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MICROSTRUCTURE OF AlSi17Cu5 ALLOY AFTER OVERHEATING OVER LIQUIDUS TEMPERATURE

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The paper presents microstructure tests of alloy AlSi17Cu5. In order to disintegrate the primary grain of silicon the so-called time-temperature transformation TTT was applied which was based on overheating the liquid alloy way over the temperature $T_{liq.}$, soaking in it for 30 minutes and casting it to a casting mould. It was found that such process causes the achievement of fine-crystalline structure and primary silicon crystals take up the form of pentahedra or frustums of pyramids. With the use of X-ray microanalysis and X-ray diffraction analysis the presence of intermetallic phases Al_2Cu, Al_4Cu_9 which are the ingredients of eutectics α - AlCu - β and phase Al_9Fe_2Si which is a part of eutectic α - AlFeSi - β was confirmed.

Key words: casting alloys Al-Si, microstructure, heat treatment in liquid state

INTRODUCTION

Among technical alloys Al the silumins are the most important, particularly those with content of over 13 % of Si weight. It mainly concerns aviation industry, rocket technologies, engineering industry and transport. Such wide application of hypereutectic alloys Al - Si results from low thermal expansion, good physical and mechanical characteristics as well as beneficial tribological and utilitarian properties. Particularly high dimensional and thermal stability, resistance to corrosion and good heat conductivity decide upon wide application in automotive industry, inter alia, for heavily loaded casts of pistons in internal combustion engines, drive units, cylinder bodies, compressors, pumps and brakes. Microstructure of silumins is responsible for that fact because during standard conditions of casting some spread dendritic crystals of Al are formed with varied contribution of coarse-grained eutectic α(Al) - β(Si) and multi-end, star-shaped crystals of silicon which undergo primary crystallisation. A change of this unfavourable structure may be conducted with the use of modification and refining [1-5], adding alloy additives [6, 7], influence of electro-magnetic field [8], fast heat removal [9, 10] and by application of so-called thermal treatment of alloys in liquid state [11]. This process is based on overheating of liquid alloy way over temperature T_{liq}, heating in this temperature for a given time period and then casting into a mould.

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AIM AND SCOPE OF STUDIES

The aim of microstructure tests of alloy AlSi17Cu5 was to determine:

– morphological form and distribution in matrix α (Al) of primary precipitations of silicon crystals,
– the influence of degree of superheat (over temperature $T_{liq.}$) on the way of nucleation and growth of hypereutectic silicon crystals,
– morphology of primary crystals of Si in alloy subject to significant overheating,
– type of crystallising eutectics α - AlCuSi - β and α - AlFeSi - β.

TEST MATERIALS AND METHODS

Alloy AlSi17Cu5 (A390.0) series A3XX.X was chosen for tests and melted in vacuum induction furnace Balzers VSG 02/631 in a melting made of SiC with cubic capacity of 200 cm^3. To avoid the negative influence of phenomena connected with gasification of metallic bath, as a result of significant overheating of alloy over $T_{liq.}$, a protective coating of Protecol-Degasal (0,4 % mass) was used. This mixture was dipped under the surface of liquid alloy and under the layer of created slag a 0,2 % mass of formulation Rafglin-3 was introduced in order to refine the alloy. The silumin was overheated to temperature of 920 °C, kept for 30 minutes in furnace and next casted to steel mould. Samples for structural tests were taken from central part of the cast. Metallographic micro-sections were conducted according to a standard procedure on grinders and polishing machines Struers which were subject to etching in 10 % acid HF. Metallographic observations were conducted on light microscope MeF-2 by Reichert Company. X-ray microanalysis tests were conducted on scanning microscope Hitachi S-3400N, conjugated with X-ray spectrometer EDS Voyager by Noran Company. A quality phase analysis was performed with the use of ICCD cards. Knowing the types of crystalline phases present in tested material - a Rietveld procedure was used with the program DBWS 9807 and for description of profile of diffraction lines - a Pearson VII function was applied. X-ray tests were conducted with the use of diffractometer X`Pert by Philips company, with the use of lamp with copper anode ($\lambda Cu_{K\alpha}$ - 1,54178 Å).

