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Surface Topography of Arc-Sprayed Coatings by Cored Wires of Different Compositions and Its Influence on the Wear Mechanism

The purpose of this work is to study the influence of the components of the composition of powder wires on the surface characteristics of sanded electric arc coatings. For the application of coatings used electric spray and powder wires with a diameter of 1.8 mm containing powders FeSi, FeTi, FeMn, pure metals Al and Cr and carbide B4C with a filling factor reached 24%. Spray parameters: current – 150 A, voltage – 32 V, air stream pressure – 0.6 MPa, spray distance – 120 mm. The surface topography revealed the plate structure of the coating with slats of different chemical composition. In coating are presence of carbides and borides, a significant amount of iron oxides and oxides of alloyed elements at the slats. Provisions from a considerable height contribute to intense wear due to reducing the friction steam surface. The interaction is regulated by the ratio of the depth of the projections (*H*) to the radius of its sharp tip (*r*). When $H/r < 0.02$, there is only elastic interaction, with the material of counteraction elastic. In the range of $0.02 < H/r < 0.7$, the projections induce plastic deformation of the counter-body. If $H/r > 0.7$, sharp projections are cut to the surface, generating micro -cutting. Reducing the number and size of inclusions and increasing their rounding radii are critical for improving wear resistance. The coating contains complex mixtures of Fe-Cr oxide. The connection of chromium and aluminum oxides resist cutting, they will either break, forming surface ulcers or residual projections. Adding a ferromanganese to the wires produces manganese oxides with low micro -Service, which do not form the cutting of the edges during friction. Titanium applications that respond quickly with oxygen leads to a subtle formation of dispersed oxide inclusions based on those (7 GPa). These manganese and titanium oxides do not generate sharp cutting edges, reducing the surface roughness of making the coating more suitable for use in friction pairs.
electric coatings, powder wires, surface roughness, element oxides, wear mechanism

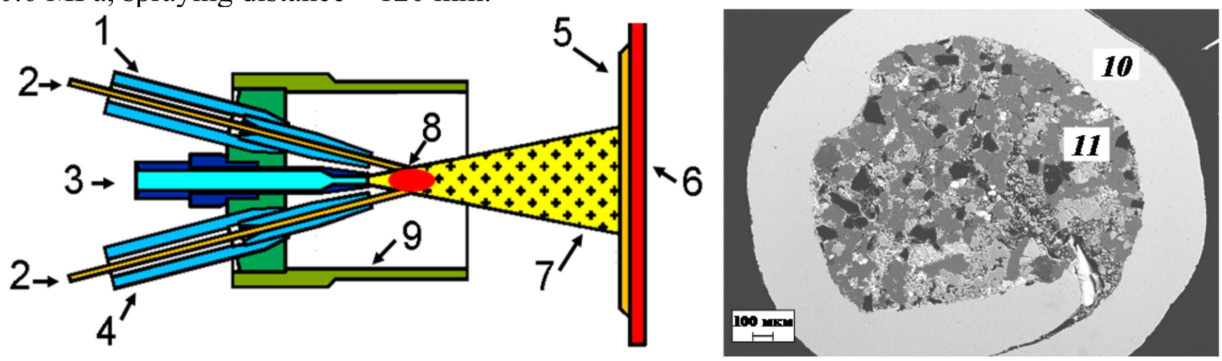
Introduction. Electro-arc coating (EAC) using cored wires (CW) are widely applied for restoring shaft-type components that operate under high specific loads in extreme lubrication conditions. Among gas-thermal coating methods, electric arc spraying method (EAM) is the most commonly used. EAM offers several advantages over other gas-thermal methods, including a simple technological process, minimal costs, high productivity, the ability to form coatings of the required thickness (0.1–10 mm) with specified properties, and minimal heating of parts (up to 150°C). Consequently, EAM enables the restoration of worn parts and enhances their wear resistance. The quality of the polished EAC surface directly affects the durability of friction pairs. Therefore, this study aims to investigate how the components of CW charge influence the polished surface characteristics of EAC.

