3 and 4, there is additional copper content above 1%. For the alloy AlSi7Mg modified with addition of 0.3%AlSr10 and 0.3%AlTi5B1 a Brinell hardness of 67 HB was achieved. Sach difference in hardness in comparison to alloy on initial state can be generated by widening of refined eutectic area with still hard crystals of phase β(Si) in relation to dendritic-shaped α phase. Additionally there are on the microstructure many very thick and long needle of Fe-rich phases that can increase hardness of the alloy.

a)



b)

Elt.	Line	Intensity (c/s)	Conc	Units
Mg	Ka	12,49	0,308	wt.%
Al	Ka	1 952,93	49,253	wt.%
Si	Ka	652,92	23,760	wt.%
Mn	Ka	37,49	3,623	wt.%
Fe	Ka	183,69	21,447	wt.%
Ni	Ka	1,77	0,333	wt.%
Cu	Ka	4,90	1,275	wt.%
			100,000	wt.%

3

Mg	Ka	31,54	0,664	wt.%
Al	Ka	3 430,06	85,470	wt.%
Si	Ka	143,43	7,307	wt.%
Mn	Ka	9,33	1,079	wt.%
Fe	Ka	28,88	4,005	wt.%
Ni	Ka	1,12	0,245	wt.%
Cu	Ka	4,02	1,230	wt.%
			100,000	wt.%

4

Mg	Ka	18,89	0,363	wt.%
Al	Ka	3 298,17	76,326	wt.%
Si	Ka	436,78	19,876	wt.%
Mn	Ka	5,69	0,635	wt.%
Fe	Ka	13,83	1,851	wt.%
Ni	Ka	0,29	0,062	wt.%
Cu	Ka	3,01	0,887	wt.%
			100.000	wt.%

5

Fig. 11. Image of the structure area with the analysed phases for the AK7 alloy after modification with 0.3% of AlTi5B1 and 0.3% AlSr10 (a) and chemical compositions of complex phases (b)

3. CONCLUSION

Due to the unfavorable structure of the primary AlSi7Mg alloy, it was decided to investigate the effect of selected modifiers (Sr and B) in the form of AlSr10 and AlTi5B1 modifying mortars. Based on the results of the conducted tests, it can be seen that adding modifier like Sr as a master alloy AlSr10 in amount of 0.3% can significantly influence on structure. This is manifested by significant fragmentation and a change in the shape of the eutectic beta (Si) phase rich in silicon from thick plates to a finer form of fibers. The confirmation of the favorable change in this case is also the increase in Brinell hardness to 62 HB in relation to the alloy in its initial state.

Also, the use of simultaneous modification with the addition of 0.3% AlSr10 and 0.3% AlTi5B1 contributed to the change in the form of the eutectic phase rich in silicon from very unfavorable plate-like precipitates to much finer ones in the shape of fibers. However, the effect of the addition of Boron (AlTi5B1) did not show such a significant effect on the primary dendritic alpha phase. This modified alloy showed an increase in Brinell hardness to 67 HB, which is the most favorable result. In further studies, it would be worth checking how additives used in quantities different from those used in the described studies can affect changes in the structure and mechanical properties of the tested alloy. It would also be important to examine the cracking course of the alloy, e.g. AlSi7Mg, in the initial state and after modification with various modifiers.

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