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INVESTIGATION OF THE PROCESS OF ELECTRIC ARC METALIZATION OF COATINGS FROM STEEL 30KhGSA

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The article considers the electric arc metallization technological modes of steel 30KhGSA wires, which affect the structure formation and properties of coatings. Electric arc spraying was carried out using an SX-600 electric arc metallizer. The properties and characteristics of the resulting coatings depend on several plating parameters such as wire feed speed, voltage, and amperage. The coating structure was studied by electron microscopy and metallographic analysis. The coating has a layered structure, which consists of frozen convective metal flows, micro-welded small metal particles and oxides. The results of the study show that an increase in the wire feed speed during metallization leads to an increase in the resulting coating thickness per unit time. On the surface of steel 45, depending on the selected mode, coatings were formed from steel 30KhGSA with a thickness in the range from 50 μm to 370 μm. It has been established that when electric arc metallization coatings are sprayed with 30KhGSA wire, the microhardness of the surface layer increases by a factor of 2 relative to the microhardness of 45 steel. Based on studies investigating the impact of various factors in the electric arc spraying process on the formation of coating structures and properties, it can be deduced that utilizing electric arc metallization on steel 30KhGSA substrates allows for the production of coatings with enhanced hardness.

Keywords: arc metallization, wire, coating, steel, structure, microhardness, wear resistance.

1. Introduction

Electric arc metallization (EAM) is a surface coating process that involves using an electric arc to melt a metal wire or powder and apply it to a substrate. The process usually includes the following main steps: surface preparation and metal plating. During the process, metal wire or powder is fed into an electric arc torch that creates a high-temperature arc that melts the material. The molten material is then sprayed onto the surface of the substrate using compressed air or an inert gas. The droplets of molten material solidify upon impact with the substrate, forming a coating. The properties of the resulting coatings depend on several plating parameters such as wire or powder feed speed, voltage, current, withdrawal distance and nozzle geometry. Arc plating has a number of advantages over other coating processes [1-2]. It is a relatively inexpensive and fast process that can be used to coat large surfaces. It can also be used to coat a wide range of materials including metals, ceramics and plastics. The resulting coatings are usually dense, uniform and have good adhesion to the substrate. They also have good resistance to wear, corrosion and high temperatures [3-5]. Coatings can be applied to improve the surface properties of a material for a variety of applications, including aerospace, automotive, and industrial applications [6–8].

One of the applications of EAM is the repair of crankshafts after wear exceeding tolerance values, which are considered to be one of the most loaded and critical parts of internal combustion engines and rotation mechanisms. Their reliability and durability play a decisive role in ensuring the safe and efficient operation of vehicles and machines. Research into the influence of EAM modes is an urgent task, and the results of the study will optimize the modes of electric arc metallization when restoring the surfaces of crankshafts made of steel 45. This can lead to an increase in the efficiency and durability of restored crankshafts, as well as improve their mechanical properties. These results have important practical applications in the automotive and67 industrial sectors, where crankshafts play a critical role in the operation of various mechanisms and equipment. Many researchers have studied the effect of a wide range of deposition parameters on the performance of arc-sprayed metal coatings, for example, [9] reported the effect of deposition parameters on the performance of arc-sprayed zinc coatings. The study showed that the characteristics of the resulting surface layer, such as

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microstructure, porosity and hardness, correlate well with the input parameters of the deposition. The authors of [10] optimized the process parameters such as current, voltage, spray distance and gas pressure in two-wire arc spraying of aluminum coating to obtain the desired microstructure, physical and mechanical properties.

As is known from works [11], during electric arc metallization during sputtering, particles from the sprayed material are subject to changes in the environment and due to the thermal effect on its morphological structure. These changes accordingly affect the mechanical properties of the resulting coating. The structural criteria responsible for the mechanical and tribological characteristics of coatings obtained by electric arc metallization from 30KhGSA steel have not been fully studied.

