ARCHIVES
Of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 9
Issue 2/2009
57-60

13/2

Structural stability at elevated temperatures of the AlSi6Cu4 matrix composite with graphite particles

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Received: 26.02.2009; accepted in revised form: 30.03.2009

Abstract

The results of investigation of structure stability of the AlSi6Cu4 matrix alloy and composites with graphite particles at elevated temperatures were presented. Composites and matrix alloy were prepared by squeeze casting method and then they were annealed at 573 K and 673 K during 1, 20, 100, 500, and 1000 hours. The structures of composites and matrix alloy were observed and compared after annealing. Changes in the structure both in matrix alloy and composite were stated at both temperatures. These changes are characterised by the change in morphology of eutectic silicon, which needle-like grains turn into spheroids. The spheroidization starts in the pure alloy after 500 hours of annealing at 573 K and after 300 hours of annealing at 673 K. The changes occur sooner in the composite than in matrix alloy: they can be stated after 100 hours of annealing at 573 K, while at 673 K they started between 50 and 100 hours. The change in the morphology of eutectic silicon takes place faster along and among the graphite particles than in particle-free regions of composite. The matrix/graphite interface was found to be free of reaction products (Al_4C_3 and others).

Keywords: aluminium alloys, pressure casting, composites, structure

1. Introduction

The squeeze casting process has many advantages over sand casting and gravity die casting for Al alloys. Solidification process takes place under a high applied pressure where excellent feeding of solidification shrinkage and a refined microstructure due to high cooling rates are achieved. The absence of shrinkage porosity, combined with a fine-scale microstructure results in very good mechanical properties for both conventional aluminium alloys castings and aluminium alloys matrix composites [1]. The cooling rate of the casting can be increased by applying high pressure during solidification, since thermal contact between the casting and the die is improved by pressurization, which results in the formation of fine-grained structures [2]. In the AlCu alloys formed by squeeze casting method the macrosegregation has been frequently found [3]. Stress-transfer analysis for particle-matrix interfaces in particle reinforced composites shows the improvement in strength and resistance fracture toughness of these materials. It was found that the end interface of a short fibre is easy to debond in the loading process. After the debonding of the end interface, the stress transfer from matrix to fibre depends on shear stress on the axial interface only [4].

Cast aluminium-graphite particulate composites are reported to possess good tribological properties. Under moderate load ranges and lubrication conditions these composites can replace commonly used cooper, lead and tin based bearing alloys with considerable cost savings and better performance [5]. Preparation of aluminium-graphite particle composites by conventional melting and casting techniques is difficult, since graphite is not wetted by liquid aluminium below 1353 K. This leads to the rejection of graphite particles from the melts. Two methods can be employed to improve the wetting between graphite and liquid metal. One of these method is using of nickel or cooper coated graphite particles and the other is mixing of graphite particles with liquid aluminium using vortex method. In this method particles added to the melt are stirred by mechanical impeller [6].

Production of stable and uniform composite suspension depends on a set of surface phenomena occurring at the interface between metal and the non-metallic particle, such as wetting, dipping, adhesion, chemical reactions, and diffusion. They are decisive for the strength of bonding between components, as well as for the reinforcement arrangement in the composite volume, which in turn provides for achieving the demanded level of composite material properties [7,8,9].

Most of alloys that were employed as matrices in composites are light alloys, particularly those based on aluminium. These matrix alloys have included both non-heat treatable and heat-treatable alloys. The heat-treatable alloys constitute a metallurgically active component of metal matrix composites which properties can be deliberately altered to influence the composite properties. Designing the composite microstructure and aging treatments based directly on the precipitation characteristics of the non-reinforced matrix material, may impair strengthening of the composite. It was observed that the kinetics are enhanced or retarded by reinforcing the matrix alloy during a heat treatment in different metal matrix composites [10,11].

2. Methodics and material

The examined composites have been made of AlSi6Cu4 alloy matrix reinforced with 8 vol. % of natural graphite particles. This matrix alloy is commonly used in foundry technology and its composition assures good wettability and arrangement of graphite particles because of its wide solidification range. This way composite slurry can be easy achieved. The alloy exhibits good casting properties what enables production of castings with complex shape. Graphite particles of 70-100 μm size have been used for preparing the composites.

