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Hypereutectic silumin modification by ion-electron-plasma method

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Abstract. In this paper, hypereutectic silumin (22-24 wt/%) was used. The structure was studied before modification. It is represented by primary silicon grains with a size of about 100 μm. Intermetallic compounds are also non-uniform distributed. After modification by an electron beam, the crystallite size was 0.4-0.5 μm. There are several layers. The modification depth was 130 μm. Hardness increased in 1.7 times, wear resistance in 1.2 times. Also, in this paper, data was given on the variation of the elementary composition with respect to the depth of the sample. The film was melt into the surface of the sample by an electron beam after depositing. The hardness increased by 1.7 times, the wear resistance increased in 2.6 times in comparison with the untreated samples. The coefficient of friction was 0.39.

1. Introduction

Hypereutectic silumin is a casting alloy of aluminum with silicon. The percentage of the silicon is above 12 wt.%. Hypereutectic silumin consists of eutectic, primary silicon grains and intermetallides. This alloy has a low coefficient of thermal expansion, corrosion resistance, low weight, increased frictional wear resistance [1]. Prospective directions of using this material are aircraft building, space industry. And also silumin are widely used as a material for the preparation of bearings and pistons. A number of shortcomings, such as low mechanical properties, heterogeneity of the structure limit its use in engineering. Also the presence of having increased hardness and brittleness primary silicon grains limits silumin's use. This fact leads to insufficiently high properties of hypereutectic silumin. Ion-electron treatment allows eliminating these deficiencies by substantial dispersion of the structure, and, as a result, leading to an increase in mechanical characteristics [2].

The main purpose of this work is the development of a method for combined electron-ion-plasma modification of the hypereutectic silumin`s surface layer, combining the thin film deposition and the subsequent irradiation of the "film / substrate" system by a high-intensity pulsed electron beam.

2. Materials and methods

Hypereutectic silumin is used as a studied material; the content of silicon is 22-24 wt%. The high of cylinder cast samples is 5 mm, the diameter is 30 mm. The coating (Zr – 5 % Ti – 5 %Cu) thickness was 1 μm. The Zr – 5% Ti – 5% Cu cathode (setup "TRIO" (IHCE SB RAS)) [3-5] was used for creating the “film (Zr – 5% Ti – 5% Cu) / (Al – (22–24) wt. % Si) substrate system”. The method was ion-plasma method during arc-sputtering. Irradiation mode was 18 keV, the energy density of the electron beam was 40 J/cm^2, the pulse repetition rate was 0.3 s^{-1}, the pulse duration was 200 μs and the number of pulses was 20. This mode has been chosen taking into account thermal calculations, ensuring the remelting of all present phases [3-5]. Optical and scanning electron microscopy and the X-ray analysis have established elemental and phase composition, defects hypereutectic silumin`s structure. The microhardness characterize mechanical properties. In the geometry of pin-on-disc at room temperature and humidity (a CSEM pin-on-disk tribometer, Switzerland) were conducted test silumin`s wear resistance.). The volume of the wear-and-tear material was estimated after conducting a profilometry of the formed track (a MicroMeasure 3D Station, Stil, France).

3. Results of the research and their discussion

The hypereutectic silumin`s structure in the initial state is characterized by the presence of primary silicon inclusions. They have mainly of lamellar form, which dimensions (longitudinal) reach 100 μm (figure 1). Intermetallics were found. Pores of micron and submicron sizes are the main disadvantage. It limits the scope of application.

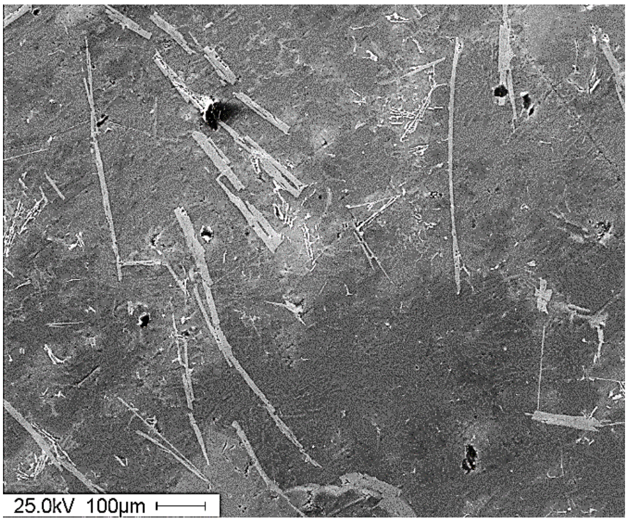


Figure 1. Hypereutectic silumin`s structure in the cast state.

