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The Influence of Remelting on the Properties of AlSi6Cu4 Alloy Modified by Antimony

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Abstract

The paper deals with the problem of multiple remelting influence on AlSi6Cu4 alloy modified by antimony on chosen mechanical characteristics, microstructure and gas content. This foundry alloy is used mostly in automotive industry. Foundry Aluminum-Silicon alloys are also used in number of industrial weight sensitive applications because of their low weight and very good castability and good mechanical properties. Modifiers are usually added to molten aluminum-silicon alloys to refine the eutectic phase particle shape and improve the mechanical properties of the final cast products and Al-Si alloys cast properties.

Keywords: Remelting, Mechanical properties, Metallography, Modification, Antimony, Gas content

1. Introduction

The excellent castability and mechanical properties of AlSi6Cu4 alloy makes it a popular foundry alloy for automotive applications. Nowadays foundry plants are forced to reduce the wall thickness of cast pieces, to keep the narrow tolerance extent (combustion chamber, canal position) and to minimize the surface roughness (suction canal). The higher requirements on cast pieces make the construction more extensive and more complicated. AlSi6Cu4 is used for castings, which are moderately highly stressed. (e.g. engine blocks, cylinder heads and pistons, clutch housings, exhaust ends, die-cast chassis). In Slovakia is AlSi6Cu4 alloy used for cylinder heads for 1.6 l engines for Kia Ceed and in the Czech Republic for Skoda Fabia 1.2 TSI. BMW, Fiat, Citroën and others use this alloy to manufacture engine blocks and cylinder heads as well. [1, 2]

The microstructure and mechanical properties of AlSi6Cu4 alloy can be improved not only through modifying, grain refinement but also through applying heat treatment and other technologies. In practice, the most common elements with the modifying effect are strontium, sodium and antimony.

Adding these elements leads to a change in the shape of eutectic silicon, resulting in an increase of the mechanical characteristics of alloys. [3]

AlSi6Cu4 castings must meet the high requirements not only on the mechanical properties but must meet high requirements on pressure tightness as well. Strontium is now widely used in practice for modification of AlSi6Cu4 alloy. When modifying AlSi6Cu4 alloys by strontium was found, that the alloy subjected to this type of modification has higher values of gas content, leading to higher porosity and thus reducing the pressure tightness. [4, 5] In general, it is observed that modified castings contain more porosity than unmodified ones. However, there is no consensus on the mechanism. Some possible reasons have been proposed and studied. In general, modifiers can increase inclusion content in the melt, decrease hydrogen solubility in solid metal, change the solid:liquid interface morphology, reduce surface tension of liquid metal and increase the volumetric shrinkage. [6]

The aim of experimental works was to investigate the influence of remelting on chosen mechanical properties and gas content of foundry alloy AlSi6Cu4 modified by antimony. The reason of investigation the influence of multiple remelting on mechanical properties is that nowadays foundries are using

secondary materials (gating systems, risers etc.) which significantly affect mechanical characteristics and foundry properties, gas saturation, shrinkage cavity, fluidity etc. of alloy.

2. Experimental procedure

2.1. Melt treatment and casting procedures

The experiments were carried out in the foundry laboratory of the Department of Technological engineering at the University of Zilina, where as the experimental material was used foundry alloy AlSi6Cu4. Chemical composition with selected elements of the alloy is listed in Table 1. The melting process and the modification were carried out in a graphite-chamotte melting crucible in an resistance oven. The grain refinement process using refining salt AlCuAB6 was carried out while overheating the metal bath to $720\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$. The modification process using antimony was carried out under the same technological conditions.

Table 1.

Chemical composition of the AlSi6Cu4 alloy

Elements	Si	Fe	Cu	Mn	Mg
(wt. %)	6,52	0,44	3,88	0,46	0,29
Elements	Ni	Zn	Ti	Cr	
(wt. %)	0,01	0,46	0,15	0,01	

The amount of antimony chosen for experiments in present work was 2 000 ppm of AISb10. This amount was determined based on the previous carried out experiments investigating the most proper amount of antimony for Al-Si-Cu based alloys, i.e. AlSi6Cu4.