Statement of the problem. Recently, electric arc spraying of powder-cored wire (CW) coatings has been considered by many industries as the most optimal method of restoring and improving the performance characteristics of parts, in particular shafts, due to its economic advantages in terms of production and maintenance. This is also due to the simplicity and availability of equipment; the quality of coatings is practically not inferior to coatings applied by the plasma method; higher thermal efficiency, reaching 57% compared to 13 and 17% for gas and plasma application; high productivity (3...4 times higher than for plasma spraying). In the process of spraying coatings, intensive oxidation of molten droplets by oxygen from an air jet occurs, which causes the appearance of solid oxides in the structure of the coatings (microhardness 2000 HV or chromium 3000 HV). During the grinding process, such sedimentary inclusions are not cut by the abrasive grains of the corundum grinding wheel (microhardness 2000 HV) since their hardness is equal to or higher than the hardness of corundum. In this case, the ground surface of the coatings has increased roughness and as a result, increased wear of the friction pair occurs. Therefore, it is important to form the charge of CW so that chromium or aluminum oxides are not formed during the spraying of CW coatings.

Analysis of recent research and publications. The use of special powder-cored wires for electric arc spraying of coatings allows to obtain wear-resistant coatings with hardness up to 1300 HV, and adhesion to the steel base up to 55 MPa [1–2]. Electric arc coatings with CW are widely used for protection against gas corrosion and gas-abrasive wear of heating elements of thermal power plants [3–4], protection against corrosion-abrasive wear of equipment for pumping wastewater [5], shaft parts restoration of equipment of food processing enterprises, mining and transport enterprises [6-9]. When restoring shaft-type parts, finishing treatment by grinding is provided. The ground surface of CW coatings has a significantly higher roughness, which negatively affects the tribological characteristics of the restored parts. There is no information in the literature on the influence of the CW charge on the quality of the ground surface of electric arc coatings.

Problem statement. To obtain high tribological characteristics of restored shaft-type parts by the method of electric arc spraying of coatings from CW, it is necessary to ensure the minimum roughness of the polished surface of the coatings, which depends on the nature of the CW charging materials. Therefore, the aim of the work is to study the influence of CW charging materials on the roughness of the polished surface of sprayed coatings.

Arc Spraying of Coatings Using Cored Wires. For EAM spraying, an electric metal-spraying device (Fig. 1 *a*) and CW with a 1.8 mm diameter were used. The CW charge included powders of ferroalloys (FeSi, FeTi, FeMn), pure metals (Al, Cr), and B_4C carbide, while the shell was made of a 10 mm-wide strip of 08kp steel with a thickness of 0.4 mm. The cross-section of the CW is shown in (Fig. 1 *b*). The CW charging coefficient reached 24%. The spraying parameters were as follows: current – 150 A, voltage – 32 V, air jet pressure – 0.6 MPa, spraying distance – 120 mm.



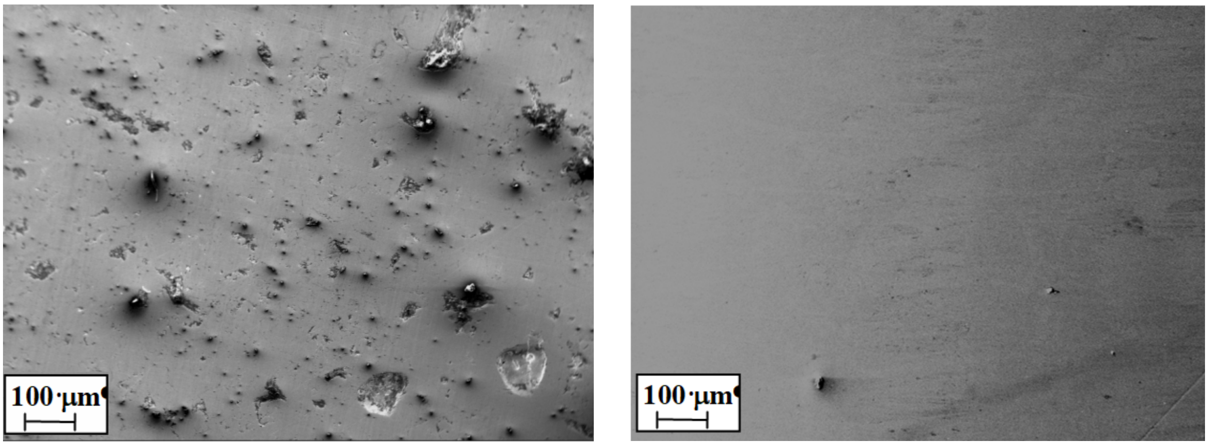
a *b*

1 – cathode; 2 – PW; 3 – compressed air; 4 – anode; 5 – coating; 6 – substrate; 7 – molten metal; 8 – electric arc; 9 – protective casing; 10 – shell; 11 – powder charge.