Table 1 **Chemical analysis of the AlSi17Cu5 cast alloy, /wt. %**

Alloy	Si	Cu	Fe	Ni	Mg	Mn	Sum of impurities	Al
AlSi17Cu5	16,72	4,86	0,29	0,03	0,02	0,02	0,01	rest

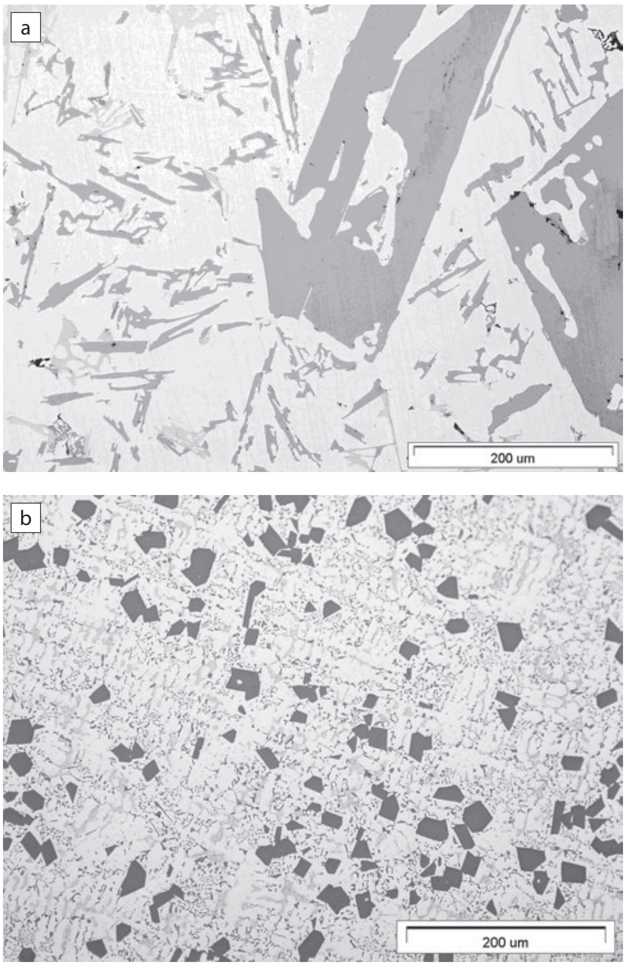

Figure 1 Microstructure of AlSi17Cu5 alloy: a) no overheating, b) after overheating to temperature of 920 °C

RESULTS AND DISCUSSION

Chemical composition of alloy AlSi17Cu5 is presented in Table 1. Example microstructures of alloy AlSi17Cu5 without overheating and after overheating to temperature of 920 °C are presented in Figures 1, 2 there are microstructures after deep etching.

As a result of alloy overheating way over $T_{liq.}$ temperature it was observed that hypereutectic divisions of silicon take up characteristic form of pentahedra or or frustums of pyramids. Examples of such crystals in alloy AlSi17Cu5 overheated to temperature of 920 °C and kept in furnace for 30 minutes are presented in Figure 3 and Table 2.

Results of X-ray microanalysis tests of alloy AlSi17Cu5

The main aim of X-ray microanalysis was to determine:

– arrangement and surface distribution of chemical elements which are parts of alloy AlSi17Cu5, particularly addition of copper and iron,

– linear distribution of chemical elements which are ingredients of tested silumin.

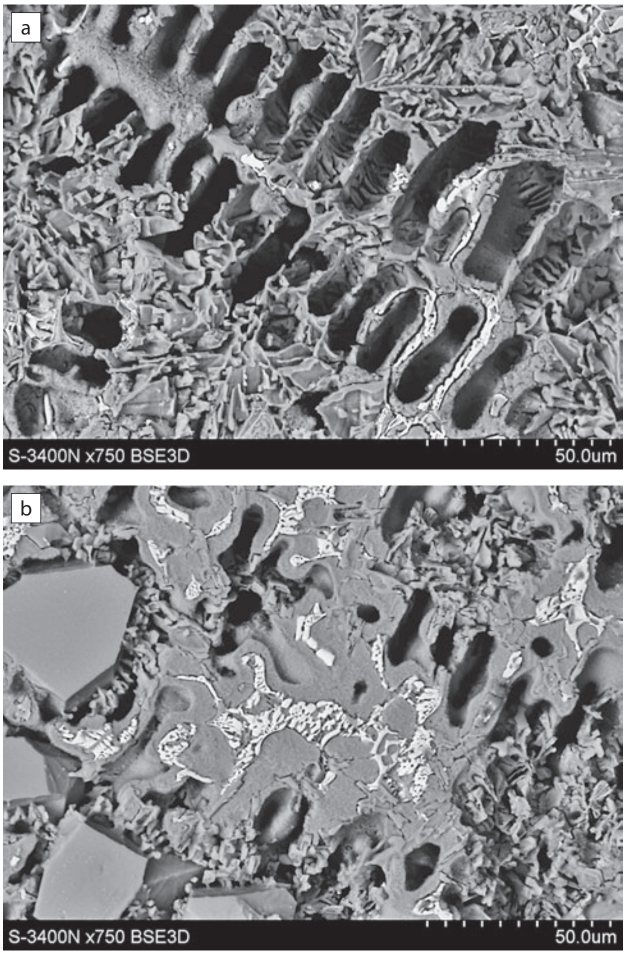

Figure 2 Microstructure of AlSi17Cu5 alloy overheated to 920 °C temperature after deep etching: a) areas of the etched dendrites of Al, b) the eutectic and primary silicon crystals

