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AlSi17Cu5Mg ALLOY AS FUTURE MATERIAL FOR CASTINGS OF PISTONS FOR INTERNAL COMBUSTION ENGINES

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The paper presents chosen properties and microstructure of AlSi17Cu5Mg alloy as future material for casting pistons in automotive industry. Tests were conducted to elaborate technology of preparation, assessment of crystallisation parameters and shaping the primary structure of the silumin with the aim to improve the working parameters and the functioning efficiency in cylinder-piston system. Refinement of Si crystals, achieved due to overheating above the temperature $T_{liq.}$ causes that the alloy reaches satisfactory properties in working chamber of the engine are optimised. Such condition of material characteristics causes that hypereutectic silumins, for chosen applications in transport, may serve as an alternative to Al - Si alloys of hypoeutectic and near - eutectic type.

Key words: Al - Si cast alloy, mechanical properties, microstructure of silumins

INTRODUCTION

Aluminum cast alloys particularly near-eutectic silumins, are widely applied materials in automotive industry due to their good mechanical and technological properties [1-3]. However, because of relatively difficult conditions of cyclic variable temperatures and workload on pistons in internal combustion engines, the search continues to find new solutions in terms of material and construction in order to improve the operational performance of the engine elements. Such solutions aim at changes in chemical composition of alloys with a view to improve the working properties as well as at application of optimal technological processes. One of such processes is the modern type of refi-ning silicon crystals through overheating far beyond the T_{liq} temperature [4-6]. Overheated of the liquid alloy about 250 °C above the temperature T_{liq}, combined with holding at this temperature for a predetermined period of time produces structure composed of fine crystals, ensur-ing high mechanical properties [7, 8].

AIM AND SCOPE OD STUDIES

The aim of this study is to influence of strong overheating on the mechanical properties and microstructure of primary silicon crystals in cast AlSi17Cu5Mg alloy. This is an alloy cast in sand and metal moulds and designed for high-loaded pistons operating in IC engines, cylinder blocks and bodies of compressors and pumps. To achieve the preset goal, the scope of the study includes:

- choice of alloy and modification concept based on the process of strong overheating,
- overheating the liquid alloy to 920 °C, holding for 40 minutes in furnace and casting,
- conducting the analysis thermal derivative, plotting the crystallisation curve and determination of the characteristic solidification parameter,
- measurement of the mechanical properties (HB, R_m, $R_{0,2}$) of cast alloy,
- study the microstructure.

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THE MATERIALS AND METHODS

The cast AlSi17Cu5Mg alloy was melted in a Balzers VSG induction furnace, using pure Al of A00 grade (99,98 % Al), technical silicon (99,96 % Si), master copper alloy AlCu30 and magnesium AlMg10 alloy. Alloys were melted in an SiC crucible of 800 cm^3 capacity and cast into a steel mould producing simultaneously Ø 200 × 1 600 mm specimens, which were next machined to the dimensions complying with PN EN 10002-1. Under the layer of produced slag, 0,2 % of the Rafglin-3 alloy refiner was added. Then the alloy was overheated at 920 °C. The temperature was recorded with an NiCr - NiAl thermocouple. This alloy modified 0,05 % of P (CuP10 master alloy) was added, and after 10 minutes, the bath was deslagged and the alloy was cast to an TA probe (Analdta software). The tested alloy was cast in four different conditions:

1. Unmodified (designated by the symbol SN),
2. Modified with phosphorus (the symbol SM),
3. Overheated at 920 °C for 40 minutes in the furnace (the symbol SP),
4. Overheated and modified according to the parameters as stated above (the symbol SPM).

Static tensile test was carried out in accordance with PN EN ISO 6892-1 on a 3382 Instron machine, using a 20:1 ratio and a constant tensile speed of 5 mm/min.

Brinell hardness test was performed in accordance with PN-EN ISO 6506-1 on a Zwick ZHF hardness tester under a load of 187,5 kg using a 2,5 mm diameter steel ball applied for a time of 35 seconds.

Metallographic examinations were carried out under an MeF - 2 Reichert light microscope and under a Hitachi S - 3 400N scanning electron microscope with EDS Noran attachment. Metallographic sections were prepared by standard procedure and etched with 10 % HCl.

RESULTS AND DISCUSSION

Results of chemical composition of the AlSi17CuMg alloy are shown in Table 1.