Figure 1 – Typical scheme of an electric metal-spraying device for EAC (*a*) and cross-section of the CW (*b*)

Source: developed by the authors

Experimental Results. During the development of CW for EAC spraying, the influence of CW charge components on the surface topography of coatings after grinding was examined. Surface cleanliness and roughness significantly affect the tribological properties of friction pairs (e.g., shaft – counter-body interfaces). Electron microscopy of the polished EAC surface revealed numerous depressions (pores) at low resolution (Fig. 2 *a*) and protrusions at higher resolution (Fig. 2 *b*).



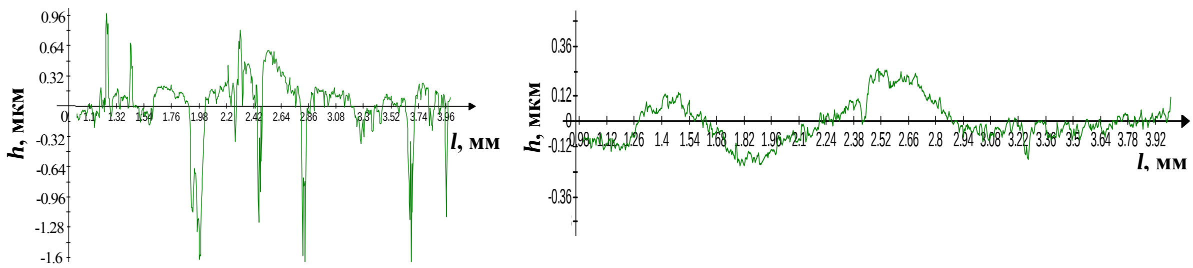
a *b*

Figure 2 – EAC surfaces made of Cr6B3Al6 CW (*a, b*) after grinding and polishing.
Depressions (*a*) and protrusions (*b*) on the EAC surface

Source: developed by the authors

The observed surface topography is associated with the lamellar structure of EAC. These lamellae typically have different chemical compositions and microhardness levels. Despite the presence of carbides and borides, a significant amount of iron oxides and alloying element oxides were found primarily at lamella boundaries. These high-strength yet brittle coating components fracture easily during mechanical processing, creating depressions. Simultaneously, unbroken high-hardness protrusions contribute to intense wear by detruncating the friction pair surface.

After identical mechanical processing (grinding followed by polishing), the roughness of the EAC surface sprayed with Cr6B3Al6 CW was significantly higher (*Ra* 1.88) than that of hardened 100Cr1,5 steel (*Ra* 0.88). Protrusions up to 1 µm high and depressions up to 1.6 µm deep were recorded on the EAC surface, whereas surface relief variations on the steel did not exceed 0.25 µm (Fig. 3).



a *b*

Figure 3 – Surface profiles of EACs made of Cr6B3Al6 CW with a roughness of *Ra* 1.88 (*a*) and steel 100Cr1,5 with a roughness of *Ra* 0.88 (*b*) after grinding and polishing. The ordinate axis shows the difference in relief heights on the surfaces, µm, and the abscissa axis shows the length of the path along which the measurements were made, µm.

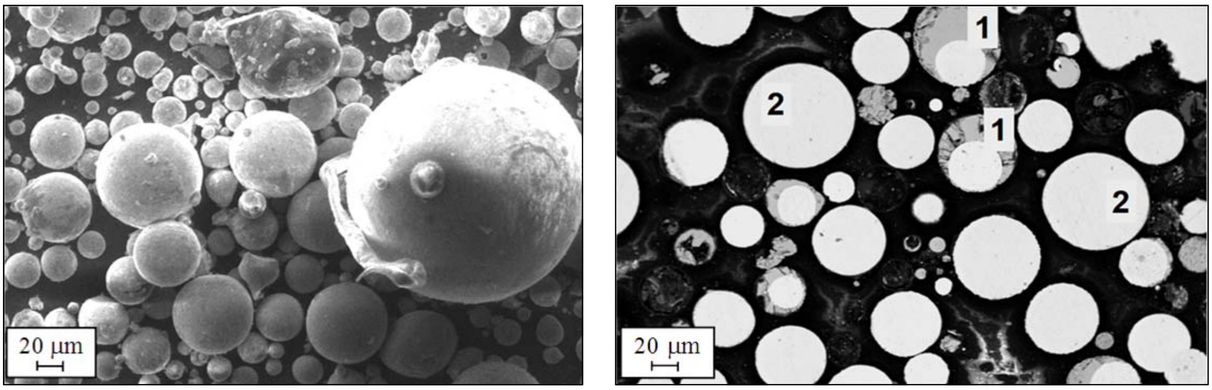
Source: developed by the authors

Influence of Surface Topography on Wear Mechanisms. The non-uniform coating surface topography presents both advantages and disadvantages. Under boundary friction at high specific loads, sharp protrusions may act as cutting edges, leading to catastrophic counter-body wear and friction pair failure. However, surface depressions serve as reservoirs for lubricant, enhancing lubrication film thickness and improving performance under insufficient lubrication conditions.

