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Investigation of the influence of the manufacturing process on the structure of hypereutectic aluminium-silicon alloys

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Abstract. **Two technological approaches were used to produce the hypereutectic aluminium-silicon alloys AlSi21Cu5MgCr, AlSi21Cu5Cr, AlSi25Cu4Cr and AlSi25Cu5Cr. In one case, alloys were melted from pure metals, metallurgical processing of the melts was carried out, and experimental castings were cast. In the other case, remelting of previously prepared alloys was carried out for casting test castings from the studied alloys, and the metallurgical processing of the melts was carried out at a lower temperature. The influence of the method of obtaining the alloys on their structure has been established.**

Keywords: ***hypereutectic aluminium-silicon alloys, technological processes, structure***

I. INTRODUCTION

The mechanical and operational properties of hypereutectic aluminium-silicon alloys are closely related to the size, shape and distribution of primary and eutectic silicon crystals in their microstructure. Phosphorus is most often used to modify primary silicon crystals, because it forms AlP, which has a crystal lattice identical in appearance to that of silicon and has comparable parameters (AlP-0.5431 nm, Si-0.5421 nm) [1]. Phosphorus modification is a well-known and most commonly used method for influencing the morphology of silicon crystals in the structure of hypereutectic aluminium-silicon alloys, but the process is characterized by its instability. There are data on the influence of the cooling rate of the alloys in the crystallization process, the size of the AlP particles, the melting temperature of the alloys, the content of P in the used ligatures on the process of modifying silicon in this type of slag [2]-[6]. New ligatures have been developed in order to achieve the maximum modifying effect of silicon crystals in the structure of these alloys [7]-[9].

To obtain alloys with increased mechanical and improved operational properties, it is necessary to modify the eutectic silicon crystals. Combinations of phosphorus and other chemical elements are used to modify primary and eutectic silicon [10]-[16].

The aim of the present study is to determine the influence of the method of obtaining the alloys on their structure.

II. MATERIALS AND METHODS

The object of the present study is non-standardized hypereutectic aluminium-silicon alloys. Two technological methods were used to prepare the alloys. In one method, technically pure metals were used, and only chromium was introduced into their composition by using the exothermic flux-ligature Al20Cr80. The alloys are melted in an electric resistance furnace with a graphite crucible under a layer of roof refining flux (10 KCl : 50 NaCl : 10 Na_3AlF_6) in an amount of 0.5% of the mass of the alloy. After melting the aluminium at a temperature of 950º C, the calculated

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amount of Si is introduced in portions. After complete absorption of silicon, copper, magnesium (AlSi21Cu5MgCr) and chromium are introduced. The alloys are degassed with argon for 3 min. Metallurgical processing ends with the modification of the alloys. The compositions AlSi21Cu5MgCr, AlSi21Cu5Cr and AlSi25Cu4Cr are modified with 0.04% P, and the AlSi25Cu5Cr alloy with 0.07% P. The phosphorus modifier was introduced into the melts of the investigated alloys through the CuP10 ligature. The alloying and metallurgical processing of the alloys (refining, degassing and modification) is at a melt temperature of 950º C. Casting of experimental castings is at the indicated temperature. Metal casting equipment pre-coated and heated to a temperature of 200º C was used. Table 1, Table 2, Table 3 and Table 4 show the chemical composition of the alloys thus prepared.

