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Structure and properties changes of Al-Si alloy treated by pulsed electron beam

Dmitry Zagulyaev [a], Sergey Konovalov [b,*], Victor Gromov [a], Alexander Glezer [c], Yurii Ivanov [d], Roman Sundeev [e]

[a] Siberian State Industrial University, Novokuznetsk, 654007, 42 Kirov Street, Russia
[b] Samara National Research University, 34 Moskovskoye Shosse, 443086 Samara, Russia
[c] National University of Science and Technology "MISIS", 4 Leninskiy Ave., 119049 Moscow, Russia
[d] Institute of High Current Electronics of the Siberian Branch of the RAS, 2/3, Academicheskii Ave., 654052 Tomsk, Russia
[e] MIREA – Russian Technological University, 119454, Vernadskogo av. 78, Moscow, Russia

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ABSTRACT

Using up-to-date methods of material studies, it is revealed that the structure of as cast Al-Si alloy (silumin) is multi-phased and morphologically heterogeneous. It consists of solid solution grains and eutectic Al-Si with a diverse morphology. With the help of selective etching intermetallic compounds (AlNiCu and AlMg) are detected on the grain boundaries of α-solid solution. Treatment of silumin samples by the intense pulsed electron beam with the diverse density results in release of the second phase sub-micro and nano-dimensional particles. According to experiments optimal energy densities of the electron beam are 25, 30 and 35 J/sm^2. Silumin irradiation results in a manyfold advance of mechanical and tribological properties of the surface layers. As found out, these characteristics of the surface layers change significantly due to the sub-micro and nano-dimensional structure of cellular crystallization formed by the electron beam, which is free of primary inclusions consisting of silicon and intermetallic compounds.

1. Introduction

To date, one of the key problems in material studies is improvement of service characteristics of industrial materials via changing structure and phase state of their surface layers; that is hardly possible for traditional procedures of thermo-mechanical and chemicothermal treatment. Recently, groups of researchers are involved into the development of new construction materials with outstanding physical and mechanical characteristics. Construction materials can be produced when a "secondary structure" with improved physical and mechanical properties is formed in the working layer; this structure is to have a longer service life and better reliability than the base material.

In recent years scientists have been focused on the influence of intense pulsed electron beam (IPEB) treatment on physical and mechanical properties of different materials, e.g., the effect of the electron beam on the composite (TiB + TiC)/Ti. It was revealed that electron beam treatment is significantly important for the evolution of micro-structure and properties of composites with a titanium matrix, and also deteriorates mechanical characteristics, e.g. wear resistance [1]. Electron irradiation is widely used in industries for welding, and the instant high temperature of this process, is significantly advantageous for the synthesis of metallic materials [2,3]. This technology can be considered a procedure for manufacturing nano-composite materials of metals and oxides using oxide layers [4]. The change in the surface roughness and wear resistance before and after electron beam treatment was studied. It is disclosed that surface roughness and microhardness depend on the changing beam current. In comparison with samples in the initial state roughness decreased 2.5 times and hardness increased twofold at a beam current of 7 mA [5].

Some necessary equipment is required for the development of new technologies involving the use of concentrated energy flows. Research and industrial company "Eltekhmash" (Vinnica, Ukraine) has already succeeded in the development of this kind of equipment [6–10].

Therefore, the purpose is to study changes in the surface silumin layer structure processed by the sub-millisecond pulsed electron beam.

2. Materials and methods

The surface of samples was treated by the IPEB using laboratory unit "SOLO" [11]. IPEB parameters were as follows: energy of

* Corresponding author at: Samara National Research University, 34 Moskovskoye Shosse, Samara 443086, Russia.
E-mail address: ksv@ssau.ru (S. Konovalov).

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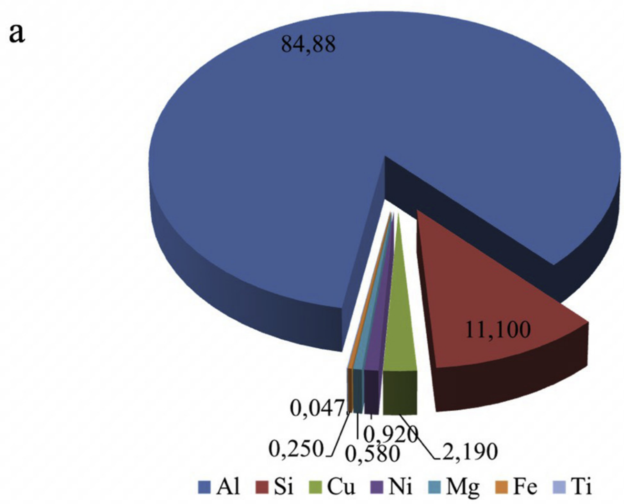

