

# Structure and Mechanical Properties of AlSiCuMg Alloy after Thermo Processing

J. Piątkowski <sup>a,\*</sup>, P. Kamiński <sup>b</sup>

<sup>a</sup> Silesian University of Technology, Faculty of Materials Science, Krasińskiego 8, 40-019 Katowice, Poland

<sup>b</sup> Kamsoft – Joint Stock Company, 1-May 133 street, 40-235 Katowice, Poland

\*Corresponding author. E-mail address: jaroslaw.piatkowski@polsl.pl

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## Abstract

In the dissertation it has been shown, that so called „time-thermal treatment” (TTT) of the alloy in liquid state, as overheating the metal with around 250°C above the  $T_{liq}$ , and detaining it in this temperature for around 30 minutes, improves the mechanical properties (HB,  $R_m$ ,  $R_{0.2}$ ). It was ascertained, that overheating the AlSi17Cu5Mg alloy aids the modification, resulting with microcrystalline structure. Uniform arrangement of the Si primeval crystals in the warp, and  $\alpha(Al)$  solution type, supersaturated with alloying elements present in the base content (Cu, Mg) assures not only increased durability in the ambient temperature, but also at elevated temperature (250°C), what is an advantage, especially due to the use in car industry.

**Keywords:** Hypereutectic Al-Si alloys, Overheating, Modification with CuP10 master alloy, Mechanical properties, Microstructure

## 1. Introduction

Amongst the technical Al alloys, due to advantageous useable properties, the Al-Si-Me foundry alloys became the most frequently used, as a main construction material in many branches of the industry. The advantageous relation between mechanical and technological properties comes, between other, from optimal microstructure, which in case of hypereutectic silumines, is created by primeval silicon crystals, multicomponent eutectics and  $\alpha(Al)$  solution dendrites.

In standard casting conditions, the Si allotments are solidifying as a multibranch, star-like polygons of complicated morphology, which needs to be crumbled and uniform distribution in the warp. It can be done with modification [1÷5], fast heat abstraction [6, 7] and other methods [8÷11]. However, as the newest research shows [12÷16] obtaining microcrystalline structure can be done through the so-called „thermo processing of alloys in liquid state”. Which is done by overheating the liquid alloy much above  $T_{liq}$

temperature, and then holding at that temperature for a defined time before casting it to the mould [17÷21].

## 2. Scope and purpose of research

The aim of the study was the evaluation of mechanical properties (HB,  $R_m$ ,  $R_{0.2}$ ) in the ambient temperature (20°C) and in elevated temperature (250°C), and forming the microstructure AlSi17Cu5Mg silumine, subjected to heating up to the temperature of around 920°C, holding at that temperature for about 30 minutes and casting it to the permanent mould.

The scope of research included:

- development of material concept and technological process of overheating and holding at the temperature of the liquid alloy,
- casting the samples for mechanical properties testing,
- SEM microstructure research.

### 3. Research methods and materials

The AlSi17Cu5Mg silumine was chosen, according to the ASTM, is marked as A3XX.X (A390.0) and is casted to sand moulds and to permanent moulds for heavy burdened pistons casts and combustion motors heads, blocks and cylinders corpses.

The alloy was melted from master alloys: AlSi20, AlSi11, AlCu30 and AG10 in SiC crucible of 200m<sup>3</sup> capacity in Heraeus PT-60/Pr furnace. To avoid negative impact of phenomena connected to gassy metallic melt, what is the effect of substantial overheating the alloy above T<sub>liq</sub>, the Protec-ol-Degasal protection cove was used as 0,4 wt%. Under the slag layer formed on the surface 0,2 wt.% of Rafglin alloy refiner was added. The casting temperature was registered with thermo-element NiCr-NiAl. After around 10 minutes the bath was deslagged and the alloy was poured to the metal mould, producing 3 samples at a time, which were subjected to mechanical processing until the dimensions compliant with PN-EN 10002-1 were achieved.

Mechanical properties were determined on the samples for static tensile test, which was conducted in accordance to PN-EN ISO 6892-1 on Instron 3382 testing machine, using the transmission ratio 20:1 and constant tensile speed of 5mm/min. The mechanical properties in elevated temperature (250°C) were determined with the use of resistance heating. That way, 15 samples were casted in the following variants:

- unmodified (designated with SW symbol),
- modified alloy – with 0,05 wt% of CuP master alloy (SM),
- overheated alloy to 920°C (SP),
- overheated and modified alloy (SPM).