TABLE 1 CHEMICAL COMPOSITION OF ALSI21CU5MGCR (%) PURE METALS

Si	Cu	Mg	Cr	Fe	Al
20,82	4,83	1,28	0,374	0,179	rest

TABLE 2 CHEMICAL COMPOSITION OF ALSI21CU5CR (%) PURE METALS

Si	Cu	Cr	Fe	Ni	Al
20,86	4,88	0,899	0,139	0,005	rest

TABLE 3 CHEMICAL COMPOSITION OF ALSI25CU4CR (%) PURE METALS

Si	Cu	Cr	Fe	Ni	Al
24,98	3,69	0,538	0,160	0,005	rest

TABLE 4CHEMICAL COMPOSITION OF ALSI25CU5CR (%) PURE METALS

Si	Cu	Cr	Fe	Ni	Al
25,31	4,32	0,528	0,122	0,005	rest

An electrical resistance furnace with a graphite crucible was again used to melt the investigated alloys according to the second technological method. The alloys are melted according to the technology described above, and the metallurgical processing involves only refining the melts using flux. Alloys are block cast. The alloys thus prepared were subjected to remelting under a layer of roof refining flux in an amount of 0.5% of the mass of the alloy, and their degassing and modification was carried out at a lower temperature compared to the first method. The working temperature is 830º C. To modify the AlSi21Cu5MgCr, AlSi21Cu5Cr and AlSi25Cu4Cr alloys, phosphorus is again used in the amount of 0.04% P, and the amount of modifier for modifying the AlSi25Cu5Cr alloy is 0.07%, i.e. as in the first method. Casting of experimental castings was at a temperature of 830º C, and the casting equipment used was again pre-coated and heated to a temperature of 200º C. Table 5, Table 6, Table 7 and Table 8 show the chemical composition of the alloys prepared by remelting.

TABLE 5 CHEMICAL COMPOSITION OF ALSI21CU5MGCR (%) REMELTING

Si	Cu	Mg	Cr	Fe	Al
21,01	5,285	1,12	0,373	0,185	rest

TABLE 6 CHEMICAL COMPOSITION OF ALSI21CU5CR (%) REMELTING

Si	Cu	Cr	Fe	Ni	Al
20,89	4,695	0,910	0,139	0,005	rest

TABLE 7 CHEMICAL COMPOSITION OF ALSI25CU4CR (%) REMELTING

Si	Cu	Cr	Fe	Ni	Al
24,63	4,575	0,570	0,240	0,005	rest

TABLE 8 CHEMICAL COMPOSITION OF ALSI25CU5CR (%) REMELTING

Si	Cu	Cr	Fe	Ni	Al
25,48	5,216	0,522	0,149	0,005	rest

Metallographic sections were prepared from the alloys prepared by the two technological methods used. The preparation of the samples for metallographic analysis is carried out according to standard methodology: wet grinding on abrasive paper with an increasing number from № 240 to № 1000 and polishing with diamond paste and lubricant until a mirror surface of the grinds is obtained. The microstructure of the sections thus prepared is revealed with Keller's reagent (1p. HF, 1.5p. HCl, 2.5p. HNO_3, 95p. H_2O) and clarified with HNO_3. The study was performed on a Leica DM ILM microscope using software and the grain measurement and phase analysis module. Grain measurement accuracy is up to hundredths of µm.

The influence of the technological process on the shape and dimensions of the primary and eutectic silicon in the structure of the studied alloys was investigated.

III. RESULTS AND DISCUSSION

The results of the microstructural analysis show that in the structure of the alloys prepared from technically pure metals, the main amount of primary silicon crystals are unmodified, and the eutectic silicon is needle-shaped.

In the AlSi21Cu5MgCr alloy structure, the primary Si crystals are irregular in shape and cannot be measured, and the Si crystals in the eutectic composition are needle-shaped, and most of them have an average linear size of 4.54 µm, but they occur and those with an average linear size of 29.4 µm (Fig. 1).

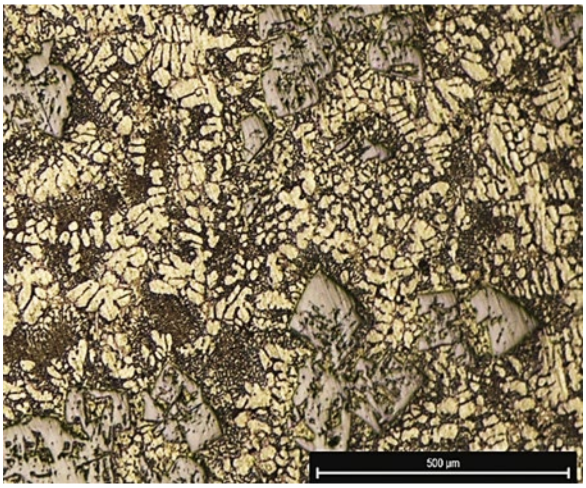

Fig. 1. Microstructure of AlSi21Cu5MgCr alloy (pure metals)

In the AlSi21Cu5Cr alloy structure, the eutectic silicon is in the form of needles with a length of up to 26.7 µm, and the primary silicon is again unmodified (Fig. 2).

