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MODIFICATION TECHNOLOGY OF SILUMINS WITH HIGH CONTENT OF IRON BY ULTRAFINE SILICON

Bogdanova T. A., Merkulova G. A., Gilmanshina T. R., Kosovich A. A., Lytkina S. I and Cheglakov A. V
[1]Department of Materials Science and Materials Processing Technologies, Polytechnic Institute, Siberian Federal University, Krasnoyarsk, Russia
[1]Siberian Federal University, Krasnoyarsk, Russia
E-Mail: tgilmanshina@sfu-kras.ru

ABSTRACT

The most promising direction in the modification of aluminum alloys, including silumins, is the use of ultrafine modifiers (carbon nanoparticles, ultrafine carbides, nitrides, oxides, etc.) with a particle size of 0.1-1 μm, which can improve the quality of alloy with minimal implementation costs. According to the results of the work done, it was found that the technology for modifying silumin based on primary aluminum with high iron content by a tablet modifier leads to a change in the morphology of the β-phase. This allows increasing the elongation of the alloy by 50 % and the ultimate tensile strength by 20 %.

Keywords: silumin, tablet ultrafine modifier, silicon carbide, elongation, ultimate tensile strength, yield tensile strength.

INTRODUCTION

Recently, in the foundry, special attention has been paid to out-of-furnace methods for processing melts to improve their quality. Out-of-furnace processing is of particular importance for aluminum alloys, since due to refining and modification operations, the required level of quality indicators can be achieved and the operational reliability of products can be guaranteed. There is no universal method of out-of-furnace treatment, which would allow melt degassing, clean it of large and dispersed non-metallic inclusions, uniformly distribute the modifier over the melt volume.

In modern industrial practice of Russia manufacture of cast products is widely used silumins, the most effective modifiers of which are strontium and titanium. However, their use has the following problems [1-6]:

- high cost, since the most effective modifiers are supplied by foreign companies;
- low engineering feasibility during processing of a large volume of melt;
- necessity for precise control of temperature at which the modifier is added to the melt, and its exposure time, due to the low viability of the modifiers.

Therefore, the need for the development of domestic modifiers and their application in the technological process for the production of cast products is obvious.

The most promising direction in the modification of aluminum alloys, including silumins, is the use of ultrafine modifiers (carbon nanoparticles, ultrafine carbides, nitrides, oxides, etc.). A number of works [7-16] are devoted to the addition of ultrafine modifiers to melts. However, many authors note the difficulty of using such modifiers.

The aim of this work is to study the structure and mechanical properties of silumin with high iron content - up to 0.5 %, modified with an ultrafine modifier based on silicon carbide, added by various methods.

MATERIAL AND RESEARCH METHODOLOGY

The alloy AK12 (DIN AlSi11, ISO AlSi12) was prepared in an induction furnace IAT-2.5 using the following charge materials: primary aluminum of grade A7 (DIN 3.0275, ISO Al99.7) and crystalline silicon Kr00 (according to GOST 2169-69).

For research, an ultrafine modifier based on silicon carbide was selected, which was introduced into the melt in the form of tablets under the stream of metal [16]. The treated alloy was poured into the ingot at a temperature of 780 °C.

The chemical composition of the alloy was evaluated by spectral analysis on a SPECTROMAX spectrometer according to GOST 11069-2001 and GOST 1583-93. The study of the microstructure was carried out using an EVO50HVP scanning electron microscope. The mechanical properties of the experimental alloys were determined according to GOST 1497-93 on a universal tensile testing machine WDW-20 at room temperature.

The foil was studied on a JEM-2100 transmission electron microscope. Ion thinning was performed on the equipment of model EM-0900100IS, located at the Institute of Advanced Materials Physics in Ufa. In this connection, the authors express their gratitude to senior research assistant M. Yu. Murashkin.

RESULT AND DISCUSSIONS

It is known that with the forced method of moving the melt, namely, stirring, at the interface between the aluminum melt and solid particles of silicon carbide due to the difference in the oscillation rates of the solid and liquid phases, viscous friction forces arise that reduce the surface tension at the interface between the solid and liquid phases. Because fluctuation processes are intensified in the field of elastic vibrations, which determine the probability of the transition of the metal from the liquid phase to the solid state, it is assumed that

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elastic vibrations change the activation energy of nucleating SiC particles. Because of changes in surface tension and activation energy, the work of nucleation decreases and the probability of solid phase nucleation increases, which in turn increases the crystallization rate [14].

Mixing of liquid modified aluminum alloys has a strong catalytic effect on the “melt - SiC modifier” system, positively affects the capillary microrelief of the surface of dispersed silicon carbide particles, turning them into active crystallization centers.

When SiC is added to the aluminum melt, a reaction with the formation of aluminum carbide (Al4C3) is likely [20]. However, thermodynamic calculations performed in the Chemistry software show that the probability of aluminum carbide formation in the temperature range from 0 to 1000 °C is quite low (Figure-1).

