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Study of the Structure of Wear-Resistant Coatings Obtained under Different Technological Modes of the Arc Metallization

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***Abstract*—Arc metallization of the cored wires is one of the modern surface engineering technologies assuring high quality surface layers. The wire arc spraying process is widely used for protection of metal against corrosion and for restoration of worn parts of machines and mechanisms. The present study used a cored wire development IPNPN with additives of corundum. Wear resistant coatings of about 300 μm thickness were prepared through arc metallization of the flux-cored wires onto steel substrate. Technological modes of arc metallization such as current strength and arc voltage have a significant influence on the formation of coatings. The structure of coatings obtained at the current strength of 220-250, 250-280 and 280-300 A was studied. The microstructure of the coatings was characterized by scanning electron microscope (SEM) and X-ray diffraction (XRD). The structure of the metallized layer is characterized by a non-uniform layered structure. The distribution and number of reinforcing phases significantly affect the wear resistance, hardness and strength of the treated surface of machine parts and mechanisms. The study of the structure of the wear-resistant coating and the influence of technological modes of arc metallization on its formation will help in the further development of this method of surface treatment of parts and machines.**

***Keywords*— wire arc metallization, cored wire, wear-resistant coating, modification, powder wire, structure, corundum**

I. Introduction

Electric arc metallization of flux-cored wires is an effective method of applying wear-resistant coatings on parts of machines and mechanisms of metallurgical, mining, energy, chemical equipment, parts of road, rail and ship transport, gas pumping plants, etc. [1-3]. The advantage of using flux-cored wires is the active interaction of the components of the powder charge between themselves and the substrate, which has a beneficial effect on the quality of coatings. As a powder material, self-fluxing alloys based on nickel or cobalt are often used, as well as their mixtures with modifiers of refractory metals, carbides, nitrides, oxides, etc. When welding flux-cored wires, corrosion-resistant coatings with high values of resistance to wear by friction and abrasive particles are formed. Coatings obtained by arc metallization are characterized by a high degree of heterogeneity of the structure due to the rapid flow of the process (10^{-3}-10^{-5}c) and heating of the powder material to the melting temperature followed by high-speed cooling and solidification [4-11]. The presence of reinforcing phases in the structure of coatings of flux-cored wires significantly affects the performance of the treated surface of machine parts and mechanisms. The nature of the distribution and the volume fraction of the reinforcing phases significantly affect the wear resistance of the treated surface [12-14].

II. Eperimental procedure

A. Materials

The flux-cored wire filled with charge with refractory additives of corundum Al_2O_3, developed at the Institute of physical-technical problems of the North. V. P. Larionova SB RAS (Yakutsk, Russia) (“Poroshkovaya provoloka dlya polucheniya pokrytiy” [Flux cored wire for coatings]. Patent RF, no. 2048273 [12]) was chosen as the research object of this work. The wire cover was made from steel and the filling material was mixed of ferrochrome and aluminum oxide powders of the following composition: C ~0,47 – 0.51% wt.; Cr ~2 – 4% wt.; Al_2O_3 ~10 – 15% wt.; Fe – other. The introduction of ferrochrome and aluminum oxides increases

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the hardness and strength of coatings. The diameter of the cored wire was 2 mm. The filling coefficient of the cored wires was 31%.

B. Coatings preparation

The wire-arc spraying was performed by EDU-500 equipment (Scientific and Production Co. Ltd, "VEKHA-1", Komsomolsk-on-Amur, Russia). The process of arc metallization consists in heating the flux-cored wire with an electric arc followed by spraying the molten metal with a jet of compressed air (fig. 1). A pair of flux-cored wires is feed with constant speed and is melted by electric arc. Melted metal particles are sprayed by compressed air and then thrown onto the surface of substrate. Melted metal particles of wires hit the base metal, and harden after rapid cooling. Arc metallization ensures high quality coatings characterized by low porosity and strong adhesion or to the base metal. The use of direct current allows the melting process to be more stable, which provides a high dispersion of the deposited metal particles, as well as the density of the coatings they create compared to alternating current. The higher the value of the current strength, the higher the combustion temperature of the electric arc and the dispersion of molten particles. The wear-resistant coatings were sprayed at the following technological modes (table. 1).