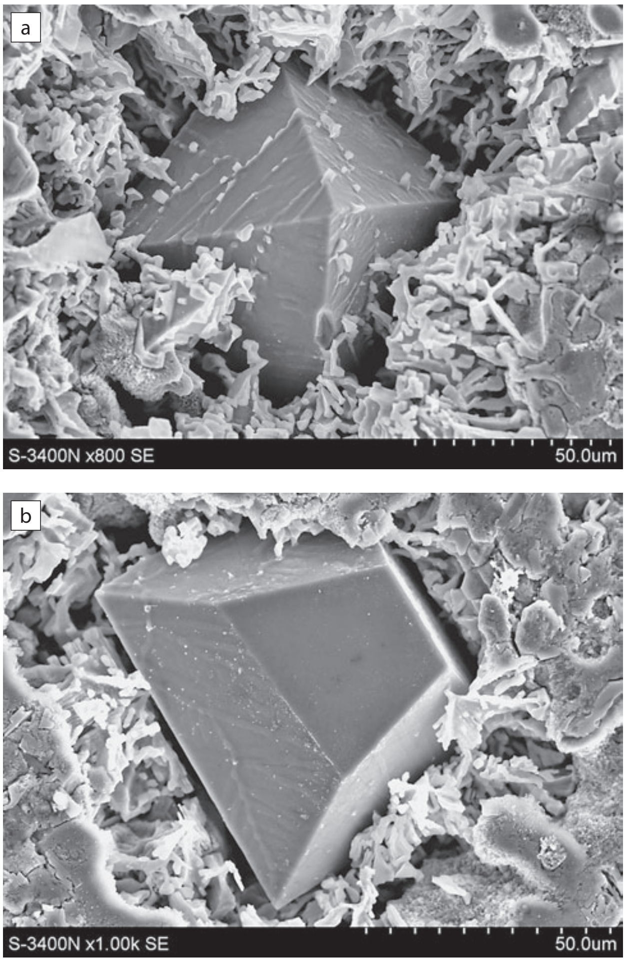

Figure 3 Primary silicon crystals in AlSi17Cu5 alloy overheated to a 920 °C temperature: a) in the shape of pentahedra, b) in the shape of a truncated pyramid apex

Results of tests of chemical composition in micro-areas of alloy AlSi17Cu5 after overheating to temperature of 920 °C, keeping for 30 minutes in furnace together with mass and atomic share of elements Al, Si and Cu are presented in Figure 4.

Table 2 **Information about point (according to Figure 3)**

% mass	Al - K	Si - K	Cu - K
point 1	0,8	99,2	
point 2	39,0	13,2	47,9
% atom.	Al - K	Si - K	Cu - K
point 1	0,8	99,2	
point 2	54,2	17,6	28,2

Surface distribution of copper proves that this chemical element is a part of crystallisation eutectic in temperature range 511 - 520 °C. It was confirmed by tests of thermal analysis ATD. Copper, present in form of intermetallic compound Al_2Cu, gathers mainly in solution αAl) and in eutectic. Iron gathers mainly in eutectic which forms the shape of “Chinese letters” and crystallises in temperature of about 505 - 508 °C [12].

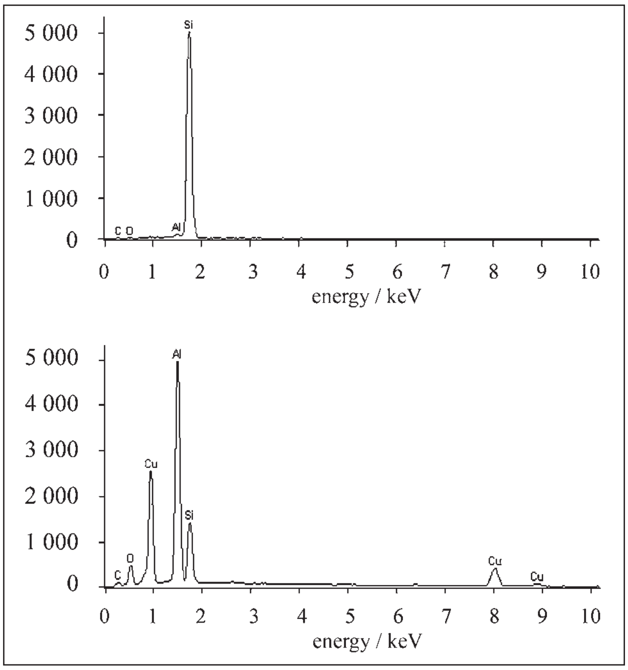

Figure 4 The results of chemical analysis in micro-regions of the AlSi17Cu5 alloy after overheating to 920 °C temperature with the well-formed silicon crystals

RESULTS OF X-RAY DIFFRACTION PHASE ANALYSIS OF ALLOY ALSI17CU5

Results of tests of phase composition with the use of XRD method are presented in Figure 5. and results of network parameters calculations of identified phases – in Table 3.

