CHANGE OF SELECTED RESULTING PROPERTIES OF AlSi9CuMnNi ALLOY BY HEAT TREATMENT AND ANTIMONY

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Abstract. Modification of alloys is an important part of the metallurgical process, and this also applies, of course, to aluminium alloys, particularly for Al-Si (silumins). As a modification of the material we can use the modification using the selected element or heat treatment of alloys, or a combination of both processes. One of the elements used to modify the alloy of Al-Si is antimony (Sb). The paper examines the possible effects of the modification of that element and heat treatment on the selected final properties of the alloy AlSi9CuMnNi. The described experiment and analysis are part of extensive research at the Faculty of Production Technology and Management, J. E. Purkyně University in Ústi nad Labem.

Keywords: alloy, modification, heat treatment, antimony, machining.

Introduction

Generally, alloys are modified and thermally processed for improvement of their chosen technological properties. This applies, of course, to aluminum alloys and specifically for alloys based on Al-Si, called Silumins [1; 2].

Modification of aluminum alloys is a process, by which the melt is deliberately modified by various elements in order to influence the mechanism of eutectic solidification. Modification changes the morphology and size of crystals of silicon (in the case of Silumin), causing a significant increase in the mechanical properties compared to unmodified alloys. Large size silicon of crystals has lower strength properties of Al-Si alloys. Strength and plastic properties of the modified alloys are therefore higher in comparison to unmodified alloys. Modification is meaningful only for aluminum alloys with a silicon content of more than 5 % [3-5].

As the modifying element also antimony can be used. It is an element belonging to semimetals. Most often antimony is used as a minor component of various alloys. They serve to improve the mechanical properties and increased resistance to chemical influences [6-9].

The investigated alloy was also heat-treated. Heat treatment of aluminum and its alloys can be in the sense for CSN 42 0056 defined as the process by which a product or product parts in solid state is subjected to one or more cycles of annealing to achieve the desired structure or substructure and properties.

The article describes the part of the experiments that are carried out at the Faculty of Production Technology and Management (FPTM) University of Ústí nad Labem and deals with the analysis of structures resulting in the production of experimental samples.

Materials and methods

Alloy AlSi9CuMnNi, which will then be investigated, falls into the group of alloys based Al-Si. Within the experiments at the FPTM this alloy was modified by 0.2 wt. % antimony, and thermally processed, too. Because the basic research in this field is conducted that at the FPTM JEPU, it is important to get the widest portfolio of knowledge about this alloy.

For the experiment castings from alloy AlSi9CuMnNi were made, a total of twelve castings (Fig. 1). They were divided into four groups of three castings. The first group of castings has not been modified or thermally processed. The second group was modified by antimony without further heat treatment. The third group of castings were heat treated without antimony modification. The last group was modified by antimony with subsequent heat treatment.

The alloy AlSi9CuMnNi was made at the FPTM from individual components, master alloy is not applied. For modification 0.2 wt. % antimony (Sb) was used.

Casting was carried out by gravity into the selected metal mold of desired dimensions and the equipment was used, which is available at the FPTM. Mold dimensions have to comply with the requirements for the size of the casting, to enable subsequent machining.

It was necessary to modify the castings for machining. Input sample dimensions for machining length were 220 mm and diameter 60 mm [10-12].

As a kind of heat treatment solution annealing was carried out leading to an increase in material hardness and uniformity of the chemical composition. In the first part, hardening of the material by supercritical cooling, and in the second part by artificial aging. The entire course of the heat treatment process took approximately 16 hours. First, the samples were heated in the melting furnace for a certain time, the next step was rapid cooling in a water bath, and the samples were then put into the drying furnace for the rest of the process. The drying furnace was set to turn off automatically after six hours at a temperature of 160 ºC, cooling of the samples was carried out in shutdown of the furnace [8; 9].

Fig. 1. **Experimental castings**

For checking the correct chemical composition of the samples spectrometric analysis was carried out. The results of the spectrometric analysis carried out on samples No. 1 to 6, which have not been modified by antimony, showed that during production of the castings a certain quantity of manganese and nickel in the alloy was lost. For the samples that have been modified by antimony, again decrease of a certain quantity of manganese and nickel is evident. There was also a slight decrease in antimony.