2.2. Mechanical properties

There were 3 samples cast, of which they were made test bars for tensile testing according to EN 10002-1. The tensile test was performed on a tensile machine ZDM 30 at $21\text{ }^{\circ}\text{C}$. Values of ultimate tensile strength (UTS) determines the average value of 3 test bars (Fig. 1). Percent elongation (Fig. 2) was for each sample calculated using mathematical formulas. When measuring the Brinell hardness on the measuring device CV-3000 LDB, the parameters used were HBS 5/250/15. Hardness values were determined as average values of 5 measurements on one sample of the each cast (Fig. 3).

Fig. 1 shows that increasing cast number decreases ultimate tensile strength. Remelting generally led to a reduction of ultimate tensile strength, however 3rd cast showed unexpected high UTS = 235 MPa, i.e. 10 % increase comparing to 1st cast where UTS reached value of 212 MPa.

Fig. 2 demonstrates the AlSi6Cu4 alloy subjected to remelting exhibits decreasing values of percent elongation, where the highest value of $A_5 = 1,84\%$ was measured in the case of the first cast.

Fig. 3 shows the relationship between Brinell hardness and cast number. Alloy AlSi6Cu4 reported the 1st cast, HBS = 104 and the highest hardness was measured in the case of 4th cast, HBS = 107. The lowest measured value was HBS = 101 corresponding to 2nd cast.

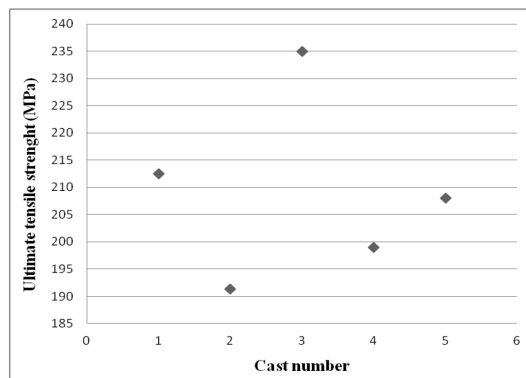


Fig. 1. Relationship between ultimate tensile strength and cast number

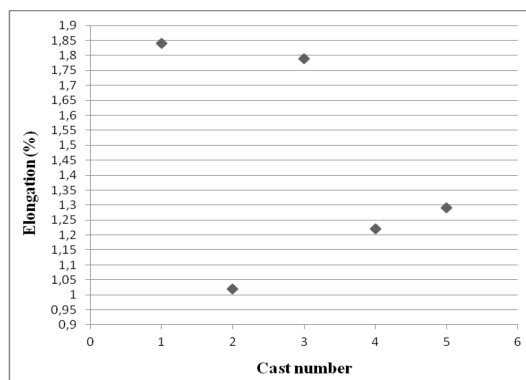


Fig. 2. Relationship between elongation and cast number

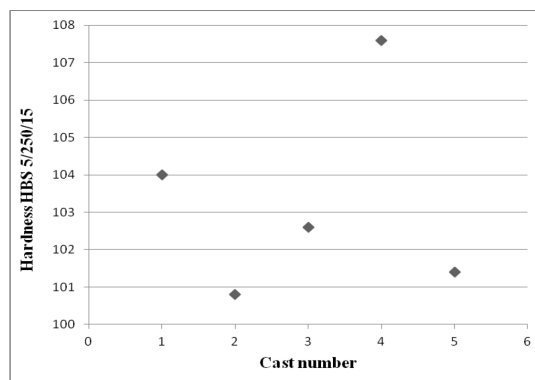


Fig. 3. Relationship between Brinell hardness and cast number

2.3. Microstructure analysis

For metallographic examination, samples (15 mm x 10 mm) were sectioned from each cast. The microstructures were analyzed according to EN - STN 42 0491 using NEOPHOT 32 optical

microscope in conjunction with image analyzer. Microstructure and morphology of silicon AlSi6Cu4 alloy from each cast are shown in Figure 4 to Figure 14. In all samples, the structure consists of dendrites α - phase, in which the plane metallographic sample is observed in the form of white bodies and eutectic silicon excreted in the form of gray bodies.