In this regard, this article proposes to carry out comprehensive experimental work aimed at understanding the influence of spraying parameters on the structure and properties of coatings based on grade 45 steel.

The purpose of this work is to study the influence of operating parameters, such as voltage, current and wire feed speed of electric arc metallization on the mechanical properties of the resulting coating of 30KhGSA steel on a substrate of grade 45 steel.

2. Research method

The formation of coatings was carried out on a supersonic electric arc metallizer SX-600 (Fig.1.). The complex consists of a power source, a supersonic arc atomizer, a control system and a compressed air system.

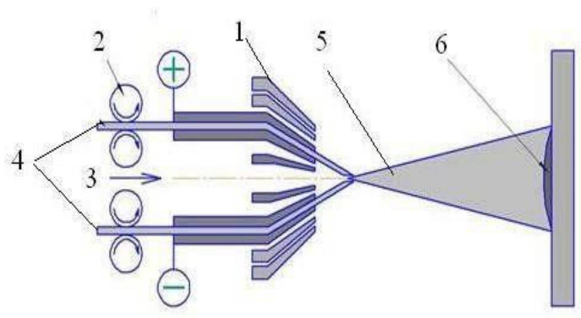

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Fig.1. a) Process diagram SX-600: (1 – metallizer body; 2 – wire feeder; 3 – air supply channel; 4 – electrode wires; 5 – electric arc with sprayed wire particles; 6 – sprayed coating; b) appearance of the pistol; c) appearance of the complex for supersonic electric arc metallization.

The process of electric arc plating involves melting the wire with an electric arc and spraying it onto the surface of the steel with compressed air. The molten wire solidifies on the surface of the substrate, creating a coating characterized by high hardness. Coating thickness can be controlled by adjusting the wire feed speed and the distance between the wire and the surface of the sprayed sample. The properties of the resulting coatings depend on several plating parameters, such as wire feed speed, voltage, current, and withdrawal distance. The coatings were obtained with the selected parameters, which are shown in Table 1. The metallization modes in the experiments have been changed within the limits that made it possible to obtain a coating without cracks and delaminations. Steel grade 30KhGSA was used as the welding wire. The samples were cut in the form of a disk segment of one quarter from a disk 65 mm in diameter and 10 mm thick from a bar of steel grade 45 (GOST 1050- 2013). Before the EAM, samples were prepared by mechanical (grinding) and sandblasting (quartz sand). The roughness of steel 45 after sandblasting was determined using a Model 130 profilometer.

Table 1. Modes of coating 30KhGSA by electric arc metallization.

Sample name	Voltage, V	Current, A	Wire feed Speed in percentage scale of the SX-600 metallizer	Wire feed speed, cm/s	Compressed air pressure, bar	Spraying distance, mm	Application time, s
No.1	31	120	25%	1	9	350	10
No.2	37	120	25%	1			
No.3	43	125	25%	1			
No.4	43	150	50%	3.4			
No.5	45	300	100%	12.8			

The microstructure of the coatings was studied using a JSM-6390LV scanning electron microscope and an ALTAMI-MET-5C metallographic microscope. The microhardness of the formed coatings was determined on a Vickers microhardness tester HLV-1DT, with a load on the indenter P=2H and a holding time at this load of 10 s. An Anton Paar TRB3 tribometer was used to measure the tribological properties of the coatings. In this study, the sample was placed in the holder in such a way that the surface of the coating was perpendicular to the plane of the rod trajectory. A ball 3 mm in diameter, made of 100Cr6 steel (similar to ShKh15), was attached to the end of the rod. By adjusting the displacement sensor, the radius of curvature of the wear surface of the sample was selected. A friction force compensation sensor was also used, which made it possible to determine the value of the friction coefficient at a given point in time. The tests were carried out in the open air at a load of 6 N and a speed of 2 cm/s. The radius of curvature of the wear surface ranged from 1.5 mm, and the length of the friction path was 60 m.

