SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
19 (2014)

EFFECT OF THE DIFFERENT TECHNOLOGICAL PROCESSES DURING AND AFTER CASTING OF HYPOUETECTIC ALUMINIUM ALLOYS ON THE EUTECTIC Si PARTICLES MORPHOLOGY

Lenka HURTALOVÁ, Eva TILLOVÁ, Mária CHALUPOVÁ

Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina

1.Introduction

The Al-Si alloys are the most used cast light alloys and now constitute 90% of the Al alloys used in the automotive sector. The automotive manufacturers have increased attention to the production of lighter vehicles in order to satisfy the increasing demand of reducing fuel consumption and pollutant emissions in recent years. Their success is primarily due to the combination of excellent physical and chemical characteristics such as lightness and corrosion resistance, wear resistance, with a high specific strength, excellent castability, high productivity, low volume shrinkage during solidification, low density and thermal expansion, recycling possibilities, and low cost [1, 2, 3]. The Al-Si alloys are used for the production of components such as engine blocks and heads, wheels, pistons and steering gearboxes, which have been previously made of ferrous alloys [1]. Final microstructure of aluminium material determines the technological and mechanical properties of cast components.

The previous studies showed how the final mechanical properties are strictly related to the morphology, distribution and volume of Si particles in α-matrix (the shape and the distribution of the Al-Si eutectic), presence of defects, and initial chemical composition of the alloy (the volume fraction of the intermetallic phases) [4-6]. The properties of aluminium alloy are mostly affected by casting method, solidification rate, heat treatment,

modifying, grain refining, or by controlling microstructural parameters such as the distance between the secondary dendrite arms (SDAS) because these methods led to changes of structural parameters morphology [1,7].

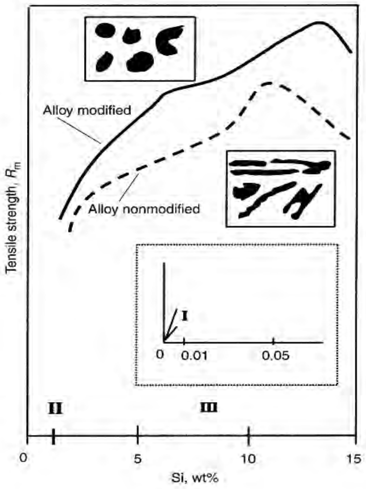


***Fig. 1** The silicon content influence on the tensile strength in Al-Si cast alloy [4].*

The contribution is focused on morphology of eutectic Si particles and therefore is necessary to mention that the optimum tensile, impact and fatigue properties are obtained with small, spherical and evenly distributed particles (Fig. 1) [8-10]. The different heat treatment and modification were used for affecting the morphology of Si particles in this experimental work. Chemical modifiers influence microstructure formation during solidification and improve the mechanical properties [9,10]. The Si- morphology can be affected with the addition of certain elements such as sodium (Na), antimony (Sb), strontium (Sr), and other in Al-Si alloys [11-13]. These elements are known as modifiers.

The heat treatment is one of the major factors used to enhance the mechanical properties of heat-treatable Al-Si alloys, through an optimization of both solution and aging heat treatments. A typical process of Al-Si cast alloy heat treatment consists of the following stages [14-17]:

1. Solution treatment, that is necessary to produce a solid solution. Production of a solid solution consists of keeping the aluminium alloy at sufficiently high temperature for such holding time, that provide dissolution of the undissolved or precipitated soluble phase constituents and to attain a reasonable degree of homogeneity;

2. Rapid cooling, also called quenching, usually into water with temperature from 40 up to 60 °C, to obtain a supersaturated solid solution of solute atoms and vacancies in solid solution;
3. The third step of T4 heat treatment is natural aging to receive the desired mechanical properties of casting. For T6 heat treatment (age-hardening) is: artificial ageing at elevated temperature to force precipitation from the supersaturated solid solution.