Based on the alloy microstructure observation in Figure 4 to Figure 8 and comparing them with each other, it can be concluded that the microstructure of the most common 100 x magnification has not essentially changed, it can be observed slightly changing dendrite as well as silicon shape. Figures 9 to 13 show microstructures of same casts where 500 x magnification has been used for analysis the microstructure for each cast.

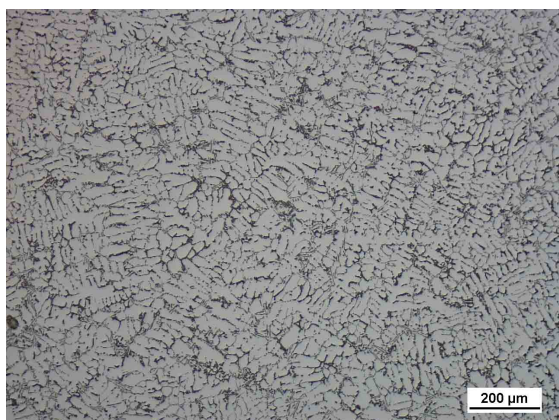


Fig. 4. Optical micrographs showing microstructure of 1st AlSi6Cu4 alloy cast

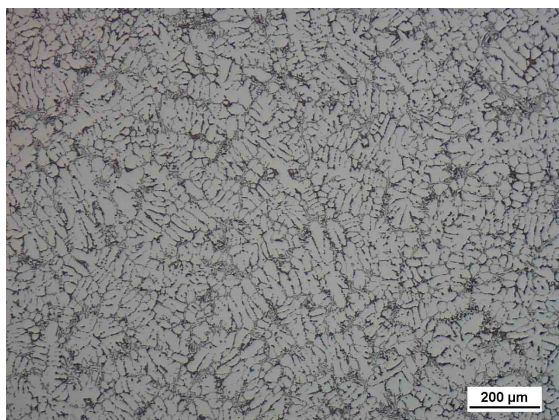


Fig. 5. Optical micrographs showing microstructure of 2nd AlSi6Cu4 alloy cast

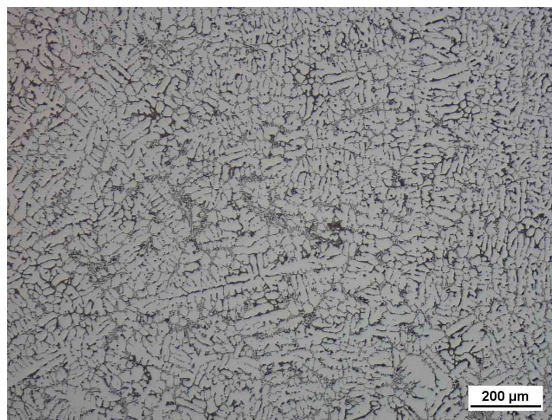


Fig. 6. Optical micrographs showing microstructure of 3rd AlSi6Cu4 alloy cast



Fig. 7. Optical micrographs showing microstructure of 4th AlSi6Cu4 alloy cast



Fig. 8. Optical micrographs showing microstructure of 5th AlSi6Cu4 alloy cast

Higher magnification e.g. 500 x allow us to compare shape of silicon phases and dendrites between each cast. On Fig. 9 can be observed big “square like” silicon phases.