For determining the effect of heat treatment and Sb modification to the alloy AlSi9CuMnNi microscopic analysis was carried out. For examination of the microstructure the samples were prepared by conventional metallographic procedure.

It was necessary to modify the castings for machining. The test samples were machined on a lathe Emco Mat-14 S, which is available at the FPTM.

The set cutting conditions were based primarily on the type of the machine and tool. The used cutting tools were plates (inserts) PRAMET DCMT 070202 E – UR and based on the material to be machined and the used machine and tool were set at the depth of cut a_p=1 mm and feed per revolution $f = 0.12$ mm·rev^{-1}. On the base of the possibilities and calculations the cutting speed for the actual machining v_c was adapted to used the lathe with the resulting value $v_c = 200.96$ m·min^{-1} [13; 14].

The wear of the cutting insert after machining of the experimental samples was measured in the back and the following parameters were examined:

- wear in the peak VBc
- back wear VB
- maximum back wear VBmax

Each area for measuring of the tool wear are shown in Fig. 2. Evaluation was carried out according to the wear characteristics of the standard ISO 3685 [13; 14]. For measurement the software QuickPHOTO CAMERA 3.2 was used.

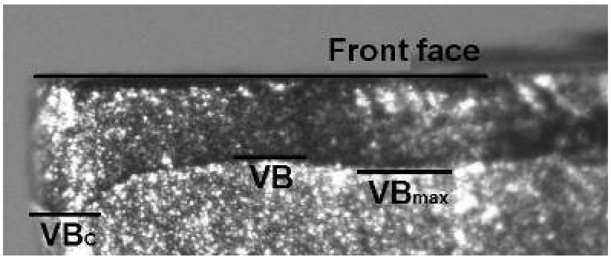

Fig. 2. **Principle of measurement of wear values of cutting plate (insert)**

The values were averaged and the middle standard deviation was determined according to the equation (1) [20].

$$\sigma = \pm\sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \overline{X}\right)^2}{n}} . \quad (1)$$

Results and discussion

As the first the samples of the alloy were analyzed, which was not modified with antimony or the material heat treatment had not taken place. Fig. 3 shows the structure of this sample. From this image it is evident that the structure is not affected, as it was expected.

The structure of all samples without modification and heat treatment is very similar. Silicon needles are relatively large and irregularly arranged. Generally, in the castings occasional occurrence of porosity can be observed, which is the consequence of the casting technology. All samples were prepared by gravitational casting.

Further the samples were analyzed without modification with antimony, but after heat treatment. The example of the microstructure of these samples is shown in Fig. 3. On the microstructure more uniform distribution needles of silicon is evident.

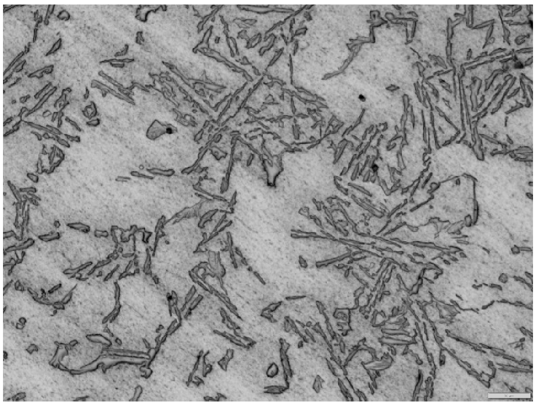

Fig. 3. **Example of structure of unmodified casting, mag. 100x**

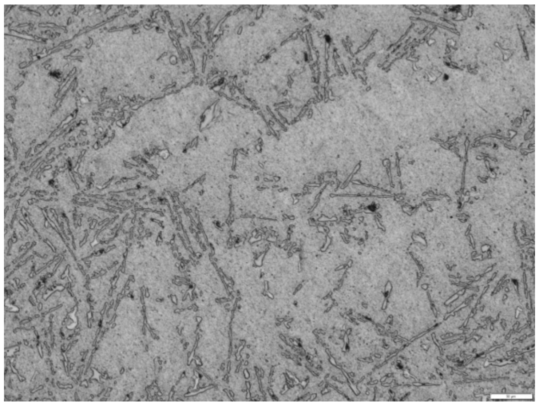

Fig. 4. **Example of structure of unmodified casting after thermal processing, mag. 100x**

Other evaluated samples were modified with antimony, but without heat treatment. The example of the structures is shown in Fig. 5. From these figures it is evident that modifications to the microstructure are significantly affected and there is therefore the modifying effect of antimony seen. The microstructure consists of eutectic structure (composed of fine platelets of eutectic silicon in solid solution α) and α phase. Silicon has the shape of finer needles, which are on the edges slightly rounded.