Hardness testing with Brinell hardness testing method was performed as per the PN-EN ISO 6505-1 on Zwick ZHF hardness tester, under the load of 187,5kg; using a Ø 2,5 mm steel ball applied for a time of 35 seconds. Structure testing was done with standard procedure of metallographic microsection preparation.

### 4. The results of investigations

The result of chemical composition analysis of AlSi17Cu5Mg cast alloy is given in Table 1.

Table 1. Chemical composition of AlSi17Cu5Mg cast alloy (wt.%)

	Si	Cu	Mg	Mn	Fe	Ni	Al
alloy	16,81	4,78	0,94	0,03	0,04	0,13	rest

Based on the static tensile test, the HB hardness tests were conducted for AlSi17Cu5Mg alloy, as per 4 chosen technologies in ambient and elevated temperature – figure 1.

On the basis of static tensile test the durability testing was also conducted for tensile strength - R<sub>m</sub> and yield strength - R<sub>0,2</sub>. The results are shown on the figures 2 and 3.

Complementary to mechanical properties testing the microscopic research has been done. Exemplary structures of AlSi17Cu5Mg alloy unmodified and after modification with 0,05wt.% P has been shown on figure 4, and after overheating to the temperature of 920°C of unmodified and after modification on figure 5.

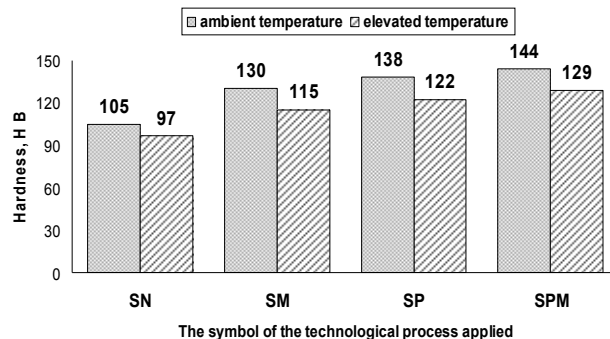


Fig. 1. The result of HB hardness testing results for technologies

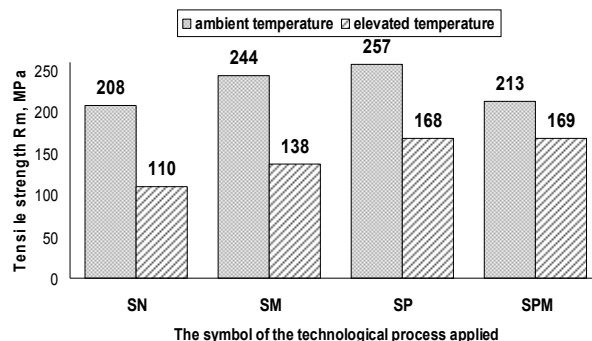


Fig. 2. Tensile strength R<sub>m</sub> of AlSi17Cu5Mg alloy in relation to the applied technology

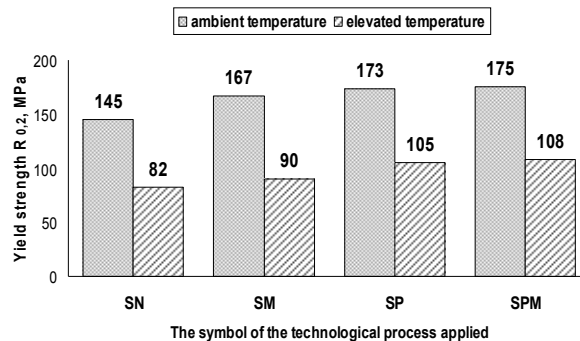


Fig. 3. Yield strength R<sub>0,2</sub> of AlSi17Cu5Mg alloy in relation to the applied technology

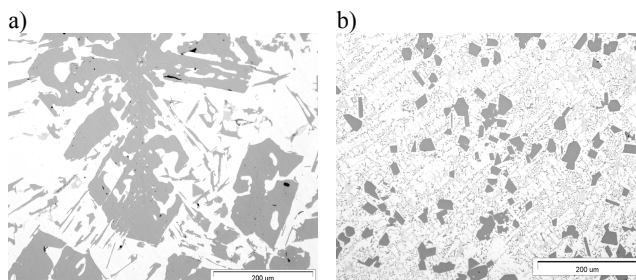


Fig. 4. The AlSi17Cu5Mg cast alloy microstructure: a) without modification, b) after modification with 0,05wt.% P (CuP)