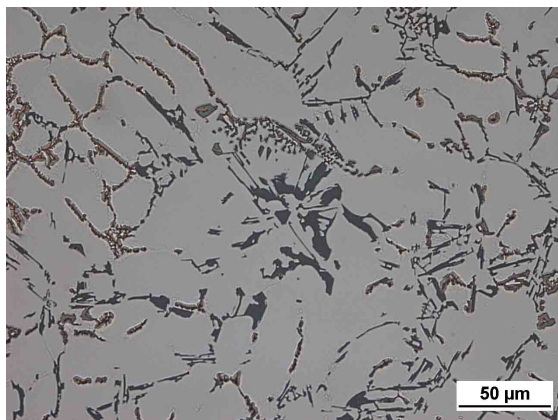


Fig. 9. Optical micrographs showing microstructure of 1st AlSi6Cu4 alloy cast

Shape of silicon phase is changing from big “square like” to “needle like” shape (Fig. 10). This might affected the mechanical properties in negative way.

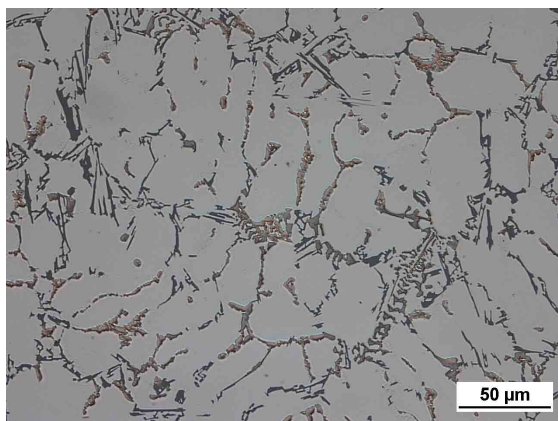


Fig. 10. Optical micrographs showing microstructure of 2nd AlSi6Cu4 alloy cast

Figure 11 shows smaller, more subtle silicon phases with ovate shape, which resulted in good mechanical characteristics comparing to figure 9. This shape and disposition of silicon phases and dendrite spacing obviously has led to the positive influence on ultimate tensile strength and elongation. In case of cast number 3, combination of the shape of silicon phases and dendrite spacing properties reached highest UTS and second highest elongation.

Shape of silicon phase on figure 13 can be considered as ovate small and most subtle from all the observed shapes. Dendrite spacing is similar to cast number 2 (Fig. 10) which might led to similar mechanical properties as well.

On the figures 9 to 13 can be observed phases of various shape with slightly red color. These phases are probably phases on Cu base created during melting, casting and cooling. Copper in AlSi6Cu4 alloy is mostly creating Al_2Cu and $Al_5Mg_8Cu_2Si_6$ phases. These phases were not the aim of investigation in the present work.