Fig. 2. Microstructure of AlSi21Cu5Cr alloy (pure metals)

In the AlSi25Cu4Cr alloy, the main amount of Si crystals are unmodified, but there are also those that have a regular shape and sizes in the range of 35 to 50 µm. Eutectic silicon has a needle-like shape and a length in the range of 30 to 54 µm (Fig. 3).

The bulk of the primary silicon crystals in the AlSi25Cu5Cr alloy structure are unmodified, irregularly shaped, and unmeasurable. That part of the crystals that have been modified is in the form of polywalls with a conditional average diameter of 32 µm. The observed Si in the composition of the eutectic is in the form of needles with an average linear size of 25.7 µm (Fig. 4).

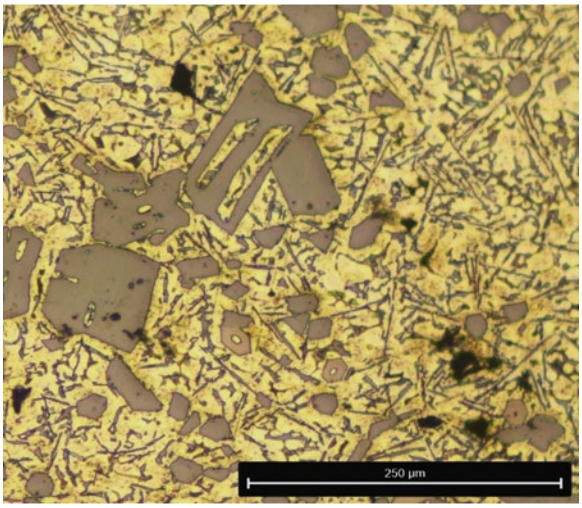

Fig. 3. Microstructure of AlSi25Cu4Cr alloy (pure metals)

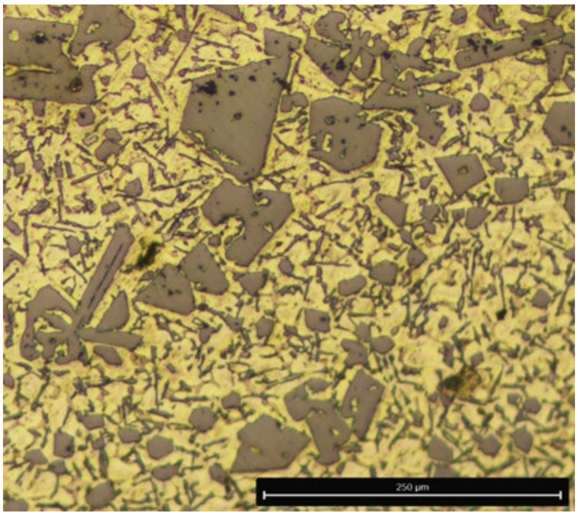

Fig. 4. Microstructure of AlSi25Cu5Cr alloy (pure metals)

In [17], the influence of T6 heat treatment on the structure of hypereutectic aluminium-silicon alloys was studied. A change in the shape and size of the primary silicon crystals after T6 was not observed, but a change was recorded only in the eutectic silicon crystals. In view of this, obtaining such type of alloys with a completely modified structure after casting requires the use of different technological approaches. The structures of the investigated alloys prepared from technically pure metals under the specified conditions are unsatisfactory.