Thus, the selection of optimal parameters for arc plating is crucial to achieve the desired properties of the coating, and research is needed to determine other mechanical and tribological characteristics of coatings.

3. Results and discussion

Fig. 2 shows SEM images of cross-sections of coatings obtained by arc metallization. The EAM coating has a dense lamellar structure (Fig.2 d, e) with low porosity. The formation of the lamellar structure of the coatings is associated with a high compressed air pressure of 9 bar (0.9 MPa). In a jet of compressed air, droplets of a metal melt hit the sprayed surface with greater force, are strongly flattened and form lamellae. And also, with an increase in the wire feed speed, the value of the current strength increases, which leads to the release of more thermal energy in the electric arc for melting the wire and, accordingly, contributes to the formation of dense coatings with low porosity [12,13]. The welding wire feed speed of the deposition directly affects the thickness of the resulting coating with the same duration of metallization. However, this dependence is non-linear, which can also be explained by the fact that with an increase in the wire feed speed, the amperage in the electric arc increases accordingly, which led to the coating compaction. This statement can be confirmed by the fact that a study on a scanning electron microscope showed that at high values of amperage, porosity decreases, leading to a compaction of the resulting layer.

The surface layer differs in structure from the substrate, however, there is no clearly defined interface between the coating and the substrate, which indicates the high adhesive strength of the EAM coatings. The adhesion strength of the coating to the base depends on the distance of spraying and the speed of particles before impact, which is controlled by compressed air pressure [14].

An increase in the speed of metal particles during EAM contributes to their deeper penetration into microroughnesses on the surface, the destruction of the oxide film, and enhances adhesive and chemical bonds. The main condition necessary for the strength adhesion of the coating to the base is surface activity, which largely depends on the nature of the surface roughness and the method of its preparation. To increase the adhesion strength, the surface of grade 45 steel was sandblasted with corundum. The surface roughness of steel 45 was 5–6 μm.

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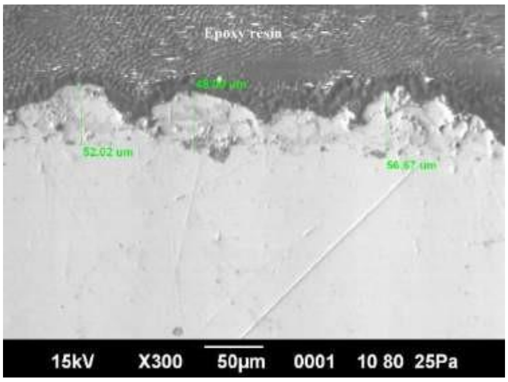

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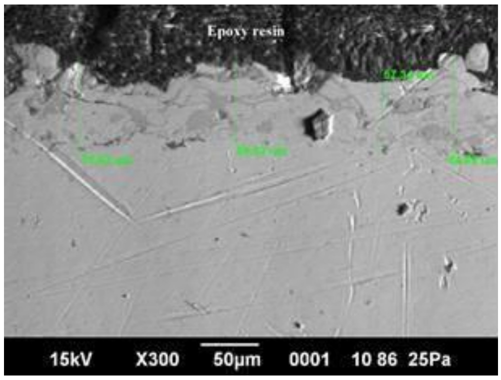

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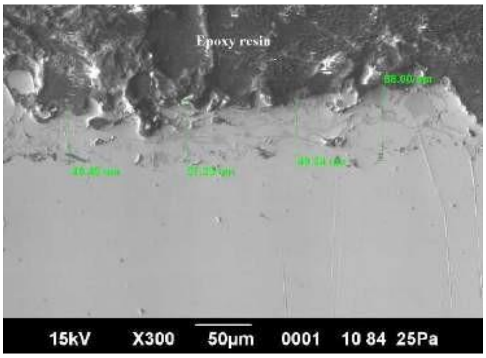