Composite suspension has been prepared by mechanical mixing method. The matrix alloy was melted in the induction crucible furnace and overheated up to the temperature of 993 K. Then reinforcing particles have been introduced into the stirred molten alloy by means of a dosing spout. Mixing has been done by turbine mixer of 0.05 m diameter equipped with four blades of the angle of slope equal to 45º, which have been placed at the distance equal to one-third of the height of the liquid metal from the bottom of crucible in its axis. The mixing time has been 10 minutes and the angular velocity of mixer has been set for 500 rpm. Composite production process parameters selected in this way have enabled the uniform distribution of graphite particles within the matrix volume.

After mixing the squeeze casting method was used for sample preparing. Slab-shaped specimen castings of dimensions 200×100×20 mm have been produced in the die block mounted on the PHM-250C hydraulic press. Pressing in a solid-liquid state has been realised at constant alloy temperature equal to about 923 K. The examination has been realised for the pressing pressure 90 MPa and die temperature was 523 K.

All experimental specimens were prepared in the same manner: cut out of the base billet of material, ground to appropriate roughness (grid 400 for elevated temperature and corrosion experiments and diamond for observation of the structure after temperature and corrosion experiments). Each specimen was fitted with a hole to suspend it in a furnace and corrosion cell.

Thermal conditions to which both matrix alloy and composite were exposed were the temperatures of 573 K and 673 K for the annealing times of 1, 20, 100, 500 and 1000 hours. Both of selected temperatures represent conditions under which commonly used aluminium products work (e.g. as engine parts or automotive structures). Different times of annealing were long enough to observe the changes occurring in materials at both temperatures. Structural stability was evaluated in terms of the changes in morphology of matrix and composite phases, in composition and distribution of the phases and at matrix/graphite interfaces. In order to observe the morphology, the specimens were prepared in a standard metallographic manner and the observation was carried out on optical and electron microscope.

The changes in structure were also monitored by hardness measurements at given times of annealing. Hardness measurements were performed according to Rockwell hardness measurement in H scale (HRH) with 9.525 (3/8") mm steel ball and maximum load of 600 N. Each specimen was measured at least five times on two parallel sites and the results were processed using statistic methods.

3. Results of the experiments and conclusions

Microstructure of the as-cast composite is shown in Fig.1.

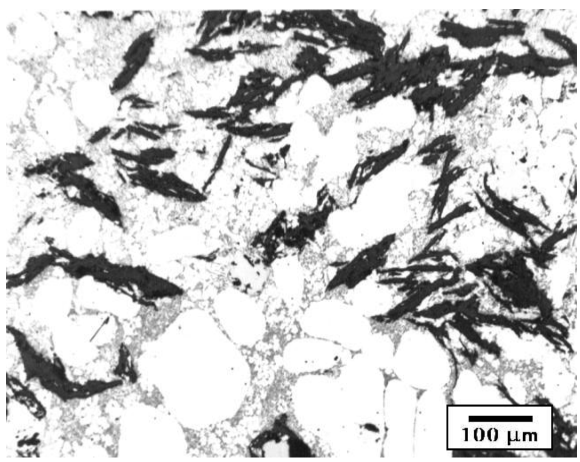

Fig.1. Microstructure of the AlSi6Cu4 alloy matrix reinforced with 8 vol. % of natural graphite particles composite

Graphite particles of reinforcement are arranged in interdendritic spaces due to crystallisation front motion. Microstructures of composite matrix alloy after 1000 hours of annealing at 573 K at different magnification are shown in Fig.2 and Fig.3.

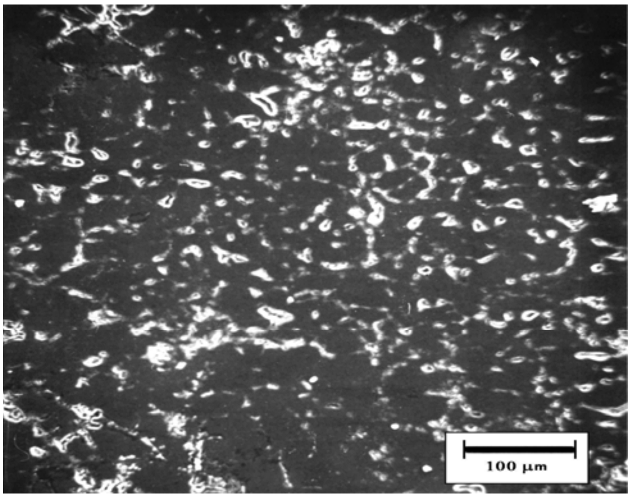

Fig.2 Microstructure of the AlSi6Cu4 alloy after 1000 hours of annealing at 573 K