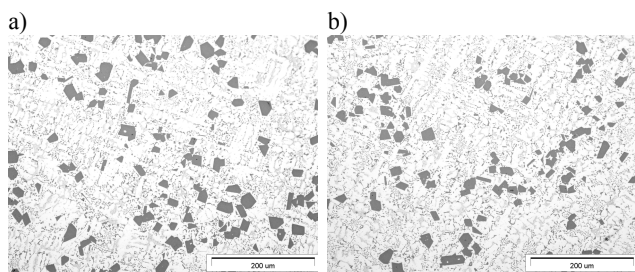


Fig. 5. The AlSi17Cu5Mg cast alloy microstructure: a) after overheating to the temperature of 920°C, b) after overheating and modification with 0,05wt.% P (CuP master alloy)

## 5. Summary of the results

Since the alloy selected for the research in car industry is usually casted to metal moulds, the metal mould was used also during the casting of the samples, with which 15 samples was casted for each technology. As it comes from the research, use of:

- modification with 0,05 wt.% P (CuP10) – SM,
- overheating to 920°C for 30 minutes – SP,
- overheating and modifying – SPM designation,

results with increased HB hardness in ambient temperature (20°C) with respective 18% and 27%. Combined process of overheating and modification with phosphorus results with increase of hardness by around 43% in comparison to unmodified AlSi17Cu5Mg alloy (SW designation).

Overheating the alloy to the temperature of 920°C gives similar effects of increased hardness as modification or modification with overheating. It is connected to surfusion level, which value reaches even  $10^6 \text{ K}\cdot\text{s}^{-1}$ , what is related to the speed of phase growth of approximately  $200 \text{ m}\cdot\text{s}^{-1}$  [15].

Alloy casting to the moulds enhances the crystallization process, what is one of casting techniques, with which the metastable and amorphous alloys are produced. Also, fast heat evacuation causes refinement of structure with increase of potential base Si nucleus of crystallization. Another advantage of fast crystallization is homogeneous alloy in result, limiting heterogeneity of chemical composition and increase of solubility limit of alloying elements in the solid phase. The increase of mechanical properties compared to traditionally casted alloys may be explained this way.

Similar growth tendencies can be observed for hardness HB results in elevated temperature (250°C).

The hardness level for modified alloy (SM) is 112 HB and it is 22% higher, than that of a not modified state (SW). Overheating the alloy causes increase of hardness with around 30%, while combined process of modification with phosphorus and substantial overheating above  $T_{\text{liq}}$  results with hardness increase of around 35% compared to base alloy (SW designation).

Balance part of the study for the influence of the applied technologies on the mechanical properties regarded the results of static tensile test. On the basis of the results of tensile strength ( $R_m$ ) and yield strength ( $R_{0,2}$ ) every time the increase of analyzed material properties was observed in comparison to the base alloy – figures 2 and 3. For the research in ambient temperature 20°C it was found that modification with phosphorus and substantial

overheating, separately and jointly leads to increase of tensile strength with around 18-24% comparing to the base alloy, while combined process of substantial overheating and phosphorus modification gives the increase with around 2% (in ambient temperature).

In case of the result acquired in temperature of 250°C it was found, that the increase of tensile strength is as high as 28-58% comparing to the base alloy. Similar dependence was noted for yield strength. Modification and substantial overheating above  $T_{\text{liq}}$  as well as combining the processes ensured the achievement of  $R_{0,2}$  at the level of around 175 MPa. What in comparison to unmodified state and without overheating equaled to 20% of increase (in ambient temperature) and to around 30% in elevated temperature (250°C).

As it was stated before, the practical use of the examined alloy is concentrated on pistons casts and combustion motors heads. On a crown of a cylinder head most often is properly shaped combustion chamber, where almost all heat delivered with the fuel is being emitted. Such conditions results in increased thermal load of the piston, which often (with extreme use conditions) heats to around 310°C, with change within one cycle of 12°C. This information was the base for conducting the mechanical properties testing in temperature of 250°C. It was determined, that modification or other treatment, which causes refinement of structure is necessary, especially with the use of Al-Si-Me alloys for the elements which will work in elevated temperature (in the engine working chamber).