Table 1 **Chemical analysis of the AlSi17Cu5Mg cast alloy / wt. %**

Alloy	Si	Cu	Ni	Mg	Fe	Ti	Al
AlSiCuMg	16,72	4,48	0,01	0,93	0,11	0,01	rest

A view of the broken piston in automotive industry is shown in Figure 1, and the piston good is shown in Figure 2.

Figure 1 View of the area of the damaged piston in automotive industry

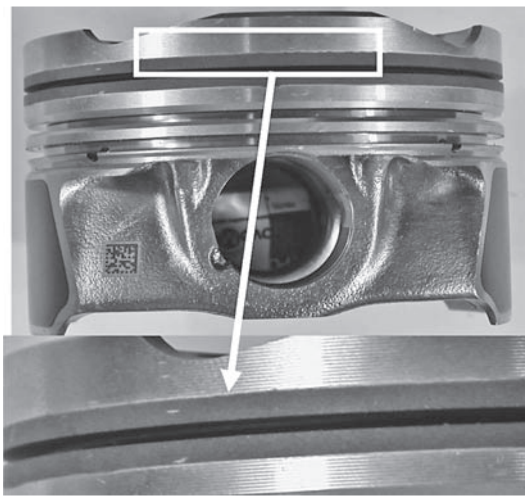

Figure 2 View of the good piston in auto-motive industry

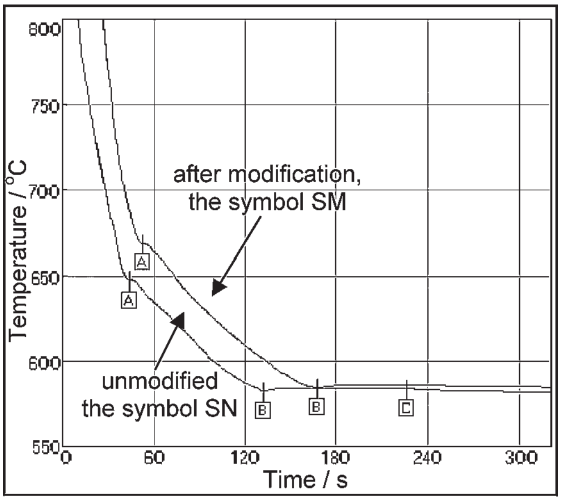

Figure 3 Thermal analysis for AlSi alloy after modified and unmodified

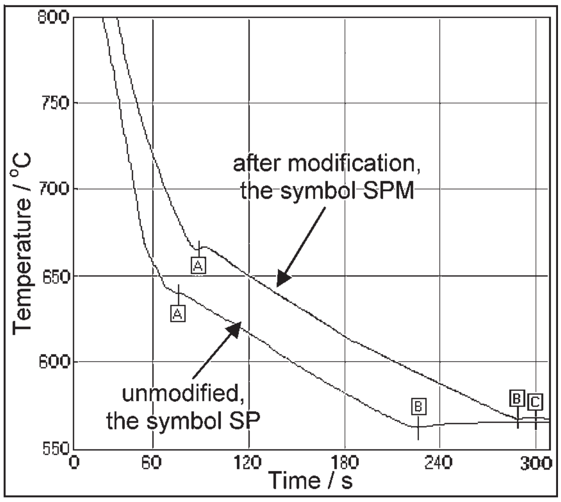

Figure 4 Thermal analysis for AlSi alloy after overheated to 920 °C

Was determined following temperature: T_{liq} (the crystallisation temperature of primary silicon crystals), $T_{E.min}$ (the mini-mum temperature of α – β binary eutectic crystallisation) and T_E (the temperature of α – β binary eutectic crystallisation). The results of thermal analysis (TA) carried out for the four different conditions are shown in Figures 3 and 4.

Crystallisation temperatures of the alloy tested in four different conditions are compared in Table 2. The results of hardness *HB*, tensile strength R_m and yield strength $R_{0.2}$ measurements obtained for the aforementioned four different conditions are shown in Figure 5 a - c.