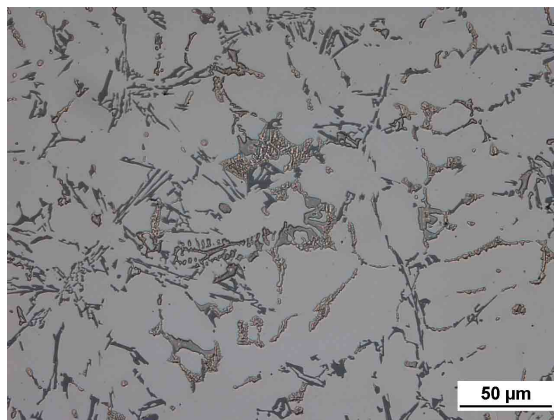


Fig. 11. Optical micrographs showing microstructure of 3rd AlSi6Cu4 alloy cast

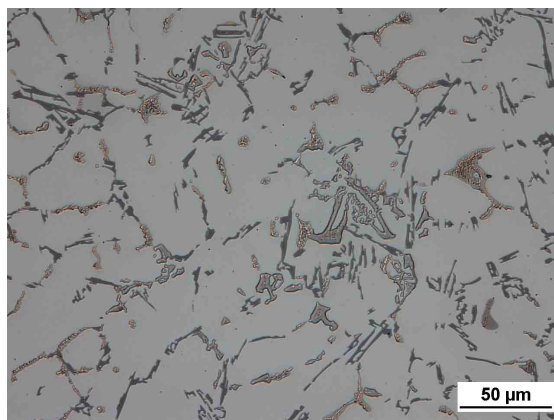


Fig. 12. Optical micrographs showing microstructure of 4th AlSi6Cu4 alloy cast

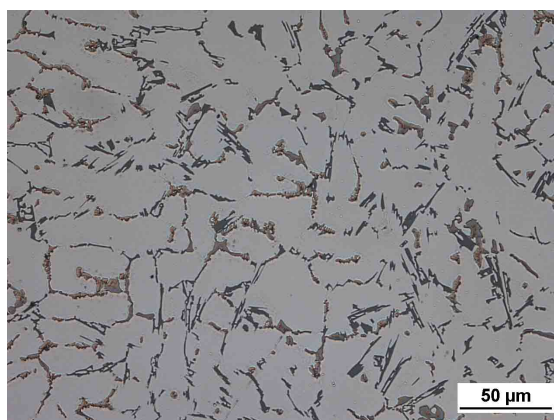


Fig. 13. Optical micrographs showing microstructure of 5th AlSi6Cu4 alloy cast

2.4. Evaluation of chemical composition

Chemical composition of aluminum alloys has a great influence on the mechanical properties. During multiple remelting it might come to incineration of some elements. Chemical

composition with selected elements of individual casts is listed in table 2. Table 2 shows the average values for antimony and copper in each cast. Figure 14 shows the dependence of the Cu content on cast number. Figure 15 shows practically stable antimony content with increasing number of remelting.

Table 2.

Chemical composition of the AlSi6Cu4 alloy

Cast number	1	2	3	4	5
Cu (wt. %)	3,548	3,632	3,615	3,697	3,609
Cast number	1	2	3	4	5
Sb (wt. %)	0,013	0,013	0,013	0,017	0,012

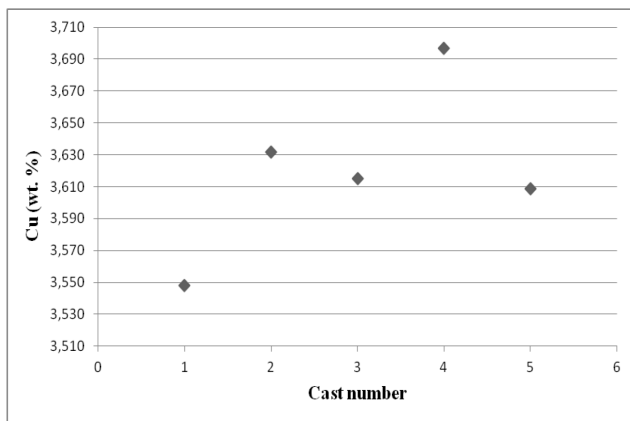


Fig. 14. Relationship between copper and cast number

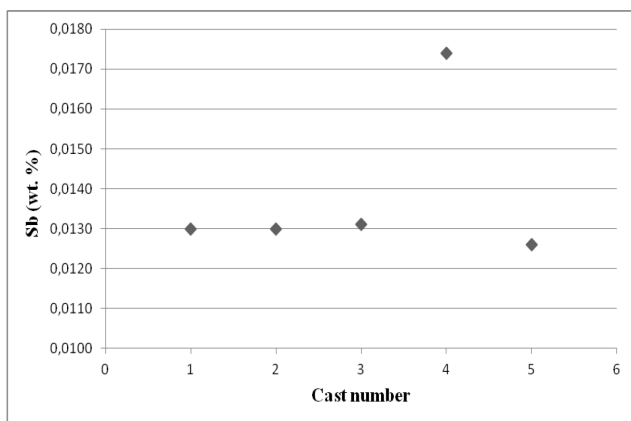


Fig. 15. Relationship between antimony and cast number

2.5. Gas content of AlSi6Cu4

AlSi6Cu4 alloy was subjected to the same technological processes as in the analysis of mechanical properties and the same amount of antimony – 2 000 ppm AlSb10. To detect the gas content was used equipment Vacuum Density Tester 3VT-LC, vacuum forming and weighing-machine MK 2200LC (Fig. 16), which were used for weight identification of the experimental samples. Weighing-machine evaluated the density of samples and also a percentage, based on mathematical and physical