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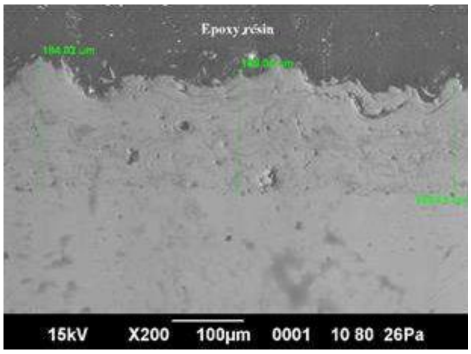

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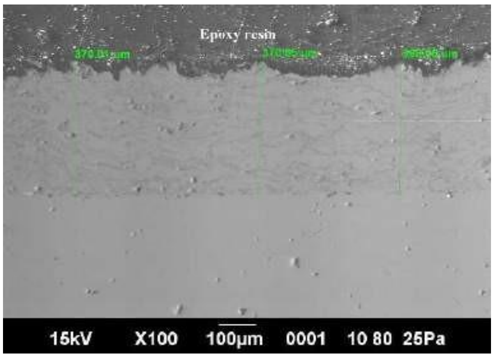

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Fig.2. SEM images of the cross section of 30KhGSA coatings on steel 45 obtained under different spraying modes: No.1; b) No.2; c) No.3; d) No.4; e) No.5

Fig. 3 shows the structure of the coating obtained by electric arc metallization (sample No. 5, table 1). The shape of the flattened metal particles allows us to conclude that at the moment of impact they were in a plastic state, in which they are easily deformed. In [15], the mechanism of coating formation during electric arc metallization was shown and it was found that large metal particles reach the surface mainly in the liquid state, while smaller ones in the plastic and even solid state. Liquid metal wets the surface and fills in irregularities, while colder (semi-liquid) metal particles are deformed upon impact and mixed with hotter ones, forming a single coating layer. The result of a metallographic study of the structure of the coatings shows that the coating consists of a mixture of phases of different densities. In the applied surface layer, frozen convective metal flows, microwelded small metal drops and oxides are observed in the liquid metal (Fig. 3). At high pressures of compressed air up to 0.9 MPa, the size of liquid metal droplets may decrease, and during crystallization, they are partially microwelded.

Table 2 shows the characteristics of 30KhGSA coatings on steel 45 obtained by EAM. After spraying, the roughness of the coatings was 9–11 μm. To measure the hardness of the coatings by the Vickers method, the surface was polished to a value of ≤0.23 μm. The study of coatings from steel grade 30KhGSA on a steel substrate 45 showed that an increase in the wire feed speed leads to an increase in the thickness of the resulting coating with the same duration of the deposition process of 10 s (Fig. 2 d, e), while varying the voltage value does not lead to significant changes in thickness obtained coatings (Fig. 2 a-c). Depending on the deposition parameter, the thickness of 30KhGSA coatings can reach a maximum of 370 μm in 10 seconds of deposition.

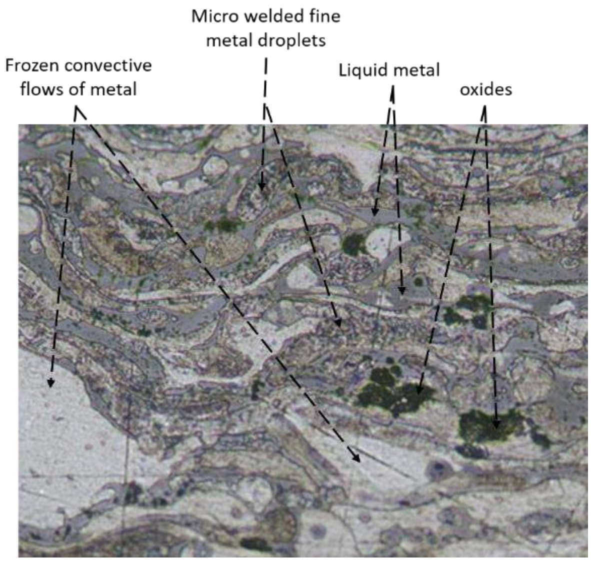

Fig.3. The structure of the coating of steel 30 KhGSA, obtained by the method of electric arc metallization