Actual construction tendencies of piston structure in the new generation of motors indicates decrease of piston height with around 20-40%, in order to increase the power of the engine and better fuel combustion. Such change causes the increase of both: mechanical and heat burden, event to 120MPa. Out of the result shown on figures 2 and 3 it can be determined, that each of technologies used complies with this criteria.

The data shows, that overheating the alloy to the temperature of 920°C and holding at that temperature for 30 minutes (SP designation) and combined process of overheating and phosphorus modification - master alloy CuP10 (SPM designation) causes the least decrease of  $R_{0,2}$  in elevated temperature (42%). Biggest decrease of  $R_{0,2}$  (in temperature of 250°C) is observed for the alloy subjected only to modification process with 0,05wt.% phosphorus (49%) and 47% for base alloy (SW designation) in comparison to the measurements conducted in ambient temperature (20°C).

Concluding, the increase of mechanical properties (HB,  $R_{0,2}$ ,  $R_m$ ) is a result of modifying influence of phosphorus and substantial overheating the alloy above  $T_{\text{liq}}$  with subsequent fast cooling. It is in line with the assumptions of the thesis about winning light, hypereutectic Al-Si-Me alloys subjected to time-thermal treatment while still in liquid state, which has – after cooling down – high mechanical properties. Such beneficial relation of material characteristics will allow to achieve for some applications the competition to hypereutectic, casting alloys Al-Si-Me in comparison to other Al cast alloys.

The confirmation of the mechanical properties testing are the observations of the microstructure. Casting the alloy without modification nor the overheating (Fig. 4a) does not cause any changes to the microstructure of a tested alloy. The crystals of silicon grow big, star-like shape, what is characteristic for the

alloy which is not modified. Modification of AlSi17Cu5Mg with CuP10master alloy results with fine-grained microstructure by refinement and uniform distribution of primeval silicon crystals in the Al warp. Overheating the alloy to the temperature of 920°C and holding at that temperature for around 30 minutes causes substantial refinement of the structure. The silicon crystals become smaller, more compact and are uniformly distributed in the eutectic warp of  $\alpha(\text{Al})-\beta(\text{Si})$ . Simultaneous process of modification and overheating (Fig. 5) causes refinement of the structure. The silicon crystals are smaller, more compact and uniformly distributed in the eutectic warp. It may be the premise, that overheating the alloy is strong factor of silumines structure modification.

Modification and/or substantial overheating of the alloy above  $T_{\text{liq}}$  causes the appearance in liquid state the micro spaces of different concentration of silicon atoms. In case of modification it is caused by the introduction of crystallization centers to the alloy, (AIP particles), while substantial overheating leads to complete dissolution of the solid particles of silicon in the liquid. The effect of that is appearance of the areas of close arrangement with relatively short fluctuation time and micro areas depleted of close arrangement. With decreasing temperature of the liquid, clusters of Si-Si are being created of increasing concentration, what is the result of specific over-cooling of liquid alloy. As a result the number of clusters of hypercritical radius increases, what leads to intensive growth of hypereutectic silicon secretion. As a result of silicon depletion in the crystallization front (in a condition of fast heat abstraction), these areas crystalize and creates the  $\alpha(\text{Al})$  dendrites. The temperature range of dendrites forming is probable the result of different silicon content in these areas.

## 6. Conclusion

On the basis of the research the following conclusion has been formulated:

1. Overheating the AlSi17Cu5Mg alloy to the temperature of around 250°C above temperature  $T_{\text{liq}}$ , gives similar effects of structure and properties change as phosphorus modification process.
2. Overheating the alloy results with increased durability of around 27%, combined process of overheating and phosphorus modification with around 34% in comparison to the base state. Similar relation is being observed at the temperature of 250°C.
3. Highest value of tensile strength (246 MPa – in the temperature of 20°C) and 158 MPa (for 250°C) was a result of thermo processing of the alloy in liquid state.
4. Highest increase of yield strength  $R_{0.2}$  (with around 20% in temperature of 20°C and around 30% in 250°C) was noted for those technological variants which involved substantial overheating of the alloy above  $T_{\text{liq}}$  temperature.
5. Overheating the AlSi17Cu5Mg cast alloy to the temperature of around 250°C above temperature  $T_{\text{liq}}$  causes refinement and uniform distribution of primeval silicon crystals in the warp, what is typical for the alloy modified with phosphorus.

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