Table 2 **Selected crystallisation tempera-tures of AlSi17Cu5Mg alloy / °C**

Point on TA curve	O	A	B	C
Alloy symbol	T_{start}	T_{liq}	$T_{E.min.}$	T_E
SN	806	648	568	570
SM	802	668	571	572
SP	921	641	566	568
SPM	919	668	573	574

A complementary research to the solidification process was study of microstructure. Samples were taken

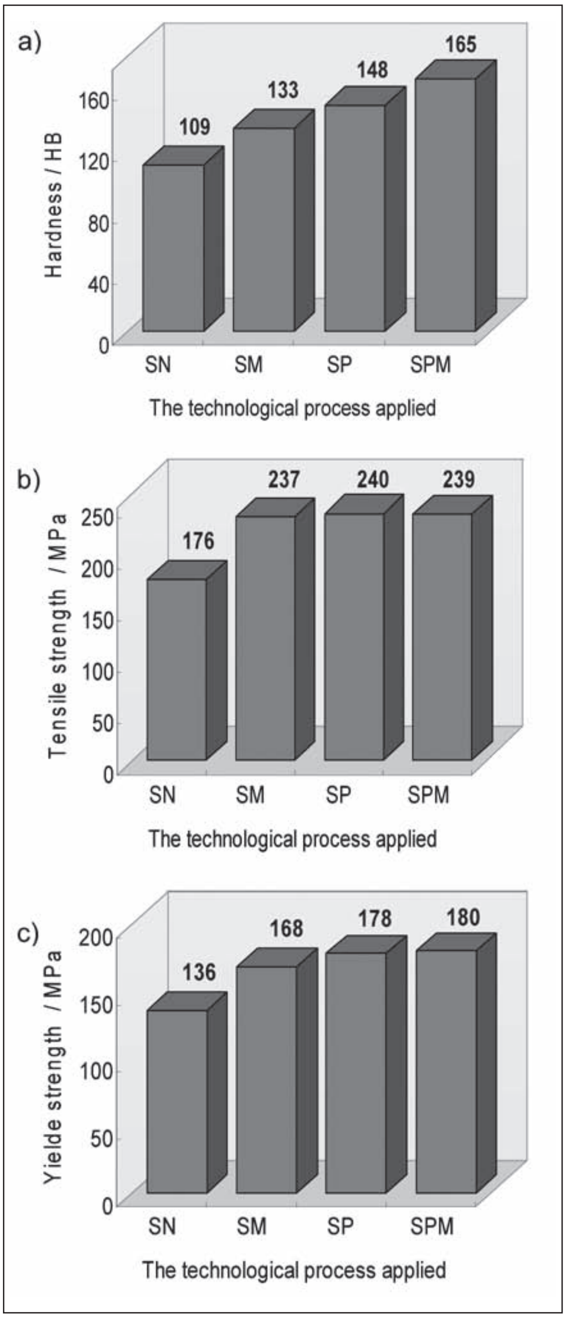

Figure 5 Mechanical properties of AlSi17-Cu5Mg alloy: a) *HB* hardness, b) R_m and c) $R_{0,2}$ as a function of applied technologies