The hardness of coatings obtained by arc plating depends on several factors, including the material used for coating, the plating process and application conditions. The hardness of the coating 30KhGSA is much higher compared to the material of steel grade 45 and has a value of 380-420 $HV_{0.2}$. The increase in the hardness of the EAM coating is explained by the fact that at the moment of impact on the substrate, the metal particles, simultaneously with deformation, undergo a sharp cooling by a cold jet of compressed air, which causes their instantaneous hardening.

The results of testing the wear resistance of 30KhGSA coatings according to the standard "ball-disk" test scheme showed that despite a significant increase in hardness, its wear resistance decreases compared to steel45. For a sample of steel 45, the average value of the friction coefficient is 0.45 (Table 2) at a distance of 60 m (Fig. 4). After coating, the average value of the friction coefficient varied from 0.48 to 0.63 depending on the EAM coating parameter. Table 1 shows that the coefficient of friction for coatings No. 3, obtained at a voltage of 43 V and a current of 125A, corresponds to the value of the original sample, which is equal to μ = 0.454. A factor of high tribological properties of the coating is its higher plasticity index [16]. However, with an increase in the amperage at EAM, a denser coating is formed and the heterogeneity of the coating decreases. Due to the difference in the wear mechanism of the coatings under consideration, a more detailed tribological study is required.

Table 2 - Thickness and properties of 30KhGSA coatings on steel 45 obtained by EAM

Sample name	Wire feed speed, cm/s	Coating thickness, μm	Coating hardness, $HV_{0,2}$	The average value of the coefficient of dry friction (counterbody steel ShKh15)
No.1	1	52.2±3.2	404.50±25.37	0.630
No.2	1	72.3±2.7	388.16±31.58	0.571
No.3	1	56±2.5	417.27±24.983	0.482
No.4	3.4	170.7±4.7	401.83±26.91	0.555
No.5	12.8	369.7± 7.3	400.88±34.86	0.594
Steel 45 uncoated	-	-	190.00±19.25	0.454