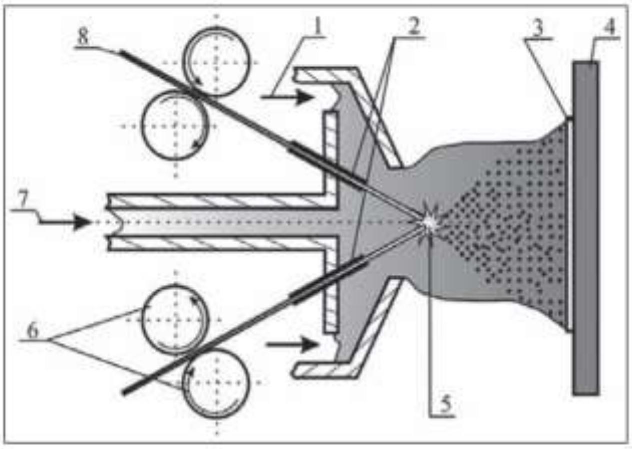

Fig. 1. A scheme of wire arc spraying: 1 – compressed air; 2 – wire electric contact; 3 – sprayed layer; 4 – substrate; 5 – electric arc; 6 – wire feeder; 7 – compressed air; 8 - flux-cored wire [3].

TABLE I. TECHNOLOGICAL MODES OF ELECTRIC ARC METALLIZATION

№	*Arc voltage U (B)*	*Current strength I (A)*	*Spraying distance L (mm)*
7	40	220-250	130
8	40	250-280	130
9	40	280-300	130

C. Research methods

The deposited coatings were polished in cross section for metallographic analysis. The microstructure of powder coatings obtained after different technological modes was studied using AXIO Observer D1m "Carl Zeiss Microscopy GmbH" optical microscope. The surface morphology was characterized by HITACHI-TM 3030 scanning electron microscope (SEM). Elemental composition of powder coatings was carried out using EDS analyzer XFlash 6 "Bruker".

III. Results and Discussion

A. Coating microstructure

During the process of arc metallization heating of the flux-cored wire occurs and the splats of melted metal deposit on substrate. When spraying different modes of arc metallization (table 1) significant difference in the formation of the coating structure is not observed (fig. 2). The refractory components of the powder material are isolated as separate non-melted particles, all coatings are characterized by a heterogeneous microstructure. The cross sections of the particles have a predominantly ribbon-like curved appearance. As you can see from figure 2: the microstructure of the sprayed coatings is layered, heterogeneous, consists of separate droplets of the melt of the sprayed material with a layer thickness of 1 to 40 μm. The particles of the refractory additives are not melted in the plating process and are in the form of individual inclusions.

As it is known the higher the value of the current strength, the higher the combustion temperature of the electric arc and the dispersion of molten splats. At a current of 220-250 A, the average thickness of the layers in the wear-resistant coating was 3.75 μm. The increase in the current to 250-280 and 280-300 A led to a decrease in the average thickness of the layers to 2,65 and 2,74 μm respectively.

Fig. 2 (b), (d) and (f) shows typical SEM images of powder coatings with severals colors and shades of structural components. Mostly there are fragments of white color, which is interspersed with dark grey and black inclusions of different size and configuration, which reflects the typical structure of sprayed on impact on the substrate splats sprayed material

To determine the structural components in the coating, it is necessary to identify the elements of the structure with the determination of their chemical composition. For this purpose, X-ray diffraction was carried out.

