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Evaluation of Sb effect onto eutectic Si changes and mechanical properties in an 4xxx Al cast alloys series

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Abstract. The purpose of this article is to examine the effect of modifier based on AlSb10 on the structure and mechanical properties of the AlSi7Mg0.3 and AlSi6Cu4 cast alloys. The changes of these parameters were studied on samples in untreated states (without heat treatment). Structural changes were studied on light and scanning electron microscopes. Several types of etching were used, which included normal black and white etching (0.5% HF), colour etching (Weck-Al) and deep etching (HCl), for studying structural parameters morphology. The influence of modifier on mechanical properties (UTS, Brinell hardness test) was studied at room temperature. The present work shows that the antimony has not had a significant effect on mechanical properties (UTS, Brinell hardness test), but structural parameters were changed.

Key words – 4xxx Al alloys, mechanical properties, antimony modification, microstructures changes

1. Introduction

The 4xxx Al alloys series are material with main addition Si and belong to the predominant alloys used for light metal castings (TIMPEL M. 2012). These materials have excellent castability, good corrosion and wear resistance, high strength stiffness to weight ratio, low density and thermal expansion, high productivity and low shrinkage rate, recycling possibilities, and inexpensive, therefore have been used in cars and trucks all over the world for many years. (TILLOVÁ E. et al. 2014, MOUSTAFA M.A. 2003, FARAHANYA S. 2013). Due to the increasing production of aluminium casting for automotive or aircraft applications it is necessary to control their strict microstructures. The final microstructure of aluminium material determines the technological and mechanical properties of cast components. Mechanical properties can be influenced by casting method, solidification rate, heat treatment or modifying and grain refining because these methods lead to structural changes (XIUFANG B. 2001). Morphology of eutectic Si particles strongly influence mechanical properties of the Al-Si alloys (TIMPEL M. 2012, FARAHANYA S. 2013). The Si- morphology can be altered with the addition of certain elements such as sodium (Na), antimony (Sb), strontium (Sr), and others in Al-Si alloys (ASM HANDBOOK 2002, KNUUTINEN A. 2001, COMALCO 1997, FABRIZI A. 2013). The modification with Sb was developed a few years later and led to reducing the susceptibility to gassing, thereby producing very solid castings. It was a good method for production casting applicable to the production of high-performance wheels and suspension system components for automobiles. Even the treatment with Sb is not dependent on such processing variables as holding time, re-melting, and degassing as by modification with Na and Sr additions (Xiufang B. 2001).

Furthermore, copper and manganese strongly affects the behaviour of Al-Si-Cu or Al-Si-Mg alloy. The cooling rate is a key parameter which can determine the kinetics of phase reactions, the thermo-physical properties and consequently the microstructure and mechanical properties of castings. The Mg addition increases strength, but decreases plasticity of material.

2. Experimental procedure

The base experimental alloys (AlSi7Mg0.3 and AlSi6Cu4) were casted in the foundry laboratory of Technological Engineering Department University of Žilina. The melting process and the modification were carried out in a graphite melting crucible in a resistance oven. Refining salt AlCuAB6 was used for the grain refinement process alongside experimental material AlSi6Cu4, salt Dursalit LK 59/2 for experimental material AlSi7Mg0.3 and it was carried out while overheating the metal bath to 730°C ± 5°C.

Antimony was added to the melt in the form of AlSb10 master in the range from 0 to 10 000 ppm in AlSi6Cu4 alloys and from 0 to 300 ppm in AlSi7Mg0.3 alloy, under the same technological condition. These melts were casted in to metallic mould and from the castings were made specimens for mechanical testing according to standards - STN EN 10002-1 and STN EN 10045-1.

The tensile test was performed on a tensile machine ZDM 30 at 21°C. Values of ultimate tensile strength are determined by the average value of three test bars. Hardness measurement was performed by a Brinell hardness tester with a load of 62.5 kp, 2.5 mm diameter ball and the dwell time of 15 s according to standard STN EN ISO 65061. The Brinell hardness value at each state was obtained by, on average, at least six measurements.

3. Results and discussion

Chemical composition of both materials are: for AlSi7Mg0.3 (wt. %): 7.1Si; 0.38 Mg; 0.095 Ti; 0.12 Fe; 0.005 Mn; 0.001 Cu; 0.025 Sr; 0.0008 Na; 0.0001 Sb; 0.002 Ca; 0.003 Zn; base of Al; and for AlSi6Cu4 (wt. %): 6.52 Si; 3.88 Cu; 0.29 Mg; 0.15 Ti; 0.43 Fe; 0.45 Mn; 0.01 Cr; 0.01 Ni; 0.46 Zn; base of Al. Both experimental materials are suitable for high-temperature (up to max. 250 °C) applications (dynamically exposed casts): pistons, cylinder heat, water-jacket, gearbox and other related materials (Náprstková N. 2013a, Náprstková N. 2013b, Hansen S.C. 2000).