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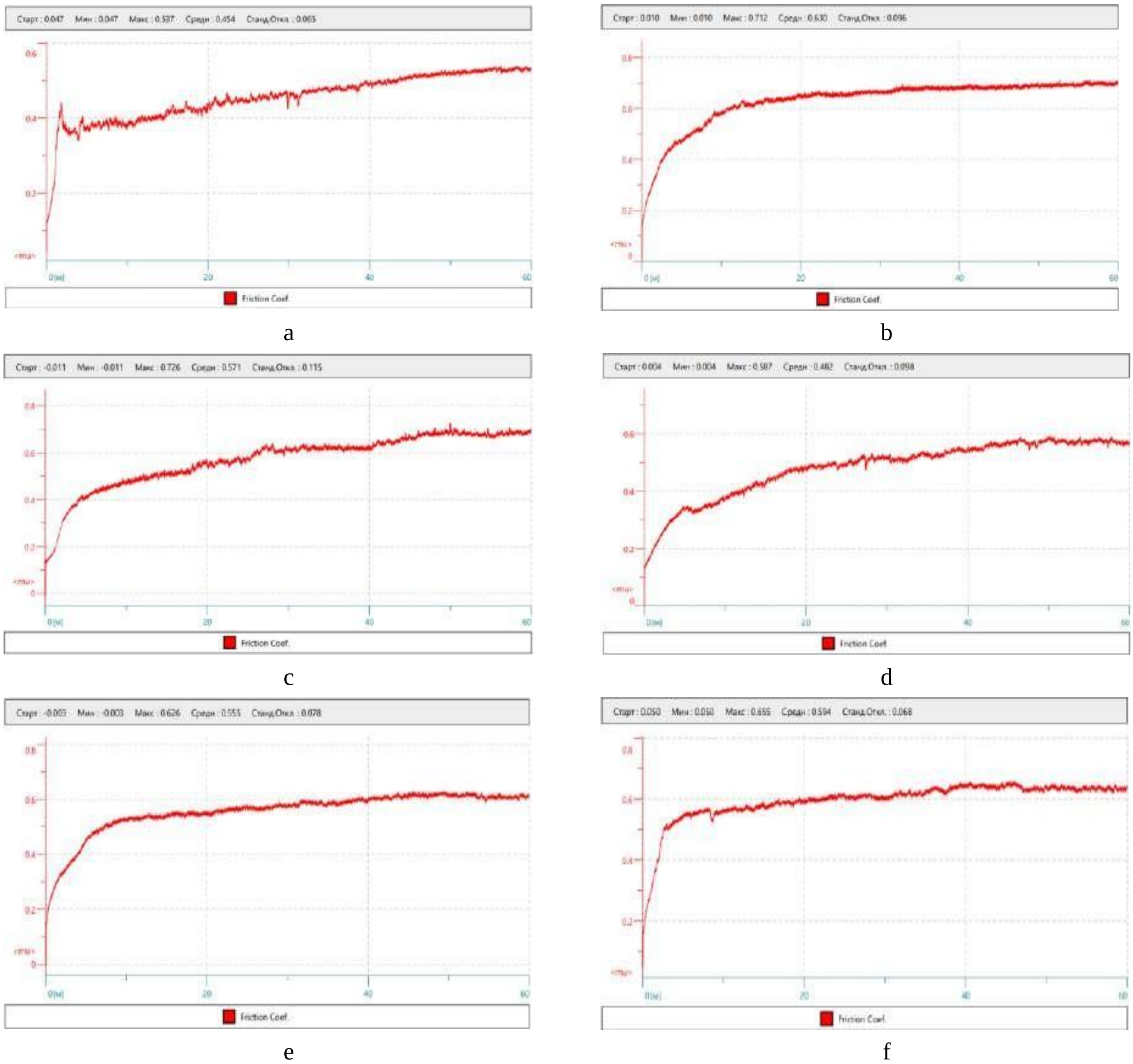

Fig.4. Results of tribological tests of 30KhGSA coatings: a) steel 45; b) No.1; c) No.2; d No.3; e) No.4; f) No.5.

4. Conclusion

The work investigated the influence of the operating parameters of electric arc metallization on the structure, hardness and coefficient of friction of the resulting coating made of 30KhGSA steel on a substrate of grade 45 steel. The relationship between these characteristics of the resulting surface layer and voltage, current strength and wire feed speed was comprehensively studied.

It has been established that the coating has a lamellar structure, which consists of frozen convective flows of metal, micro-welded small metal particles and oxides. This structure is explained by the formation of the coating as a result of successive impacts of particles from the 30KhGSA metal and their severe deformation, which in turn are formed under the influence of melting and dispersion of the metal during the metallization process.

The conducted studies revealed that an increase in the wire feed speed (steel 30KhGSA) leads to an increase in the thickness of the resulting coating. The results of a study of the cross-section of the coatings showed that the thickness of the coating varies from 50 to 370 microns. Also, as the wire feed speed increases, the current increases. When analyzing SEM images of cross sections of the samples under study, it was revealed that samples No. 4 and No. 5 have a more homogeneous structure and include a small number of pores.

When studying the hardness of sprayed samples, it was shown that the values of this parameter do not differ much (average hardness value 402.53 ± 10.38 HV). It has been shown that samples made of steel 45 with a 30KhGSA coating have improved surface hardness by a factor of 2 compared to the uncoated sample. Despite the fact that the hardness of the surfacing material does not greatly exceed the hardness of steel 45, this result was obtained due to the hardening of the particles after their rapid cooling with an air jet. Hardness at given metallization parameters showed high properties for all studied samples.

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