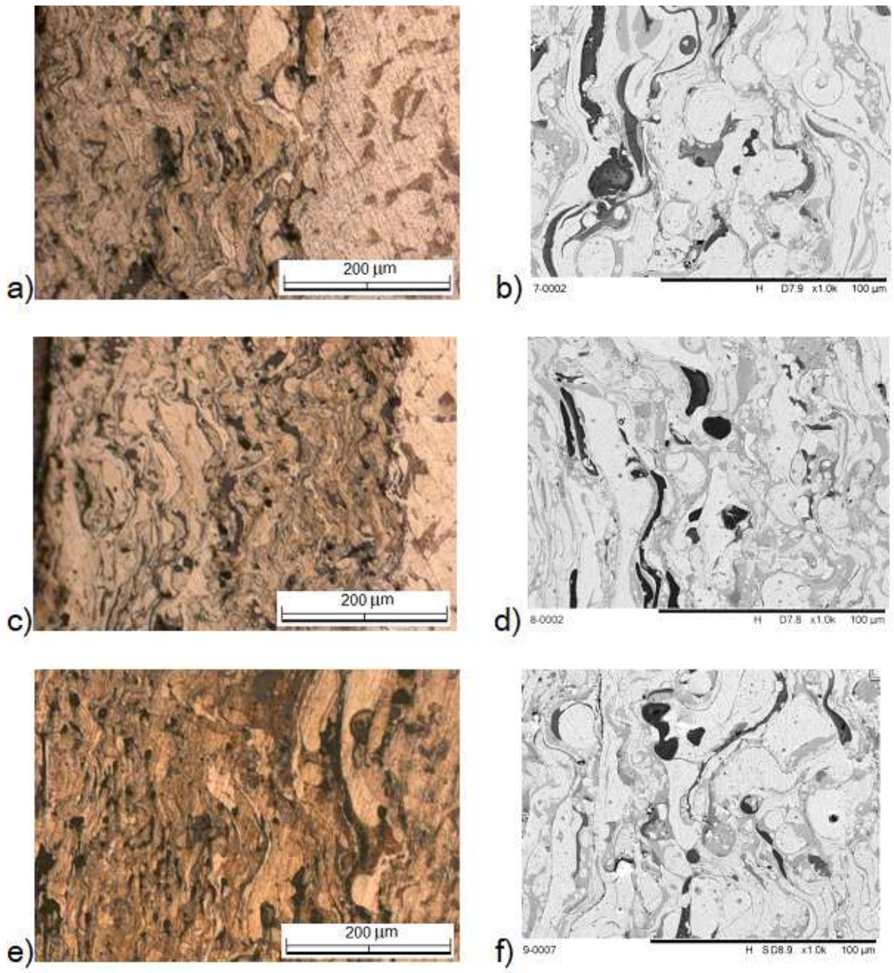

Fig. 2. Microstructure of the coatings obtained on the 6-th (a, b), 7-th (c, d) and 8-th (e, f) spraying modes.

B. SEM morphology and element maps showing

Actual is the identification of elements of the structure with the definition of their chemical composition. Scanning electron microscopy (SEM) of the coating surface showed that the light areas are mainly composed of iron, chromium and carbon (Fig. 3). These metal fragments are a solid solution of chromium in iron with the following composition: Fe – 69%, C – 21%, Cr – 4% and O – 6%. The grey areas consist of Fe – 20%, C – 5%, Cr – 1%, O – 56% and Al – 18%, these areas (Fig. 4) are most likely complexes of carbides and oxides formed during the deposition process. Much attention is paid to the study of the distribution of the main hardening phase – aluminum oxide (Al_2O_3), which significantly affects the wear resistance of the wear resistant coatings (Fig. 4). Al_2O_3 – corundum has a number of positive properties, such as hardness, wear resistance, corrosion resistance, low coefficient of friction, it is also an inhibitor of grain growth in metals. On Fig 4. a typical representation of the wire-arc coating structure with inclusion is presented. From the X-ray spectral analysis it was found that the dark inclusions are Al_2O_3 (corundum). To evaluate the calculated data on the content of corundum inclusions, a X-ray spectral analysis of the coatings was carried out, which revealed the Al in the sample. Different examination areas were selected on the surface of the section: (Fig. 3). The image of the inclusion in the coating on the strip at an increase of ×500 (a) and the map of the distribution of elements: Fe (b), O (c), C (d), Al (e), Cr (f), on which a quantitative X-ray spectral analysis was carried out. Measurements of aluminum content in the samples: 5.96; 5,05 and 5,50 %. The stoichiometric calculation of the amount of aluminum oxide Al_2O_3 shows corundum content in the coating of 11,26; 9,54 and 10, 39 %.

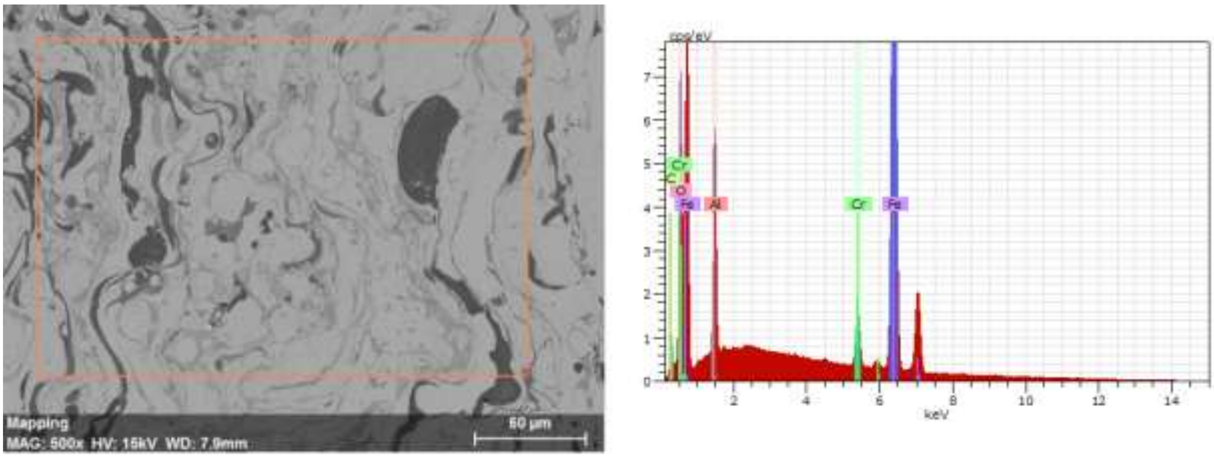

Fig. 3. XRD pattern of the selected area on the as-deposited coating.