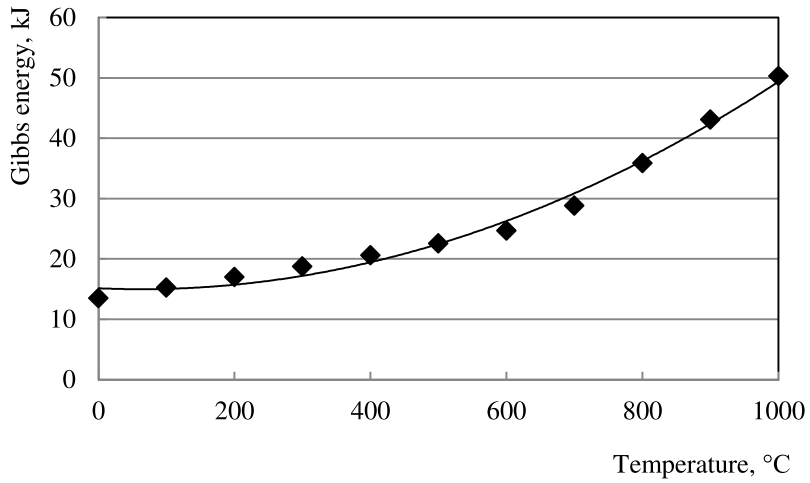
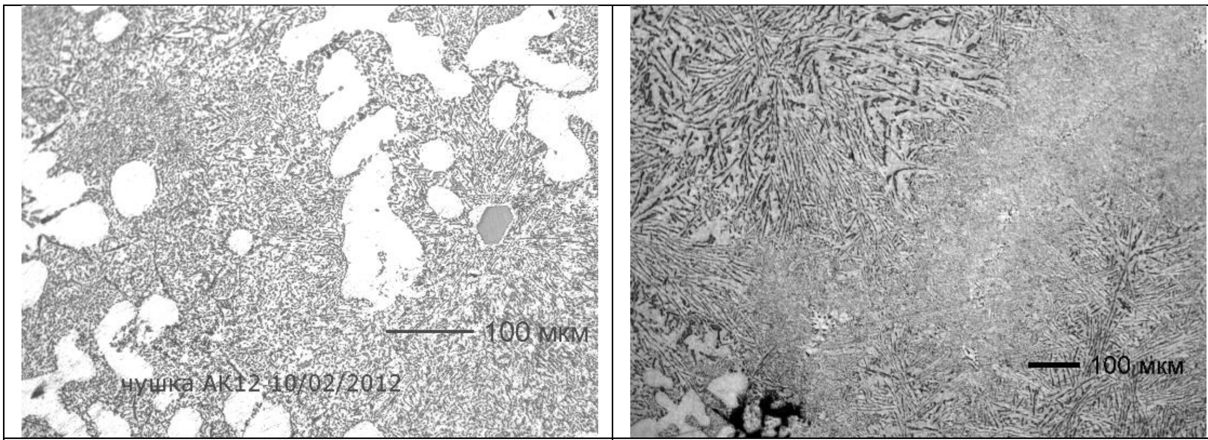


Figure-1. Gibbs energy dependence on temperature for the reaction
4Al + 3SiC = Al4C3 + 3Si.

Microstructural studies revealed uneven structure modification associated with the distribution of the modifier in the melt and a change in the morphology of the iron-containing β-phase with high iron content - more than 0.5% (Figure-2). For a better effect of the modifier on all micro volumes, it is necessary to provide additional mechanical impact when it is added into the melt.



(a)	(b)

Figure-2. Microstructure of AK12 ingots before (a) and after (b) modification.

It is known that aluminum is poorly wetted by silicon carbide. Therefore, to ensure good wettability of silicon carbide particles by the melt it is necessary to form a single crystal layer from the intermediate phase with lattice parameters close to aluminum on the surface of SiC particles [17-19]. The most possible such transitional phase may be an iron-containing phase. To confirm this assumption, foil samples were studied by transmission electron microscopy.

The results showed that on the surface of twins of silicon carbide particles, a single-crystal surface layer is formed, characterized by the presence of a moire pattern (Figure-3). At a higher magnification, it is seen that the electron moire effect is observed on the silicon carbide particle and imperfections in the form of a network of dislocations are clearly visible (Figure-4).

Additionally, based on the obtained data and the geometric parameters of dispersed silicon carbide particles (size - 0.1 μm, density - 3.21 g/cm3, particle mass - $1.68 \cdot 10^{-15}$ g), the number of new crystallization centers into the crucible was calculated. With the silicon carbide content in the tablets equal 38.4 g, the number of particles in the crucible is $2 \cdot 10^{14}$.