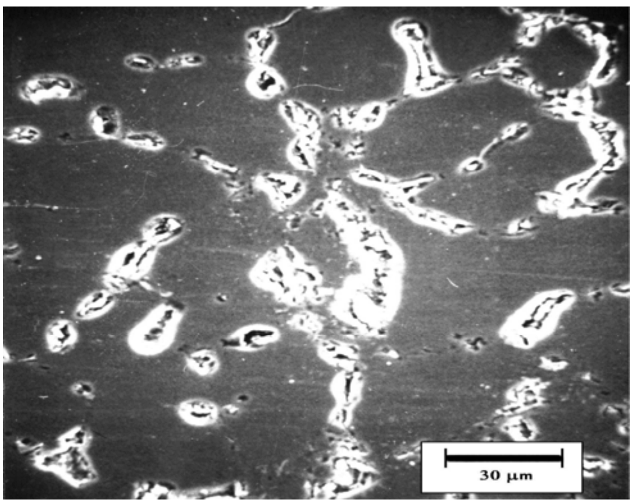

Fig.3 Microstructure of the AlSi6Cu4 alloy after 1000 hours of annealing at 573 K

Microstructures of composite after 1000 hours of annealing at 573 K at different magnification are shown in Fig.4 and Fig.5. Changes in the structure occur both in matrix alloy and composite at both temperatures. These changes are exhibited by the change in morphology of eutectic silicon whose needle-like grains turn into spheroids. The spheroidization starts in the alloy after 500 hours of annealing at 573 K and after 300 hours of annealing at 673 K. In the composite the changes set in sooner than in matrix alloy: after 100 hours of annealing at 573 K, while at 673 K it started between 50 and 100 hours. The change in the morphology of eutectic silicon takes place faster along and among the graphite particles than in particle-free regions of composite.

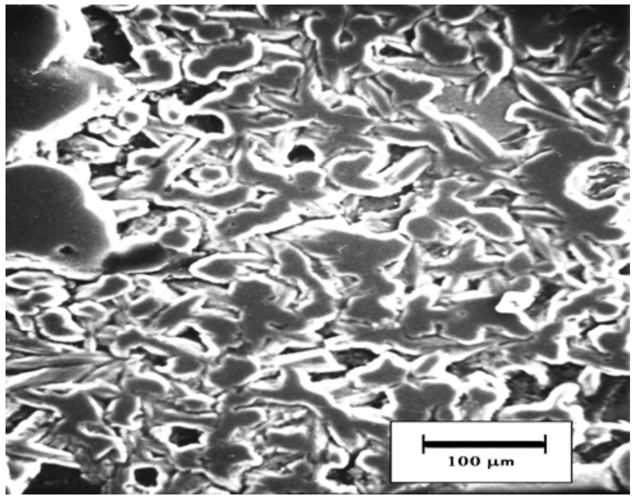

Fig.4 Microstructure of the composite after 1000 hours of annealing at 573 K

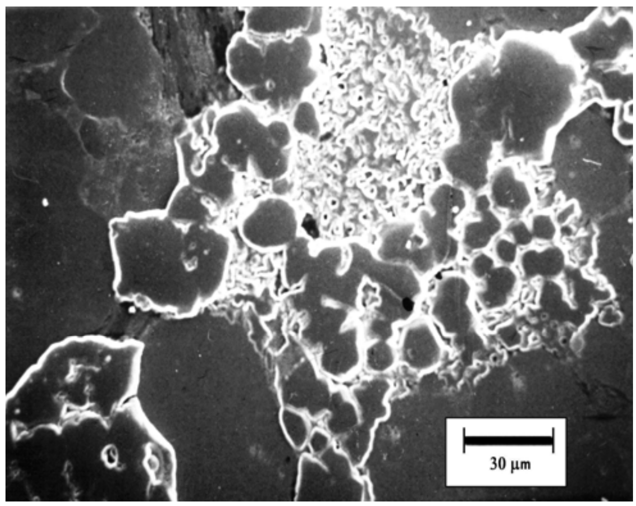

Fig.5 Microstructure of the composite after 1000 hours of annealing at 573 K

Structure contained also a few other compounds. One of them was FeSiAl intermetallic compound in the form of Chinese script. In spite of eutectic silicon as well as other similar compounds, it subjects to no changes in morphology during annealing at both temperatures. The matrix/graphite interface was found to be free of reaction products (Al_4C_3 and others).

Grain size was also evaluated. Original grain size of the range of 150-200 µm underwent a small coarsening. It was stated, however, that this coarsening had not exceeded 10 µm and it implies that it played a marginal, if any, role in annealing of both materials at elevated temperatures.

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