2.Material and experimental procedure

Experimental procedures as modifying, heat treatment, and age-hardening were tested at the AlSiCu hypoeutectic aluminium cast alloys, where addition of Cu and Mg provides heat treatment of the experimental materials. The microstructure of these hypoeutectic Al-Si cast alloys, is given by the binary equilibrium diagram, and consist of α-phase = matrix, eutectic (mixture of: eutectic silicon and α-matrix) and various types of Fe-, Cu and Mg- rich intermetallic phases (Fig. 2).

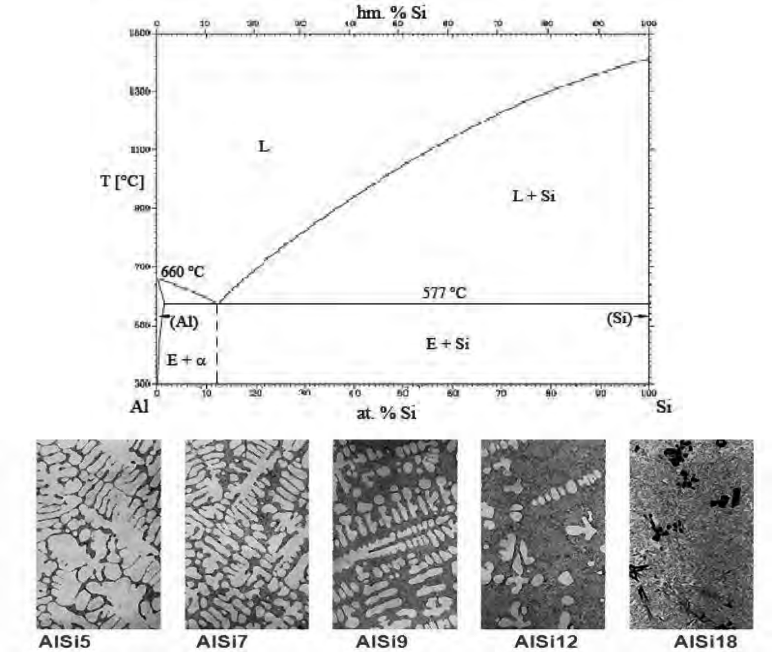


***Fig. 2** The equilibrium phase diagram of the binary Al-Si system a) hypoeutectic alloy AlSi5; AlSi7; AlSi9 b) eutectic alloyAlSi12 c) hypereutectic alloy AlSi18* [17,18]

Experimental samples 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. The refining salt AlCuAB6 was used for grain refinement process of experimental material 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 (Fig. 3) in the range from 0 to 10 000 ppm in AlSiCu alloys, under the same technological condition. These melts were casting in to metallic mould and from the castings were made specimens for mechanical test according to standards - STN EN ISO 6892-1 and STN EN ISO 148-1. Experimental specimens for mechanical test were heat treated by T4 heat treatment and by age-hardening (T6), too.

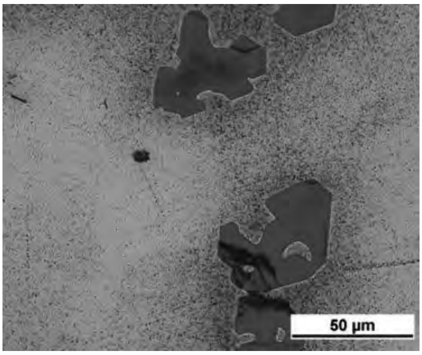


Fig. 3 *AlSb10 modifier, etch. Weck-Al.*

Heat treatment T4 for AlSiCu - consisted from solution treatment at 515°C with different holding time 2, 4, 8, 16, and 32 hours, followed by quenching into water with temperature 50°C and natural aging for 24 hours; age-hardening T6 consist of solution treatment at 515°C with holding time 4 hours, quenching into water with temperature 50°C and artificial aging using different temperatures 130°C, 150°C, 170°C, 190°C, and 210 °C with different holding time 2, 4, 8, 16, and 32 hours (Fig. 4).