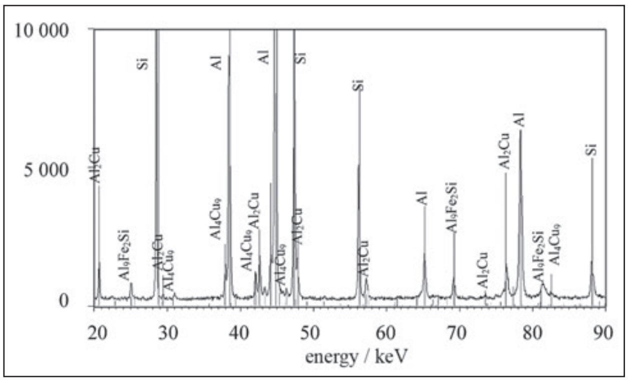

Figure 5 The XRD patterns of AlSi17Cu5 alloy overheated to 920 °C temperature

Table 3 **Characteristics of network parameters of alloy AlSi17Cu5 structure after overheating to temperature of 920 °C**

Type of parameter	Type of spatial group	Network parameter - Å			Content % mass
		Rietveld		ICDD	
Al	F m - 3 m (225)	a_0	4,049	4,05	57,5(6)
Si	F d - 3 m (227)	a_0	5,432	5,431	17,4(7)
Al_2Cu	I 4/m c m (140)	a_0	6,071	6,063	9,8(4)
		c_0	4,787	4,872	
Al_4Cu_9	P - 4 3 m (215)	a_0	8,696	8,707	11,6(6)
Al_9Fe_2Si	R - 3 c (167)	a_0	4,756	4,757	3,6(3)

CONCLUSIONS

The element responsible for beneficial relationship of utility properties in casting alloys Al - Si - Me is mainly silicon, in particular its proper form and size as well as alloy additives. The paper suggests a new method of achieving the fine-crystalline structure with the use of overheating the liquid alloy over liquidus temperature $T_{liq.}$, holding it in this temperature for a given time and casting into a metal mould. A typical hypereutectic silumin AlSi17Cu5 with elevated copper content, mainly used in automotive industry for heavily loaded casts of pistons and heads of internal combustion engines, was chosen for tests. This alloy was overheated to temperature of 920 °C, kept in furnace for 30 minutes and then the casting to a steel mould was conducted from which a material was taken to perform microstructure tests. It results from the presented research that overheating of alloy to temperature of 920 °C and keeping in furnace for 30 minutes results in significant refining of primary silicon crystals and their uniform distribution in matrix of eutectic α(Al) - β(Si) - Figure 1.

Besides the reduction of primary silicon divisions, a change in their morphology occurred turning towards the direction of block structure. As tests have shown, in hypereutectic alloys the primary silicon crystals form flat lamella which build up complicated bonds and show complex morphological character. Lamellar structure of those crystals mostly shows hexagonal or star-shaped form including radial, twin surfaces of growth. After overheating of alloy to temperature of 920 °C those crystals take up characteristic form of pentahedra or frustums of pyramids (Figure 3). Forms of tetrahedra or octahedra with close-packed lattice are the basis for a theory of simple liquids which are examples of quasi-gas models which serve for description of structure in liquid state. It is confirmed by Bernal theory [12]. Such crystals are more compact which significantly influences the improvement of machining of casts from hypereutectic silumins which were subject to significant overheating exceeding the temperature of $T_{liq.}$

In the next stage of tests an X-ray microanalysis was conducted and the chemical composition in micro-sites of alloy AlSi17Cu5 (after overheating of alloy to temperature of 920 °C and sustaining it for 30 min in furnace) as well as surface distribution of elements: Al, Si, Cu and Fe were determined. It can be concluded from the achieved results that, in alloy without overheating, copper crystallises in the form of intermetallic compound Al_2Cu, whereas after overheating the phase Al_4Cu_9 additionally crystallises. Those phases are the contents of eutectic α - AlCu - β. Iron crystallises as phase Al_9Fe_2Si, which is a part of triple eutectic α - AlFeSi - β. Presence of those phases was confirmed with tests of X-ray phase analysis XRD (X-ray diffraction analysis – Figure 6) and characteristics of network parameters of structure ingredients for alloy AlSi17Cu5 was presented in Table 3.

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Note: The responsible translator for English language is Marzena Rudnicka, Poland