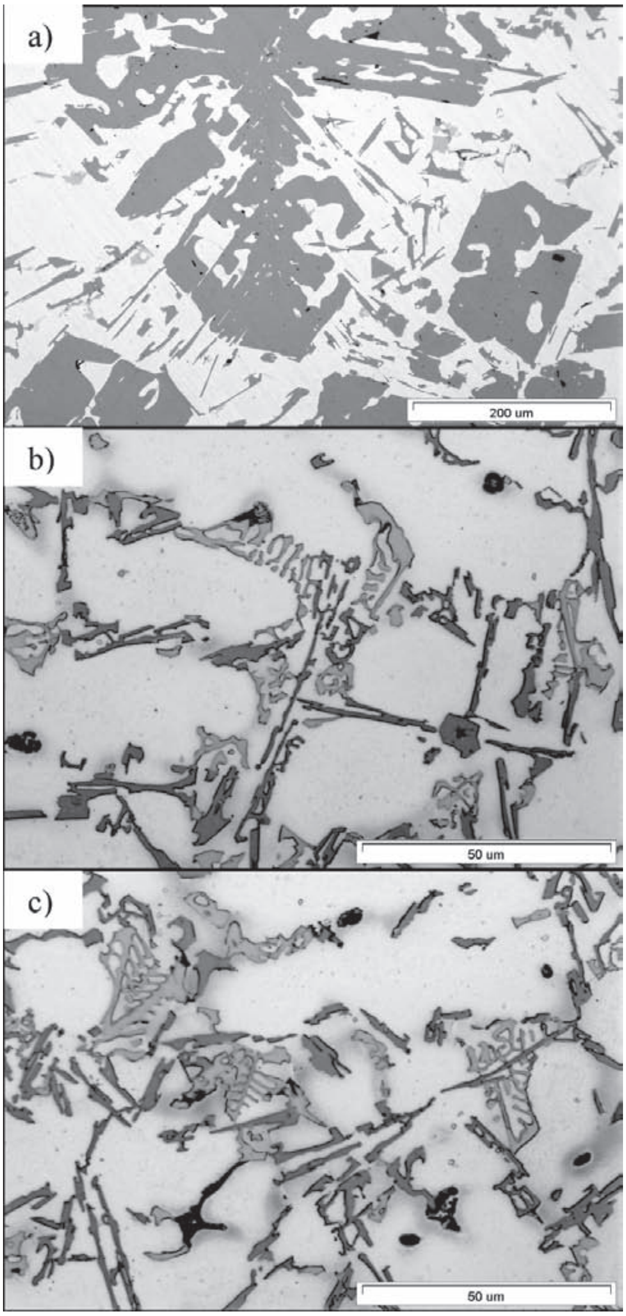

Figure 6 Microstructure of AlSi17Cu5Mg alloy: a) unmodified, b) modified with 0,05 % P, c) overheated to 920 °C temperature

from the areas of temperature measurement. Microstructures of AlSi17Cu5Mg alloy overheated to 920 °C are shown in Figure 6.

CONCLUSIONS

From the thermal analysis it follows that, for the base alloy, the temperature of the precipitation of primary silicon crystals (T_{liq}) is 648 °C, which is further confirmed by phase equilibrium diagram and chemical composition of the Al - Si system (Table 1). After modification with 0,05 % P the temperature T_{liq} increases to about 668 °C. Hence it has been concluded that phosphorus in the form of CuP10 master alloy raises the crystallisation temperature of primary Si crystals by 20 °C.

Modification or strong overheating of the alloy above $T_{liq.}$ results in the appearance of microregions with varying concentration of Si atoms. In the case of modification, this is the consequence of introducing to the alloy some nuclei of crystallisation, whereas strong overheating causes complete dissolution of the solid particles of silicon in the liquid. The result is the appearance of micro area with a short-range order and a relatively short time of fluctuations, and microregions with reduced short-range order, i.e. impoverished in silicon. When the temperature of the liquid is decreasing, Si-Si clusters are formed and grow in concentration as a result of the specific liquid alloy undercooling. The fact that the number of clusters with supercritical radius increases leads to a rapid growth of the hypereutectic silicon precipitates.

As follows from the studies, each time the application of modification with phosphorus (SM), overheating for 40 minutes to a temperature of 920 °C (SP) and overheating and modification (SPM) increased the alloy hardness *HB* by 22 % and 35 % respectively, while the combined process of strong overheating and modification resulted in a 51 % increase as compared to the AlSi17Cu5Mg alloy in an unmodified condition (SN).

The remaining part of studies concerning the effect of technological process on the mechanical properties of the investigated alloy mainly focussed on the results of static tensile test. The obtained values of the tensile strength (R_m) and yield strength ($R_{0,2}$) were analysed and showed in each case an increase in the properties of the examined material as compared to the alloy in base condition – see Figures 5b and 5c, respectively. Modification with phosphorus or strong overheating of the alloy increased the tensile strength by 36 % compared to the alloy in base condition, i.e. unmodified and without overheating, while the combined process of overheating and modification with phosphorus increased this property by 28 %. Similar correlations were observed for the yield strength. Inoculants or overheating above T_{liq} as well as a combination of these two methods finally gave $R_{0,2}$ = 168 - 180 MPa, which means about 23 - 32 % increase compared to the alloy unmodified and without overheating.

On the basis of conducted tests the following conclusions can be drawn:

- Modern technological concept, applied in tests, based on overheating the alloy far beyond the temperature T_{liq} with simultaneous process of modification with 0,05 % causes refinement of primary silicon crystals and their regular distribution in matrix which definitely influences the improvement of mechanical properties of castings of AlSi17Cu5Mg alloy.
- The process of combining overheating and modification presented in the paper causes increase of mechanical properties in comparison to this alloy in primary condition (non-modified and without overheating).
- This favourable relationship of material characteristics is expected to contribute to the fact that in some applications, the cast hypereutectic AlSi alloys will gain an advantage over their hypoeutectic alloys.

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Note: The responsible translator for English language is Dorota Sidło, Poland