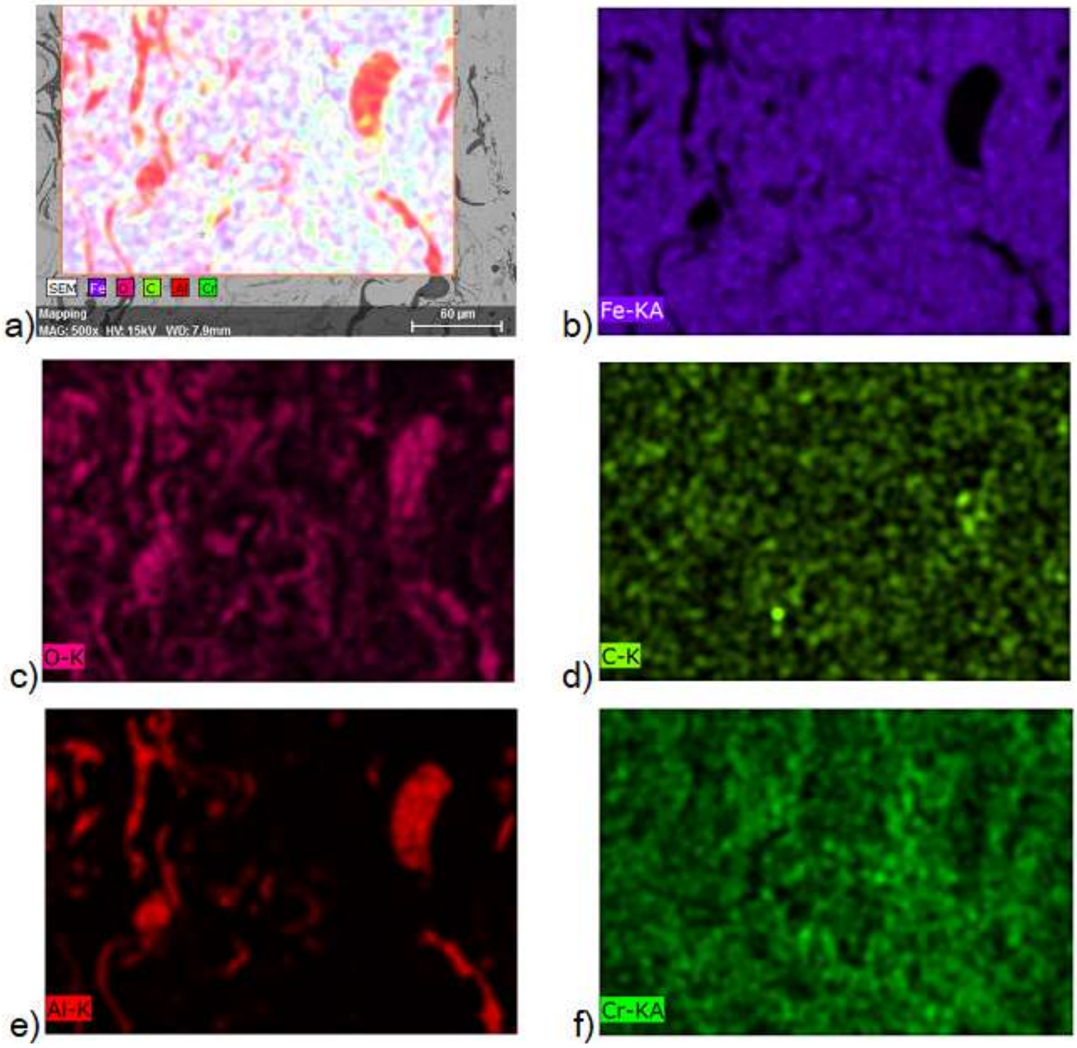

Fig. 4. SEM morphology of the coating obtained by wire arc metallization and element maps showing Fe (b), O (c), C (d), Al (e) and Cr (f) zonation in it

IV. CONCLUSIONS

The structure of wear-resistant coatings modified by refractory additives was studied. The flaky structure of the coating is formed, which consists of separate layered splits, spread and hardened on the substrate. It is shown that the change in the arc current leads to a change in the average thickness of the deposited layers. The increase in the current strength from 220-250 to 250-280 and 280-300 A led to a decrease in the thickness of the deposited layers from 3.75 to 2,65 and 2,74 μm respectively. EDS analysis showed that corundum refractory additives in coatings stand out unmelted inclusions. X-ray diffraction analysis showed that the content of corundum in the coatings is 11,26; 9,54 and 10, 39 %, which is approximately the same as the content of Al_2O_3 in the flux-cored wire.

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