Investigation of the structure and properties of aluminum-matrix composite coatings for tribotechnical purposes formed on steel substrates

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Abstract. The structure and properties of aluminum-matrix composite coatings for tribotechnical purposes, formed on steel substrates, have been investigated. Preliminarily, to limit the interaction between the materials of the substrate and the matrix of the composite material, i.e. iron and aluminum, an intermediate layer of pure aluminum was applied to the substrate surface by the explosion welding process. It is shown that the deposited composite coatings of Al-12Si + 10 wt.% SiC(40) are characterized by a uniform reinforcements distribution, and their adhesion strength values reach 66 MPa. According to the results of friction and wear tests under dry sliding friction conditions, it was determined that the manufactured samples have a 50% higher wear resistance compared to industrial bimetallic materials made of steel 20 with a B83 babbit coating, and their use in friction units will significantly expand the range of triboloading of the promising constructions.

1. Introduction

New combined parts of tribo-assemblies consisting of a steel base and a working antifriction layer based on Sn, Pb, Cu, and Al alloys are required for the development of modern technology [1–4]. However, the level of tribotechnical properties of currently widely used construction materials has reached the limit [5–7]. Therefore, the use of aluminum-matrix composite materials developed in recent years as such functional coatings can be of decisive importance in the development of designs for promising technology [8–11]. The main obstacle to their implementation is the decrease in characteristics due to the interaction between the materials of the substrate and the matrix, i.e. iron and aluminum [12–15]. Intermediate layers are used to overcome it [12]. The layers are preliminarily applied to the steel by different methods [15–17]. Previous work has shown the promise of using pure aluminum as an intermediate layer formed by the explosion welding process [17–19]. At the same time, the process of arc surfacing in protective gases (e.g. argon) is of greatest interest for the deposition of composite coatings due to its versatility and high level of implementation [15]. Therefore, the purpose of this work was to study the structure and properties of aluminum-matrix composite coatings for tribotechnical purposes, formed on steel substrates.
2. Materials and Methods

Composite coatings were obtained by the argon-arc surfacing process on plates of high-quality steel 20 (GOST 1050) with dimensions of 300x150x15 mm. An intermediate layer with a thickness of 5 mm made of aluminum grade AD1 (GOST 4784) was applied to their surface by a preliminary explosion welding process, the parameters of which are given in [18].

The developed composite rods with a diameter of 5 ± 0.1 mm, with a matrix of Al-12Si aluminum alloy (GOST 1583), containing 10 wt.% silicon carbide (SiC) particles with an average size of 40 μm were used as filler materials for the argon-arc surfacing process [20]. As it was established earlier, it is important for obtaining high-quality steel-aluminum compositions to ensure partial penetration of the intermediate layer, i.e. no contact of the melt with solid steel [18]. Therefore, the following basic argon-arc surfacing process modes were chosen: welding current – 120–160 A, arc voltage – 18–20 V, surfacing speed – 11–13 m/h.

The structure of the prepared samples was studied using optical and electron microscopy (a Leika DMILM light microscope and a Helios NanoLab 660 scanning electron microscope with an attachment for X-ray spectral microanalysis (EDX)).

The adhesion strength of the deposited coatings was determined during pull-off and shear tests according to the schemes used for bimetallic materials of friction units [18].

The tribotechnical properties of the samples were evaluated according to the results of tests under dry sliding friction conditions used CETR UMT Multi-Specimen Test System. The test scheme “rotating sleeve (counterbody made of steel 40X (HRC > 45) on a stationary disk (test sample)” repeated the operation of most real friction units. The tests were carried out in the range of specific pressures from 0.2 to 2.56 MPa and a sliding speed of 0.39 m/s for 10 minutes. The test results were compared with those for industrial bimetallic specimens of steel 20 coated with a babbitt alloy of the B83 grade (GOST 1320).

3. Results and Discussion

After machining necessary to level the plane of the working surface, the deposited composite coatings have a thickness of 2.5–3 mm (Figure 1 (a)). The coatings microstructure is characterized by a relatively uniform distribution of reinforcing filler particles in the volume of the matrix (Figure 1b).

![Figure 1. Typical macro- (a) and microstructure in the area “A” (b) of the samples.](image)

1 – substrate made of steel 20; 2 – intermediate layer made of AD1 alloy; 3 – composite coating Al-12Si + 10 wt.% SiC(40).

After the argon arc surfacing process, in comparison with the initial state, a continuous layer up to 6 μm thick is formed at the steel-aluminum interface in places where intermetallic compounds are absent. This layer consists of Fe₂Al₅ phases according to EDX data. This results in a decrease in the average length of zones free from the intermetallic phase from 20 to 5% of the total area of the joint (Figure 2). Despite this, the average adhesion strength values of the deposited coatings are 47 and 66 MPa in shear and pull-off tests, respectively. The achieved values meet the requirements for combined parts of tribo-assemblies of modern technology [14].
Figure 2. Monochrome image of steel-aluminum interface in the initial state (a) and after applying the composite coating (b).

The results of friction and wear tests of samples are shown in Figure 3 and Figure 4. It can be seen that an increase in the specific pressure leads to an increase in the wear rate and a decrease in the average friction coefficient values of the coatings. Samples with a composite coating are characterized by 30–50% lower wear rates compared to those with a B83 babbitt working layer at specific pressures up to 0.68 MPa (Figure 3).

In the same range of tribo-loading, the samples with a babbitt coating have the minimum friction coefficient values (0.18 versus 0.35) (Figure 4). A further increase in the specific pressure leads to the transition to the seizure of the coatings from babbitt. This is evidenced by a sharp increase in the intensity of the wear rate and the friction coefficient to $17.8 \times 10^{-3}$ mm$^3$/m and 0.35, respectively, as well as the peeling of coatings observed in some cases. The samples with a deposited composite coating retain their serviceability in the entire investigated range of tribo-loading.
Figure 4. Effect of specific pressure on the average friction coefficient of the samples.

4. Conclusion
Composite coatings of composition Al-12Si + 10 wt.% SiC\textsubscript{(40)} were formed by the argon-arc surfacing process on steel substrates with an intermediate aluminum layer. The coatings are characterized by a uniform reinforcement distribution and have adhesive strength values up to 66 MPa. The use of the samples in friction units makes it possible to expand the range of tribo loading, as well as to reduce the wear rate by up to 50% in comparison with bimetallic materials made of steel 20 with a B83 babbit coating.

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