The results of the microstructural analysis of the alloys prepared according to the second of the technological methods used (by remelting previously prepared alloys) show a significant change in the structures of the studied compositions.

In the structure of the AlSi21Cu5MgCr alloy obtained by remelting, the primary silicon crystals are modified and uniformly distributed in the structure. They have a conditional average diameter of 32.4 µm. The silicon crystals in the composition of the eutectic have an average linear size of 8.6 µm (Fig. 5).

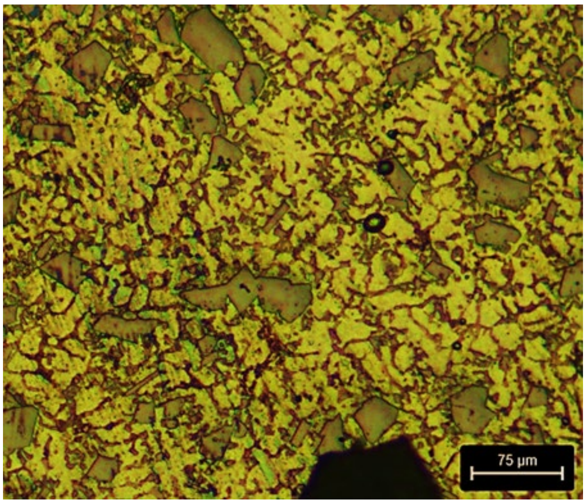

Fig. 5. Microstructure of AlSi21Cu5MgCr alloy (remelting)

The shape of the silicon crystals in the AlSi21Cu5Cr alloy structure (remelt) are polygonal in shape and dimensions not exceeding 28.2 µm. Eutectic silicon is in the form of "needles" with lengths up to 19.8 µm (Fig. 6).

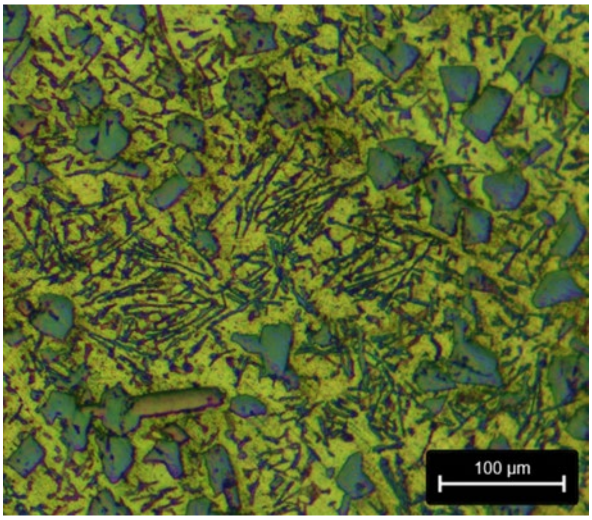

Fig. 6. Microstructure of AlSi21Cu5Cr alloy (remelting)

In the compositions with increased silicon content (AlSi25Cu4Cr and AlSi25CuCr) obtained by remelting previously prepared alloys, the primary silicon crystals are modified and of comparable size. In the AlSi25Cu4Cr alloy structure, silicon crystals have a conditional average diameter of 37.7 µm, and the same ones in the AlSi25CuCr alloy structure have sizes not exceeding 38.8 µm. In both alloys, the eutectic silicon is needle-shaped, and in the AlSi25Cu4Cr alloy it has a linear length of 24.5 µm (Fig. 7), and in the AlSi25Cu5Cr alloy, the eutectic silicon needles reach a length of 28.4 µm (Fig. 8).