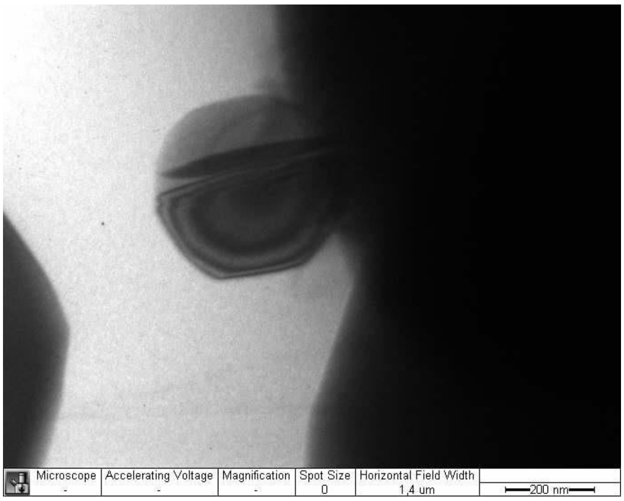


Figure-3. Silicon carbide particles with a surface layer of the transition phase.

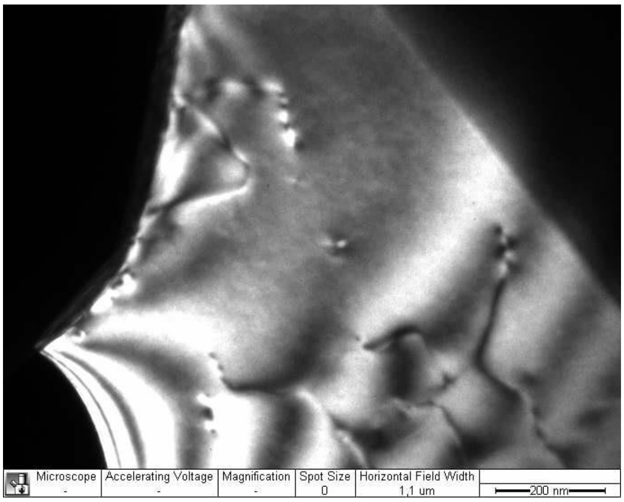


Figure-4. Picture of dislocations in the transition layer.

A noticeable increase in mechanical properties is observed for an alloy with a high content of Fe ≤ 0.5 % as shown in the Figure-5. Studies of the microstructure of the samples showed that the introduction of silicon carbide into the alloy leads to a change in the morphology of coarse inclusions of the β-phase, which led to an increase in the relative elongation and strength in comparison with the control ingot without modification.

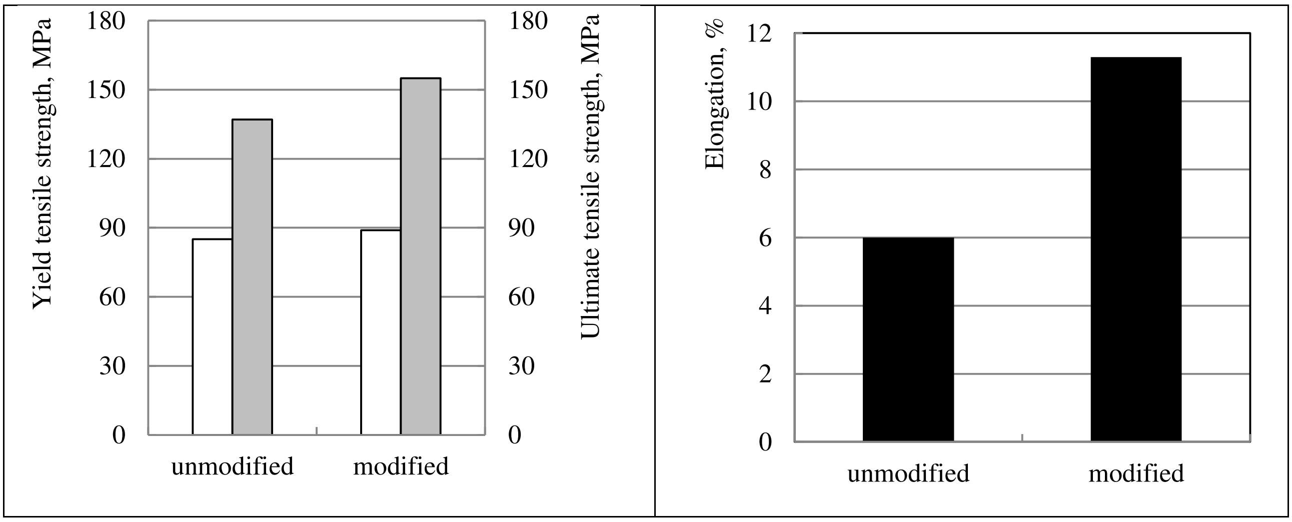


Figure-5. Yield tensile strength (□), ultimate tensile strength (■) and elongation (■) for AK12 ingot.

CONCLUSIONS

Thus, we can conclude that the technology for modifying silumin AK12 (DIN AlSi11, ISO AlSi12) based on aluminum of grade A7 (DIN 3.0275, ISO Al99.7) with a high iron content (up to 0.5 %) of a tablet modifier based on ultrafine silicon carbide leads to a change in the morphology of the β-phase, which allows to increase the elongation of the alloy by 50 %, yield tensile strength - by 20 %.

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