The effect of Sb modification on mechanical properties of the AlSi7Mg0.3 and AlSi6Cu4 alloys is shown in Fig. 1 and Fig. 2. The mechanical properties of the AlSi7Mg0.3 cast alloy after Sb-modification were modified(Fig. 1), but minimally, in comparison with the unmodified state of this material. The value of the ultimate tensile strength was changed from 164 to 188 MPa. The highest ultimate strength tensile was measured in samples modified with 50 ppm of Sb. The Brinell hardness was changed from 61 to 65 for this aluminium alloy.

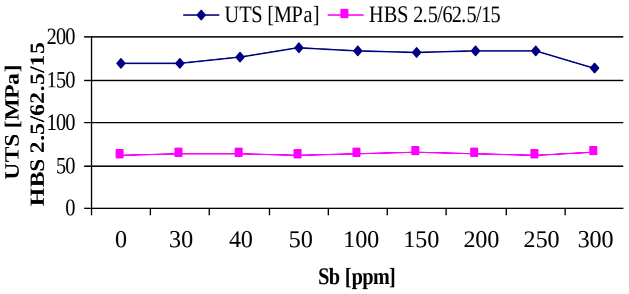


Fig. 1. Mechanical properties of AlSi7Mg0.3 alloy

Source: own study.

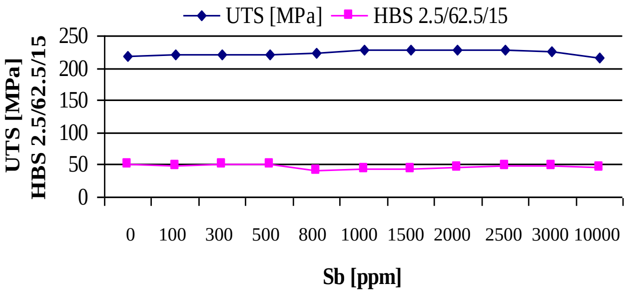


Fig. 2. Mechanical properties of AlSi6Cu4 alloy

Source: own study.

Ultimate tensile strength increases with additional Sb-modifying element in AlSi6Cu4 alloys (Fig. 2). The maximum of Sb modifier is up to 2500 ppm, because a higher amount of Sb leads to a decreasing of ultimate tensile strength. Results of Brinell hardness are comparable with Brinell hardness of AlSi7Mg0.3 alloys. Hardness changes very little (from 42 to 51). The best mechanical properties, with respect to modification with Sb, was observed in this alloy modified with 1 000 ppm Sb (it is assumed it will fully).

These results show that the modification with Sb does not have a very big effect on mechanical properties.

The samples from tensile specimens were metallographic studied (after testing). The optical microscope Neophot 32 and SEM microscope Vega LMU were used for studies of experimental material microstructure. Samples were etched in standard reagent for black-white etching. Some samples were also deep-etched for 30 s in HCl solution in order to reveal the three-dimensional morphology of the silicon phase (Fig. 3-4). Three-dimensional morphology was observed on a scanning electron microscope.

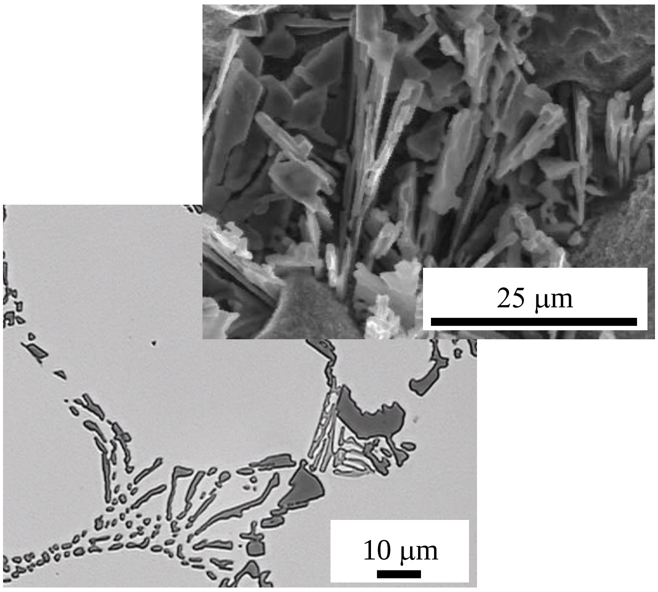


Fig. 3 Microstructure of AlSi7Mg 0.3, without modifier

Source: own study.

The as-cast microstructure of hypoeutecti experimental materials shows Fig. 3 and Fig. 4. The microstructure of AlSi7Mg0.3 or AlSi6Cu4 cast alloy without a modifier, is given by the binary equilibrium diagram, and consists of α-phase = matrix, eutectic (mixture of: eutectic silicon and α-matrix) and various types of Fe-, Cu and Mg- rich intermetallic phases. The 3D morphology of eutectic Si in AlSi7Mg0.3 cast alloy has shown that eutectic Si in as-cast state segregate in plate like form (Fig. 3). Modification did not lead to significant eutectic Si morphological changes (Fig. 5), but in samples modified more than 50 ppm Sb eutectic Si coarsen (Fig. 5b).