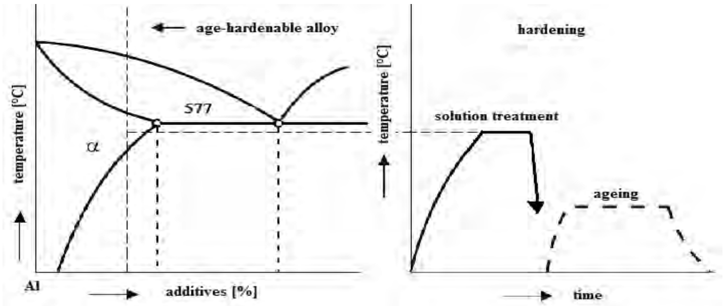


Fig. 4 *The schematic drawing of age-hardening in aluminium cast alloy*

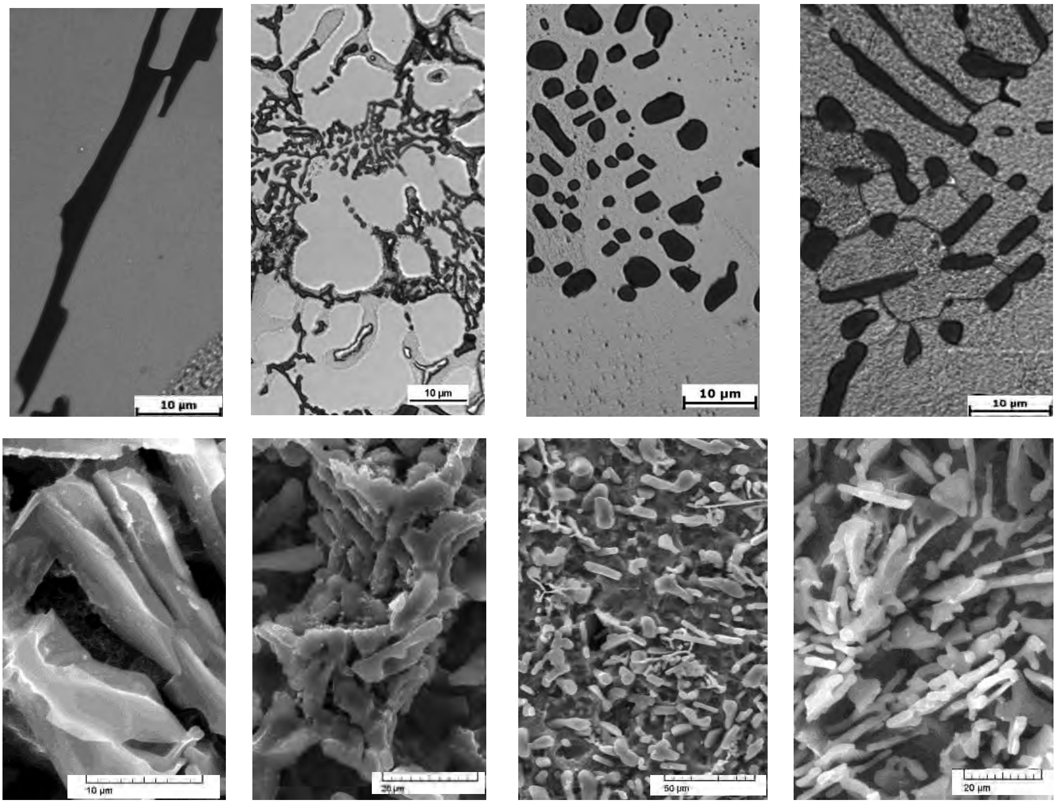
The effect of mentioned technological processes, used during and after casting of AlSiCu hypoeutectic aluminium alloys, onto morphology of eutectic Si particles was studied by using optical microscope Neophot 32 (upon black-white etching) and scanning electron microscope (SEM) VEGA LMU II (upon black-white etching and deep etching).

Metallographic samples for the study were cut from the selected tensile test specimens (after testing) and hot mounted for metallographic preparation.