The last samples were evaluated, which have been modified and have undergone thermal treatment. In Fig. 6 the example of the obtained structures is shown. This structure shows the modifying effect of antimony (eutectic formed by fine eutectic silicon in solid solution α) and also the effect of heat treatment on more uniform distribution of the structure. The silicon particles are finer and have rounded edges.

On the samples, which are modified with antimony and at the same time undergo the process of heat treatment, the modifying effect of antimony is apparent (eutectics formed by fine eutectic silicon in solid solution α), and also the effect of heat treatment on more uniform distribution of the structure is seen. In Figure 6 we can see the silicon particles, which due to the modifying effect of antimony are more uniform and finer.

In all castings, regardless of modification or heat treatment, porosity is apparent, which was caused mainly by the way of producing castings (gravity casting in the air).

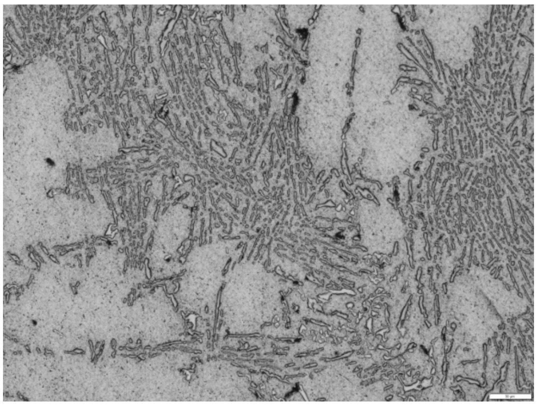

Fig. 5. **Example of structure Sb modified casting, mag. 100x**

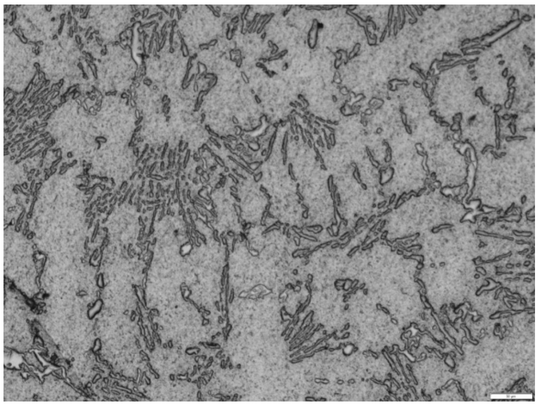

Fig. 6. **Example of structure modified casting after heat treatment, mag. 100x**

The last step was to measure the tool wear of the cutting plates after cutting of individual alloys. Generally speaking, as the wear on all plates was very small, it was difficult to see it by visual observation. The main reason was that the machined samples were from aluminum alloy, and the time during which the plate was in the work was about 25 minutes. It was possible to identify and measure the tool wear using a microscope in order to identify the differences between the different types of alloys.

Generally, it is true that on the plates the edge (built-up) formed, see Fig. 7. When machining alloys without modification the built-up was the greatest. The influence of heat treatment on the built-up edge is not at first sight too noticeable. The antimony content in the samples visibly influenced creation of the edge in the direction of its reduction.

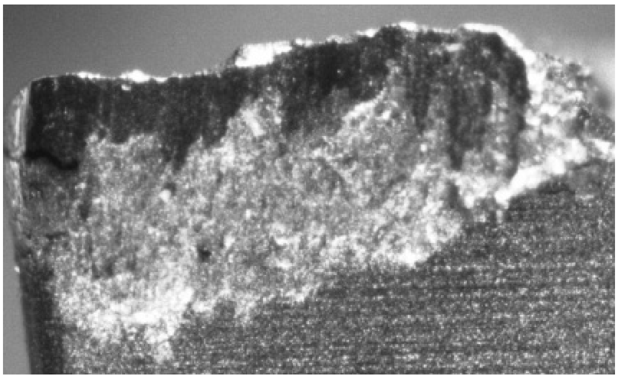

Fig. 7. **Up edge (built-up) on the tool after machining (without Sb and HT)**

In Fig. 8 there is a graph of average tool wear in the back area of the tool (VBc, VB, VBmax).