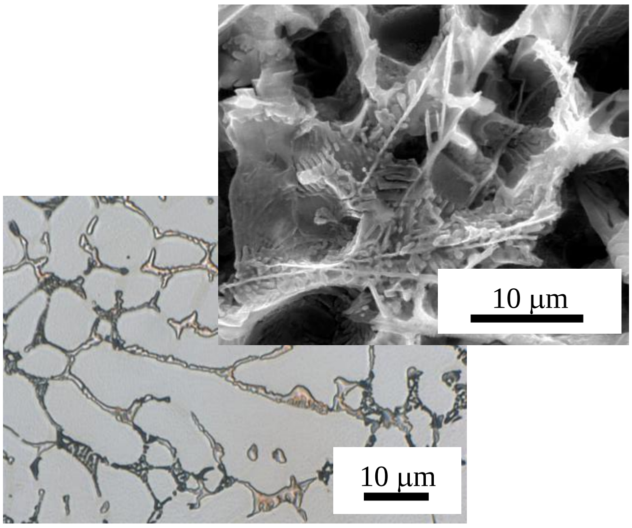
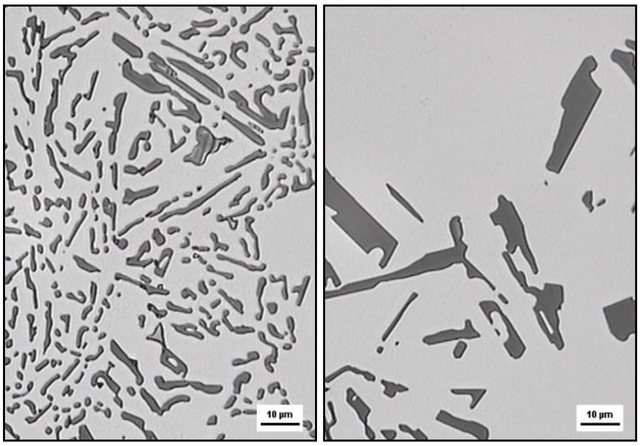


Fig. 4 Microstructure of AlSi6Cu4, without modifier

Source: own study.

The eutectic Si in AlSi6Cu4 cast alloy has compacted the divaricated structure of small plates (Fig. 4). It was not plate-like as in experimental material AlSi7Mg0.3; therefore mechanical properties (especially UTS) were higher (Fig. 1 and Fig. 2).

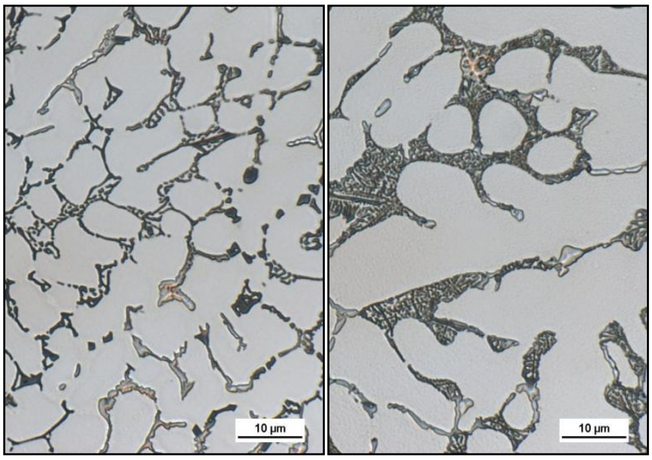


a) 50 ppm of Sb *b) 300 ppm of Sb*

Fig. 5. Changes of Si- morphology after Sb-modification, AlSi7Mg0.3 cast alloy, etch. 0.5% HF.

Source: own study.

The eutectic Si morphology in modified microstructure of AlSi6Cu4 is shown in Fig. 6. The morphology change of eutectic Si was not as marked as it was described in literature. A lower amount of modifier led to coarsening of eutectic Si morphology. However, a higher amount of modifier was used the morphology was little changed.



a) 1 000 ppm of Sb *b) 10 000 ppm of Sb*

Fig. 5. Changes of Si- morphology after Sb-modification, AlSi6Cu4 cast alloy, etch. 0.5% HF.

Source: own study.

4. Summary and conclusions

The results showed that the addition of Sb is not important in these types of aluminium cast alloys. The modification of these materials, in particular demonstrated modification was not visible. The mechanical properties and eutectic Si morphology were not as altered as it was expected.

The mechanical properties and the Si morphology were changed very little. The best mechanical properties of AlSi7Mg0.3 experimental material were observed in the specimens modified with 50 ppm antimony - UTS - 188 MPa, Brinell hardness 61 HBS. The Sb-modification improves mechanical properties, but especially UTS, only about 11% and Brinell hardness was comparable with an untreated state (0% HBS). The best mechanical properties of AlSi6Cu4 experimental material were observed in the specimens modified with 1000 ppm antimony - UTS - 229 MPa, Brinell hardness 45 HBS. The Sb-modification improves mechanical properties at about 5% UTS and 0% HBS comparison with untreated state for this material.

Acknowledgements

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