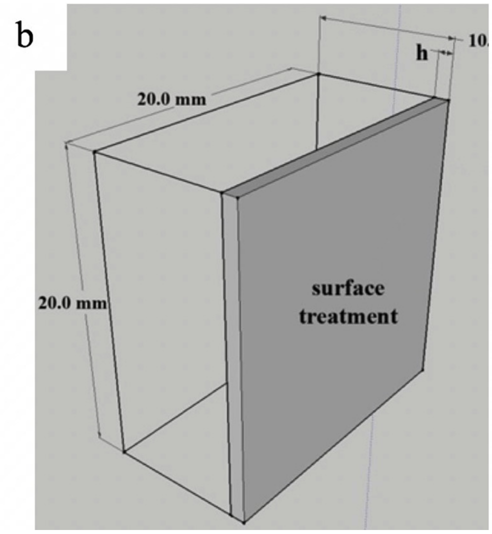

Fig. 1. X-ray spectrometry of silumin samples (a), geometry of samples and treated surface (b).

accelerated electrons 17 keV, energy density of the PEB (25, 30, 35) J/cm^2, pulse duration of the PEB 150 μs, number of pulses 3, frequency of pulses 0.3 s^{-1}.

Aluminum and silicon alloy AK10M2N was selected as research material. A chemical composition of samples (Fig. 1a) with basic elements Al – 84.88% and Si – 11.10% was assessed using X-ray spectrometry with the help of energy-dispersion detector for X-ray micro-spectrometry INCAx-act. Comparing the obtained data with the Russian state standard (GOST) 30620-98, it was revealed that the element composition of silumin is similar to that of silumin. Samples were 20 × 20 × 10 mm^3 (Fig. 1b) and oriented perpendicular to the electron beam axis.

Micro-hardness was measured to analyze mechanical properties of the surface layers, since it is one of the most precise and sensitive methods. Its values before and after treatment are necessary for assessment of hardening in modified surface layers of metals and alloys [12]. Measurements of micro-hardness were conducted using micro-hardness measuring unit HVS-1000 and according to Vickers method. To estimate micro-hardness the method of a renewed imprint (basic) was used and a tetrahedral pyramid with a square base was applied.

The element and phase composition, defect sub-structure of the modified layer were studied by scanning electron microscopy (SEM) and with units SEM-515 Philips equipped by a micro-analysis device EDAX ECON IV. The tribotester Pin on Disc and Oscillating TRIBO tester were used for tribological tests at the following parameters: a ball of steel 52,100 with a diameter of 6 mm, track radius – 2 mm, load – 1 N, distance – (5 – 80) m.

3. Results and discussion

Fig. 2 shows a typical structure of the etched thin section of as cast alloy identified by SEM. The microphotograph demonstrates a multi-phase, morphologically heterogeneous structure of the material. The micro-structure of the alloy consists of solid solution grains and eutectic Al-Si with different morphology. Selective etching on the grain edges of α-solid solution detected intermetallic compounds (AlNiCu and AlMg). Table 1 gives results of a certain inclusion tested by X-ray micro-spectrometry.

Considering the changes of mechanical (micro-hardness) and tribological (wear parameter) properties of silumin treated by the IPEB in the wide range of its densities (10, 15, 20, 25, 30, 35) J/cm^2, it was revealed that characteristics of the silumin surface changed significantly (Fig. 3). As seen in Fig. 3, the wear parameter (inverse number of wear resistance) decreases sevenfold, and micro-hardness increases by 1.7 times. The maximal drop of the

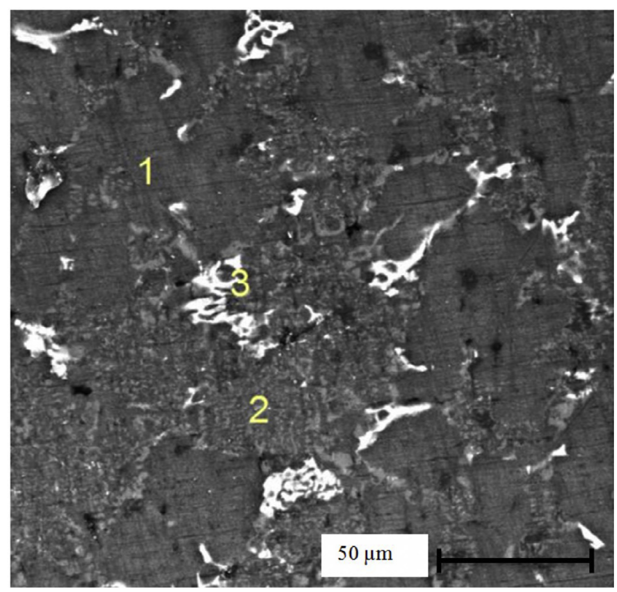

Fig. 2. Microstructure of as cast silumin, identified by SEM of the etched micro-section; zones are marked where element composition of the material was studied by X-ray micro-analysis. SEM.

Table 1
Element composition in certain zones of as cast silumin structure, its electron microphotograph is given in Fig. 2. The data are given in wt%.

Area	Mg	Al	Si	Fe	Ni	Cu
1	0.17	96.46	1.67	0.02	0.04	1.64
2	0.30	74.98	22.80	0.04	0.12	1.76
3	0.44	64.16	0.83	0.71	24.36	9.50