From this graph (Fig. 8) it is apparent that the order of tool wear for each group of the samples in all parameters (VB, VBc, VBmax) is identical. Preferably, therefore, the least worn tools are those that have been used for turning of the samples with heat treatment and modification of antimony. Conversely, the most worn tools were used for turning of the samples without heat treatment and without modification with antimony.

The heat treatment, as well as antimony as a modifier according to the measured results had a favorable, even if relatively small, effect on the size of the tool wear.

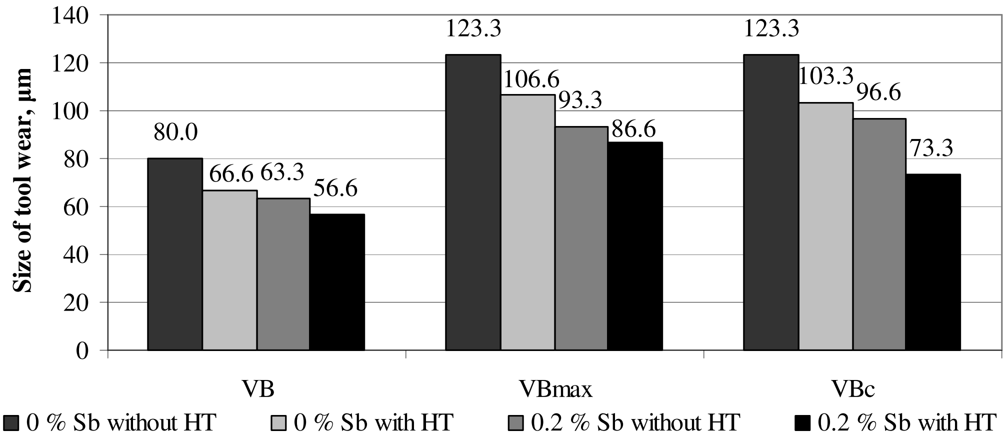

Fig. 8. **Average tool wear**

Conclusions

For this experiment a total of four kinds of castings were made. At the first melt the castings without heat treatment and without modification with antimony were made. In the second melt the castings without heat treatment and modified with antimony were made, in the third melt the castings were with heat treatment without modification with antimony and in the last fourth melt they were manufactured castings with heat treatment and modified with antimony. Antimony was dosed in pure form in an amount of 0.2 wt. %. The heat treatment was carried out at once for the said castings. As the heat treatment was applied solution annealed for more uniform structure with subsequent hardening.

At first, spectrometric analysis was carried out for control of the resulting composition of the castings. Decrease of manganese and nickel was found after casting. There was also a slight decrease in antimony.

The next step of the experiment was to analyze of the microstructure of the castings. For the samples with thermal treatment the effect of processing on the uniformity of the microstructure was detectable. Modification by antimony had a very significant impact on the microstructure. In the microstructure eutectics was formed consisting of fine particles of silicon in α phase. Due to the modification effects of antimony finer and partly curved needles of silicon formed, which should have a positive effect on the properties of the material.

The last step of the experiments was measurement of the tool wear after machining of the presented alloys. For the experiment turning inserts Pramet DCMT 070202E-UR suitable for non-ferrous metals were used. For each casting one plate was used, which was then evaluated for wear. The next step was to evaluate the wear inserts. The flank wear VB, flank wear on the tip VBc and maximum flank wear VBmax according to the standard ISO 3685 were measured. The measurements were performed on a microscope Olympus SZX 10. The measured values show that the positive effect on the tool wear not only antimony has, but especially the heat treatment. Most tool wear of plates was for turning casts without heat treatment and without antimony. Conversely, the least tool wear of the plates was for turning the castings after heat treatment with modification by antimony.

Beside the positive effect on the tool wear, there was observed the positive effect of antimony on the built-up edge, too.

The presented results are part of larger research carried out at the FPTM J. E. Purkyne University in Usti nad Labem.

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