relationships and formulas, determined the density index - DI. In each cast were made two samples where the first one was solidifying on the air and the second one was placed in vacuum for 7 minutes. Cross-section cuts of individual samples can be seen in Figures 16 to 20.

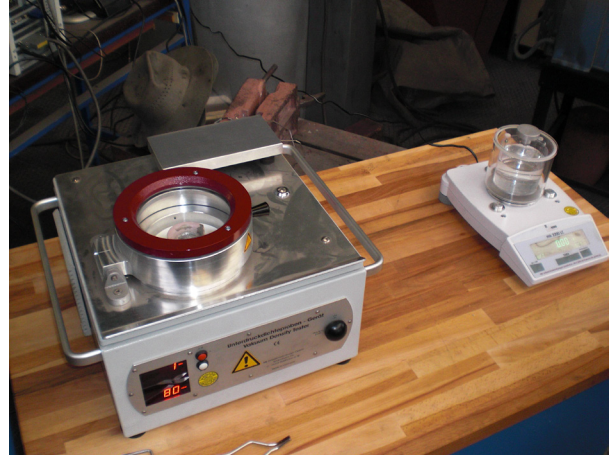


Fig. 16. Vacuum Density Tester 3VT-LC and weighing-machine MK 2200LC

Table 3 shows the calculated values of the density index of AlSi6Cu4 alloy subjected to multiple remelting on the basis of mathematical and physical relationships. Based on the comparison Table 3 and Figures 16 to 20 can be noted that mathematically determined amount of gas content was confirmed by observing cross-section cuts of experimental samples.

Cast number 1 showed DI = 11,11 %. Lowest Density Index has been achieved in cast number 4 where DI = 4,06 meaning 63 % reduction of gas content comparing to 1st cast.

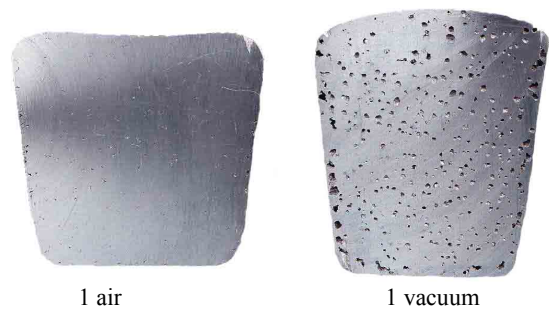


Fig. 16 Cast number 1



Fig. 17 Cast number 2



3 air 3 vacuum

Fig. 18 Cast number 3



4 air 4 vacuum

Fig. 19 Cast number 4



5 air 5 vacuum

Fig. 20 Cast number 5

Table 3

Density and density index of AlSi6Cu4 modified by Sb

Cast number	Density on air (g/cm ³)	Density in vacuum (g/cm ³)	Density index DI (%)
1	2,70	2,40	11,11
2	2,72	2,59	4,78
3	2,73	2,54	6,96
4	2,71	2,60	4,06
5	2,72	2,58	5,15

3. Conclusions

Based on the experiments can be claimed, that the best mechanical properties of AlSi6Cu4 alloy modified by 2 000 ppm of AlSb10 subjected to multiple remelting with no further modification and treatments have been achieved in cast number 3. The results of investigated properties show that alloy has the ultimate tensile strength UTS = 235 MPa at the second highest measured elongation A₅ = 1,79 % with the Brinell hardness HBS = 103. Gas content was reduced by 41 % compared to cast number 1. Location, distribution and size of pores in cross-section cuts also confirm that cast number 3 has been selected as the best choice from carried out experimental works.

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