A study on changes in the properties of silumin surface layers modified by yttrium oxide

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Abstract. In the present work, the analysis of the structure and properties of silumin, modified by deposition of yttrium oxide on the surface by electric-explosive alloying, was made, (alloying with a droplet-plasma flow produced by the electric explosion of a conductive foil with a sample of powder material). The structure and phase composition of silumin were studied by scanning and transmission diffraction electron microscopy. Formed coatings are characterized by a high level of roughness and porosity.

1. Introduction

It is known that aluminum is one of the most widespread metals and occupies the first place in terms of content in the earth crust – 81.3 kg of aluminum per ton of the earth crust, which is 31.3 kg more than iron [1]. Due to aluminum occurrence the scientific community focus their attention on the studying of its properties and the possibilities of modifying them [2-4]. One of the most common methods for modifying aluminum is the addition of alloying elements, for example, silicon during the casting process, the resulting alloys are called silumins.

Silumins – the most common foundry alloys based on aluminum [5-8]. They are widely used as a structural material due to the combination of a complex of high operational and foundry-technological properties. In particular, the pistons of internal combustion engines and compressors are manufactured mainly from eutectic and hypereutectic silumins [5-10]. Despite this fact, taking into account continuously increasing requirements to the quality of cast products, efficiency and environmental friendliness of the technological process, it is still necessary to search for new reserves for improving the technological process and effective methods for improving the silumin properties, based on modification, microalloying and intensification of the solidification process (crystallization of the alloy) in the foundry form. One of these methods, combining the introduction of various elements and refractory particles into the melt with a high rate of crystallization of the material, is electric explosive alloying [10].

The purpose of this work is to study the structure and properties of silumin eutectic composition subjected to modification by yttrium oxide particles by the methods of electric explosive alloying.
2. Materials and methods
Eutectic silumin was used as the study material, the elemental composition of which is given in table 1.

Table 1. Results of x-ray spectral analysis of silumin samples (wt%, Al is the rest).

|   | Si  | Fe  | Cu  | Mn  | Mg  | Ni  | Ti  | Cr  | Zn  | Pb |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
|   | 11.1| 0.25| 2.19| 0.029| 0.58| 0.92| 0.047| 0.005| нет | нет |

Studies of the phase composition and the state of the silumin crystal lattice were carried out by X-ray diffraction analysis (XRD-7000s, Shimadzu, Japan). Investigation of the elemental and phase composition, the defective silumin substructure, was carried out by scanning methods (Philips SEM 515 equipped with EDAX ECON IV microanalyzer) and transmission diffraction (JEM-2100F, JEOL, Japan) electron microscopy. Foils (the research object of the material by the methods of transmission electron diffraction microscopy) were produced by ion thinning of thin (100 μm) plates on the Ion Slicer EM 09100IS instrument.

3. Research and discussion
Earlier, it was established in [9] that the electric explosive alloying (hereinafter referred to as EEA) of silumin of eutectic composition is accompanied by the formation of a layer with a highly developed topography of the modification surface. Indeed, the studies presented in this paper show that as a result of silumin EEA, a surface layer is formed, characterized by the high level of roughness, containing a large number of micropores, microcraters and microcracks (figure 1).

![Figure 1](image1.png)

Figure 1. Silumin surface structure of eutectic composition subjected to EEA. Scanning electron microscopy.

Using the micro-X-ray spectral analysis, silumin elemental composition of the surface layer, subjected to EEA, was investigated. The results of the performed studies are presented in table 2.

Table 2. Elemental composition of the silumin surface layer, subjected to EEA, revealed by micro-X-ray spectral analysis of the zones shown in figure 2. Scanning electron microscopy. Results are presented in weight %.

| Zone | Al  | Si  | Mg  | Ti  | Fe  | Ni  | Cu  | Y   | O   | C   |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Figure 2, a | 47.2| 3.0 | 0.6 | 1.0 | 0.7 | 1.3 | 1.8 | 16.2| 10.8| 17.4|
| Figure 2, c | 0.8 | 0.0 | 0.0 | 0.2 | 0.7 | 0.5 | 0.7 | 34.0| 28.1| 35.0|

Analyzing the results presented in table 2, it can be noted that EEA leads to the formation of a surface layer with a high level of inhomogeneity in the distribution of alloying elements, which is most noticeable in the distribution of yttrium and oxygen atoms. These results confirm the fact that
there is a presence of powder particles of alloying material in the plasma flow, previously identified in many studies [9, 10].

The structure of silumin volume subjected to EEA was analyzed by the cross-section method. A typical image of the alloyed layer structure revealed by scanning electron microscopy is shown in figure 2. Analyzing the results obtained, it can be noted, first, that the thickness of the modified layer varies within (30 - 50) μm. Second, a high level of porosity; pore sizes vary from units to tens of micrometers.

**Figure 2.** The structure of the silumin cross-section of eutectic composition subjected to EEA. Scanning electron microscopy.

**Table 3.** Results of X-ray diffraction analysis of silumin sample of eutectic composition subjected to EEA.

| Phase   | Content, rel. % | Parameter of a lattice, nm | D(CIR), nm | Δd/d, 10^{-3} |
|---------|-----------------|----------------------------|------------|-------------|
| Al      | 68.2            | 0.40485                    | 75.01      | 0.24        |
| Si      | 30.1            | 0.54231                    | 16.4       | 0.80        |
| Y2O3    | 1.7             | 1.06010                    | 16.6       | 7.88        |

The phase composition of silumin modified by EEA was investigated by X-ray diffraction analysis. The quantitative results of the phase analysis of the X-ray diffraction obtained from the studied material are presented in table 3. Analyzing the results presented in table 3, one can note, first, an essentially high level of silicon in the surface layer of silumin, which can indicate the evaporation of some aluminum layer during EEA. Second, the presence of the phase Y2O3, which can be due to the introduction of particles of the initial yttrium oxide powder into the surface layer of silumin during EEA.

**4. Conclusion**

The modification of the silumin surface layer of eutectic composition by yttrium oxide particles was carried out by the method of electric explosive alloying. It was established that silumin EEA is accompanied by the formation of a highly porous surface layer with a thickness up to 50 μm, characterized by inhomogeneity in the distribution of alloying elements (silicon, yttrium and oxygen), a submicrocosmic and nanoscale multiphase structure, strengthening phases which are silicon particles, Y2O3, YSi2 and Y2Si2O.

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