There are two main phases – a aluminum`s solid solution and a silicon`s solid solution. This was confirmed X-ray diffraction analysis. Intermetallic compounds were found. Diffraction maximums of $Fe_2Al_3Si_3$ phase was identified by X-ray analysis.

The value of microhardness characterize the hypereutectic composition silumin`s mechanical properties in the cast state. The silumin`s microhardness (averaged over 10 measurements) is 3530 MPa. The wear parameter and the coefficient of friction characterize the tribological properties of the investigated silumin. The wear parameter of silumin is 5,86·10^{-4} mm^3/N·m, coefficient of friction is 0.4.

Coarse primary grains and intermetallic particles characterized hypereutectic silumin. The facts indicate low mechanical characteristics. Creating the system of thin film/substrate and melted is one of the perspective method of increasing surface layer`s the mechanical and tribological characteristics.

The thin film is creating with using arc sputtering of the cathode and it includes a drop fraction. The size of drops varies from a few micrometers to several tens of micrometers. It is detected by scanning electron microscopy. It was shown in figure 2.

Micro-X-ray spectrum analysis reveals the elemental composition of the surface layer of the "film / substrate" system, it is shown in figure 3.

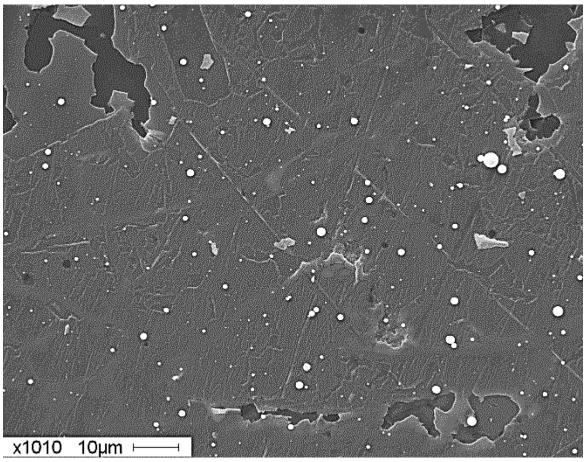
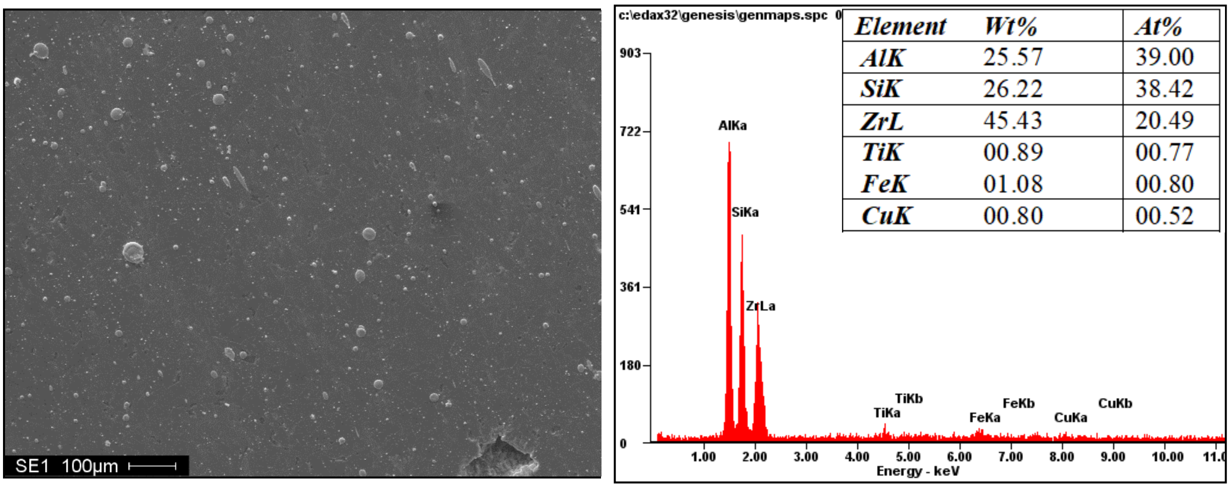


Figure 2. Film`s structure formed on the silumin surface by spraying a cathode of Zr-5% Ti-5% Cu.



Element	*Wt%*	*At%*
AlK	25.57	39.00
SiK	26.22	38.42
ZrL	45.43	20.49
TiK	00.89	00.77
FeK	01.08	00.80
CuK	00.80	00.52

Figure 3. Energy dispersion analysis of the "film- (Zr-5% Ti-5% Cu) / (Al- (22-24) wt.% Si) substrate".