The samples were prepared by standard metallographic procedures (wet ground on SiC papers, DP polished with 3 μm diamond pastes followed by Struers Op-S and etched by standard etching reagent Dix-Keller) for optical microscope study. The same methods were used for metallography study on scanning electron microscope, but the samples were etched by HF. Some samples were also deep-etched in order to reveal the three-dimensional morphology of the silicon phase and intermetallic phases. The regime for deep etching ia as follows: 30 s in HCl solution in order to reveal the three-dimensional morphology of the silicon phase. The specimen preparation procedure for deep-etching consists of dissolving the aluminium matrix in a reagent that will not attack the eutectic components or intermetallic phases. The residuals of the etching products should be removed by intensive rinsing in alcohol. The preliminary preparation of the specimen is not necessary, but removing the superficial deformed or contaminated layer can shorten the process. Three-dimensional morphology was observed in such prepared samples, on a scanning electron microscope.

3.Result and discussion

The morphology of Si particles was studied on samples affected with using different technological processes (as-cast state, after modification with antimony, after heat treatment T4, and after heat treatment T6). The morphology of Si particles was changed significantly (Fig. 5) in comparison with as-cast state (untreated). The Si needles (respectively platelets – in 3D visualization) were observed in as-cast samples (Fig. 5a). These Si particles are completely brittle and can decrease tensile strength of materials. Modification led not to greatest eutectic Si morphological changes as referred in literature. Lower amount of modifier led to coarsening of eutectic Si morphology, but when it was used higher amount of modifier the morphology was changed a little. The best effect of modification on morphology of Si particles shows Fig. 5b. Fig. 5c shows the effect of solution treatment on Si morphology. Solution treatment at temperature 515°C/4 hours author Hurtalová L. [19] determined as optimal solution heat treatment for recycled AlSi9Cu3 alloy. After this treatment were noted, that the relatively large eutectic Si needles (Fig. 5a) were spheroidised into smaller rounded particles (Fig. 5c). The studies show that T6 heat treatment does not significantly affect the Si morphology in comparison with T4 heat treatment or modification. Some of the Si particles were in form of small spherical particle; some of them were in form of small needles (Fig. 5d).



a) as-cast state *b) after modification* *c) after heat treatment T4* *d) after age-hardening T6*

***Fig. 5** Morphology of eutectic Si particles in AlSiCu cast alloy, optical microscope.*

4.Conclusions

The present study describes effect of different technological processes on eutectic Si particles morphology. Morphology changes depend on modification, heat treatment T4, or T6 of the experimental materials. The modification with antimony, T4 heat treatment - solution treatment at temperature 515 °C and holding time 4 hours, than quenching into water with temperature 50 °C and natural aging for 24 hours; T6 heat treatment – the same procedure as T4, but after quenching into water was used artificial aging at 170 °C with holding time 16 hours was used in this study. The experimental results are presented in following conclusions:

- The addition of Sb is not important in these types of aluminium cast alloys, especially is not necessary for modification of these materials, because modification effect was not visible. The morphology of eutectic Si did not change as much as it was expected.
- The T4 heat treatment causes the greatest changes from all of used technological

processes in experimental work. The Si particles were at 515°C spheroidized and were observed in rounded shape (small spherical particles);

- The T6 heat treatment - age-hardening did not significantly affect the Si morphology. Si particles after artificial aging were in form of smaller needles and small spherical particles, too.

5.Acknowledgements

This work has been supported by Scientific Grant Agency of Ministry of Education of Slovak republic N^{o}1/0533/15, N^o 044ŽU-4/2014 and project EU ITMS 26220220154.