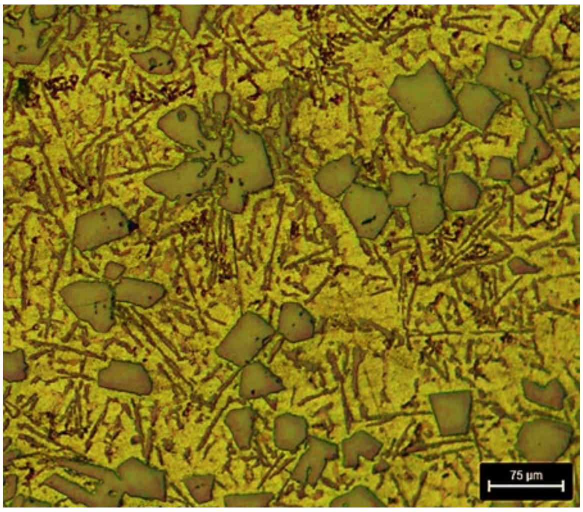

Fig. 7. Microstructure of AlSi25Cu4Cr alloy (remelting)

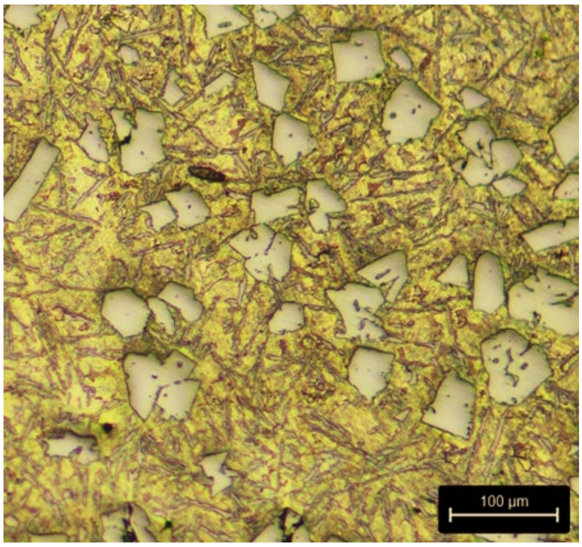

Fig. 8. Microstructure of AlSi25Cu5Cr alloy (remelting)

The results of the conducted research show that the conditions under which the processes of melting, modification and crystallization rate were carried out have a direct influence on the structure of the studied compositions. When using technically pure metals for the preparation of the alloys, the temperature of modification and casting of the experimental castings is 950º C. The low rate of crystallization of the alloys is a prerequisite for the coagulation of the AlP particles, i.e. they acquire large dimensions and as a result they do not represent crystallization centers on which primary silicon crystals can form and grow. From this it follows that not all AlP particles have the role of crystallization centers, the degree of modification is reduced and therefore, in this technological method of preparing the investigated alloys, insufficiently well modified structures were registered - the Si crystals are of irregular shape, large sizes and are unevenly distributed in the structure of the alloys.

In the second technological method of preparing the studied compositions by remelting previously produced alloys, well-modified structures (refine, regularly shaped and evenly distributed Si crystals) were observed. The processes of melting, metallurgical processing of the melts and casting of the experimental castings were carried out at a temperature of 830º C. In this case, the higher rate of crystallization hinders the growth of the formed AlP particles, i.e. they have the necessary dimensions on which to form and grow the silicon crystals separated in the temperature interval of crystallization of the alloys, as a result of which modified structures are observed.

IV. CONCLUSIONS

In order to obtain hypereutectic aluminium-silicon alloys with well-modified structures, not only the amount of the phosphorus modifier used, but also the rate of crystallization has an influence. For the modification of the AlSi21Cu5MgCr, AlSi21Cu5Cr, AlSi25Cu4Cr and AlSi25Cu5Cr alloys prepared by both technological methods, the same amount of modifier was used. In one case, the crystallization rate is lower and the resulting structures are unsatisfactory, and in the case where a higher crystallization rate is provided, well-modified structures are observed.

Carrying out the modification treatment at higher temperatures is a prerequisite for reducing the degree of modification, due to the coagulation of the formed AlP crystallization centers to sizes on which primary silicon crystals cannot form and grow.

In production conditions, it is recommended to use the technological method with remelting of previously prepared material, due to the fact that the processes of melting, metallurgical processing and casting are conducted at lower temperatures, i.e. it is economically more effective, the degree of modification is greater – alloys with well-modified structures are obtained.

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