Figure 3 demonstrates that all elements of source material and cathode were found. The microhardness of the "film ((Zr – 5% Ti – 5% Cu) / (Al – (22–24)% Si) substrate" system`s surface layer is reduced, compared with untreated silumin. It is 2310 MPa (in ≈1,5 times), the wear parameter of the "film/substrate" system is $5.8 \cdot 10^{-4}$ mm3/N·m.

The alloy was received by melting the "film-substrate" system with using an intense pulsed electron beam. In the figure 4 there is silumin surfaces structure.

There is no microdrop fraction, the structure consists of polycrystallines. The size is 0.5–1 µm (figure 4b).

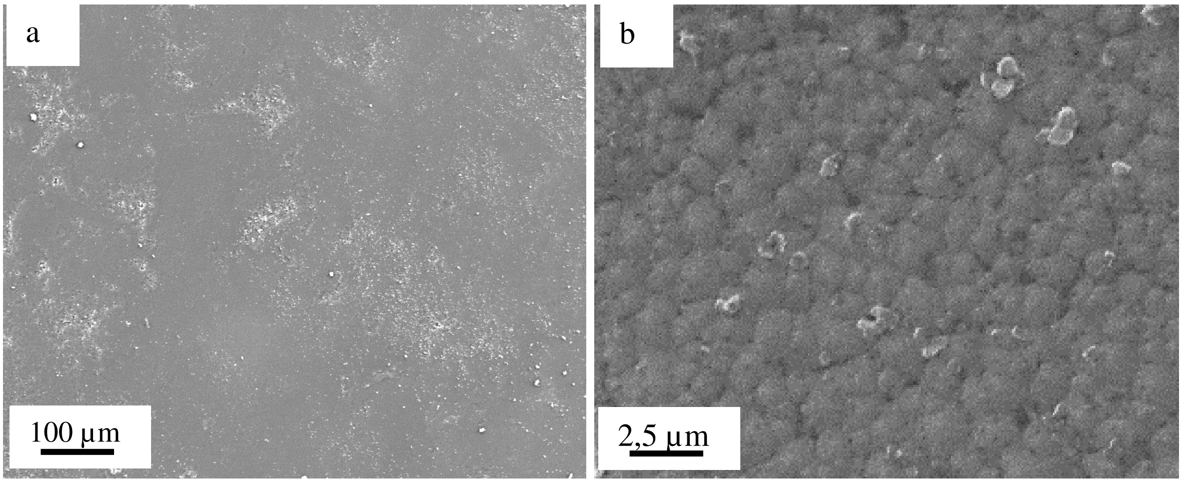


Figure 4. The film structure formed on the silumin surface after combined treatment ((1. creating "film-substrate system" 2. remelting with "Solo").

In figure 5 there is the image of the "film (Zr-Ti-Cu) / (Al-Si) substrate" system`s cross-sectional structure was irradiate by an intense pulsed electron beam. The threated layer`s thickness is 100-150 µm. The structure is quasi-homogeneous. Size of crystallites is 1–5 µm. This structure is the result of high-speed melting with subsequent high-speed crystallization.

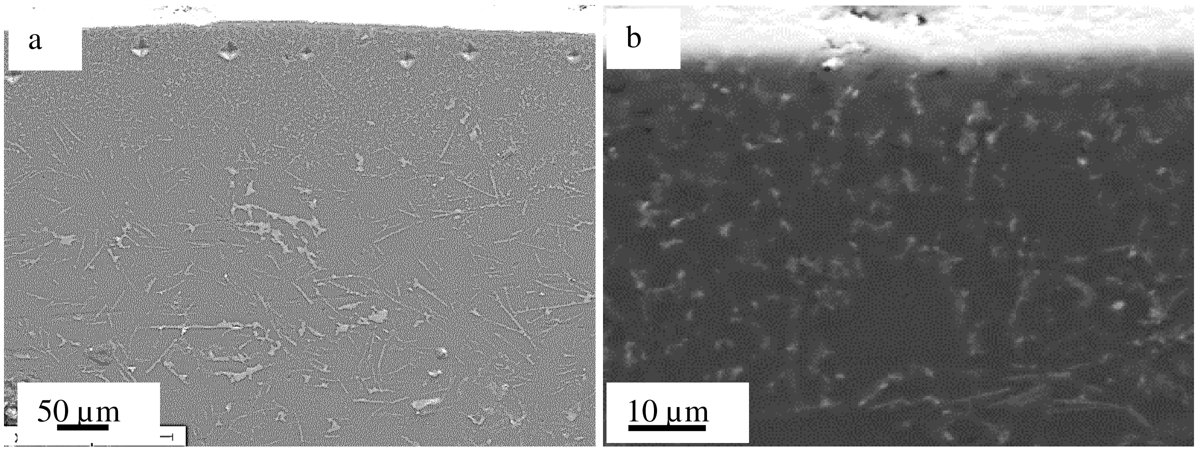


Figure 5. Cross-sectional structure of a hypereutectic silumin sample after combined treatment ((1. creating "film-substrate system" 2. remelting with "Solo").