Submitted: 14.04.2015

Literature

1. SANNA, F. et al. Multiscale characterisation of AlSi9Cu3(Fe) die casting alloys after Cu, Mg, Zn and Sr addition. La Metallurgia Italiana, s.13-24, Nr. 4, (2013).
2. MATVIJA, M. et al. The effect of ecap and subsequence post-ecap annealing on the microstructure and mechanical properties of AlSi7Mg0.3 alloy. Acta Metallurgica Slovaca, s. 4-12, Nr. 18/1, (2012).
3. UHRÍČIK, M. et al. Change of internal friction on aluminium alloy with 10,1 % Mg dependence on the temperature. Manufacturing technology, s.467-470, Nr. 14/3, (2014).
4. MAKHLOUF, M. M. et al. Microstructures and properties of aluminium die casting alloys. NADCA, Rosemont, Illinois, USA (1998).
5. LUMLEY, R.N. et al. Heat treatment of high pressure die-casting. Metall. Mat. Trans., s. 2564-2574, Nr. 38A, (2007).
6. LUMLEY, R.N. A preliminary evaluation on the fracture toughness of heat treated aluminium high pressure die-casting. Advance Materials Research, s. 99-104, Nr. 41-42, (2008).
7. XIU-FANG, B. et al. Liquid structure of Al–12.5% Si alloy modified by antimony. Materials Characterization, s. 25-29, Nr. 46, (2001).
8. ALUMINUM-SILICON CASTING ALLOYS. Atlas of Microfractographs. 2004 ASM International. Introduction to Aluminum-Silicon Casting Alloys [online]. [citting 07.04.2015] Available of www.asminternational.org
9. TIMPEL, M. et al. The role of strontium in modifying aluminium–silicon alloys. Acta Materialia, s. 3920–3928, Nr. 60, (2012).
10. FARAHANYA, S. et al. Evaluation of the effect of Bi, Sb, Sr and cooling condition on eutectic phases in an Al–Si–Cu alloy (ADC12) by in situ thermal analysis. Thermochimica Acta, s. 59– 68, Nr. 559, (2013).
11. FABRIZI, A. et al. The influence of Sr, Mg and Cu addition on the microstructural properties of a secondary AlSi9Cu3(Fe) die casting alloy. Materials characterization, s. 13-25, Nr. 85, (2013).
12. COMALCO. Modification of foundry Al-Si alloys. Comalco Aluminum Limited. Brisbane, Australia, Technical report No. 4, (1997).
13. KNUUTINEN, A. et al. Modification of Al-Si alloys with Ba, Ca, Y and Yb. Journal of Light Metals, s. 229-240, Nr. 1, (2001).
14. SJŐLANDER, E. et al. The heat treatment of Al–Si–Cu–Mg casting alloys. Journal of Materials Processing Technology, s. 1249, Nr. 210, No. 10, (2010).

15. TASH, M. et al. Effect of metallurgical parameters on the hardness and microstructural characterization of as-cast and heat-treated 356 and 319 aluminium alloys. Material Science and Engineering, s.185-201, Nr. 443/1-2, (2007).
16. ABDULWAHAB, M. Studies of the Mechanical Properties of Age-hardened Al-Si-Fe-Mn Alloy. Australian Journal of Basic Applied Science, s. 839, Nr. 2/4, (2008).
17. JOHANSEN, H. G. Structural Aluminium Materials. TALAT Lecture 2202 - Basic Level, (1994).
18. MICHNA, Š. et al. Aluminium materials and technologies from A to Z. Děčín s.n., s. 613, (2007).
19. ALERIS GERMAN Works GmbH, Casting Alloys Catalog Al-Si phase diagram and structures of various Al-Si alloys [online]. [citing 07.04.2015] Available of http://www.giessereilexikon.com/en/foundry-lexicon/?tx_contagged%5Bsource%5D=default &tx_contagged%5Buid%5D=4567&tx_contagged%5BbackPid%5D=6&cHash=ea4f2478ca0e5 cacc114a2cb43b73f9a
20. HURTALOVÁ, L. Evolution of the structure in recycled AlSi9cu3 cast alloy during solution treatment. Journal of Machine Manufacturing: Design and Manufacturing, s. 6-13, Nr. 49/ E3-E5, (2009).

Summary

Effect of the different technological processes during and after casting of hypouetectic aluminium alloys on the eutectic Si particles morphology

Lenka Hurtalová, Eva Tillová, Mária Chalupová

The purpose of this article is to examine the effect of different technological processes during and after casting of hypoeutectic Al-Si cast alloys on the eutectic Si particles morphology. The changes of Si particles morphology were studied on samples in as-cast states (untreated state). The used technological processes for affecting the Si morphology were: modification with Sb, T4 heat treatment and age-hardening. The best results were achieved with T4 heat treatment, because it caused the greatest changes in morphology of eutectic Si particles and it was the aim of this experiment. Morphology changes were studied with light and scanning electron microscope. A several types of etching methods, which includes regular black and white etching (Dix-Keller; HF), and deep etching (HCl), for studying of structural parameters morphology were used.