The results of the specimen's surface's micro-X-ray spectral analysis of the hypereutectic silumin's surface in the figure 6. It shows structure after treating with an intense pulsed electron beam.

Analyzing the obtained results, the following facts could be named. Firstly, the film / substrate system`s irradiation with an electron beam leads to decreasing of zirconium atoms concentration in the surface layer. This fact indicates the dissolution of the film in silumin. Secondly, the material is characterized by in 2 times higher concentration of silicon atoms in the surface, than in the cast silumin. It can be assumed that evaporation occurs from the silumin`s surface of aluminum atoms at the step of radiation treatment. As a consequence, there concentration of silicon in the thin surface layer is an increase.

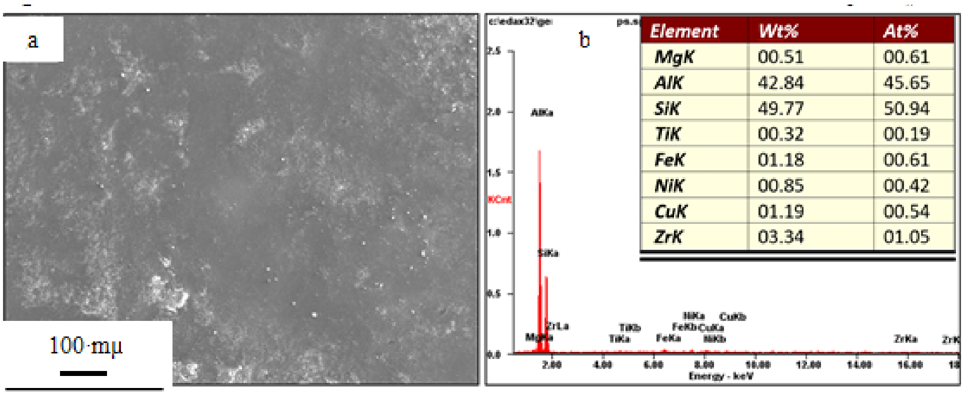


Figure 6. Modified silumin`s energy dispersive analysis after combined treatment.

There are two main phases-silicon and aluminum (63.5% –Al, 32.1% – Si). The data were obtained by X-ray diffraction analysis s. formed As the result additional phases were received by melting of the film / substrate system. There are $Cu_{9.1}$ $Al_{31.2}$ $Si_{0.78}$, $Fe_3Al_{0.5}Si_{0.5}$, Ti.

The microhardness of the doped layer is up to 2060 MPa, i.e. ≈1.7 times, the wear factor of silumin is $2.1 \cdot 10^{-4}$ $mm^3/N \cdot m$, which corresponds to an increase in wear resistance of ≈2.6 times. The material's friction coefficient is 0.39. It reduce in 1.1 times than the cast silumin's friction coefficient.

The surface alloy formation with submicrocrystalline and nanocrystalline multiphase structure was produced. That structure has high wear resistance, It is about 2.6 times greater than the cast hypereutectic silumin's wear resistance. This is due to the structural change and the surface layer remelting.

4. Conclusion

1. It has been established that silumin of hypereutectic composition (22-24 wt. %Si) in the cast state is characterized by the presence of coarse crystals of primary silicon and intermetallic compounds;

2. It has been established that, as a result of the electron-beam treatment of the "film ((Zr – 5% Ti – 5% Cu)/(Al – (22-24) wt. % Si) substrate" system, the surface alloy layer is formed. It has a submicrocrystalline multiphase structure. It is characterized by high wear resistance, ≈2.6 times higher than the wear resistance of the in the initial state silumin.

Thus, the studies performed in this paper have revealed the effectiveness of the developed method of electron-ion-plasma modification. This method allows to substantially increasing the strength and tribological properties of the surface layer of silumin hypereutectic composition by irradiating a material with an intense pulsed electron beam and forming alloy in the surface (i.e., economically alloying).

Acknowledgments

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