The frictional interaction between the polished coating surface and the counter-body is governed by the ratio of the protrusion depth (H) to the radius of its sharp tip (r). When $H/r < 0.02$, only elastic interaction occurs, with the counter-body material rebounding elastically. In the range of $0.02 < H/r < 0.7$, protrusions induce plastic deformation of counterbody. If $H/r > 0.7$, sharp protrusions cut into the counter-body surface, generating microchips.

For the “EAC–bronze BRS-30” friction pair, the maximum specific load under boundary lubrication conditions is typically below 14 MPa. Higher loads result in catastrophic wear due to counter-body surface cutting by oxide, carbide, or boride protrusions. Thus, reducing the number and size of these inclusions and increasing their rounding radii are critical for improving the wear resistance of EAC – counter-body systems.

Chemical Composition of Protrusions Remaining After Polishing. During EAC spraying, CW melts in the arc and is dispersed by an air jet into droplets of various sizes (Fig. 4 *a*). These droplets interact intensively with atmospheric oxygen, leading to different their oxidation levels (Fig. 4 *b*).

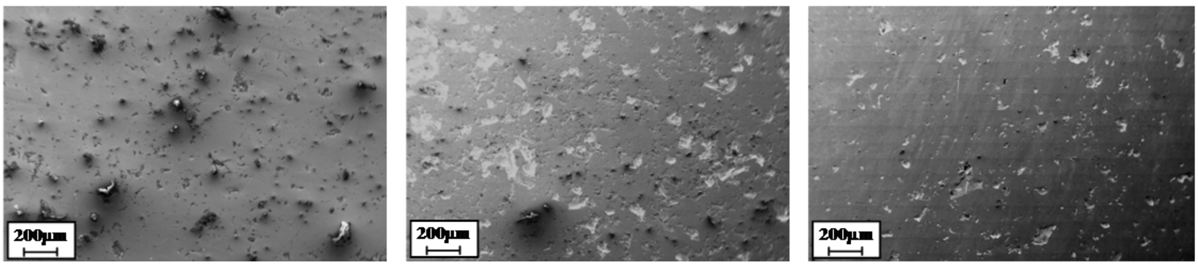


a *b*

Figure 4 – Morphological features (*a*) and cross-section of droplets (*b*) from 60Kh6R3Yu6 PW, trapped in to snow target to accelerate their crystallization. 1 – droplets with complete or partial surface oxidation; 2 – absence surface oxidation

Source: developed by the authors

Thermodynamic analysis shows that aluminum reacts rapidly with oxygen, forming large, high-hardness (20 GPa) aluminum oxide inclusions. Chromium-rich CW charges produce even harder (30 GPa) chromium oxide inclusions (Fig. 5 *a*). In most cases, coatings contain complex Fe-Cr oxide mixtures. Grinding with corundum abrasive wheels (20 GPa) leaves protrusions on the surface, which act as cutters at high loads. Since hard chromium and aluminum oxides resist cutting, they either break off, forming surface ulcers, or fragment into sharp residual protrusions.



a *b* *c*

Figure 5 – Surface topography of the polished surface of coatings from Cr6B3Al6 CW (*a*), Cr6B3MnSi CW (*b*) and Cr6B3MnSiT CW (*c*), which differed by content of alloying elements

Source: developed by the authors

Adding ferromanganese to the CW charge produces manganese oxides with lower microhardness, which do not form cutting edges during friction (Fig. 5 *b*). CW containing titanium, which rapidly reacts with oxygen, results in finely dispersed Ti-based oxide inclusions (7 GPa) (Fig. 5 *c*). These manganese- and titanium-based oxides do not generate sharp cutting edges, reducing surface roughness and making these coatings more suitable for use with standard counter-bodies.

Conclusions. The surface topography revealed a plate lailyllar coating structure with different chemical composition and micro -affirmation. The presence of carbides and Borida, a significant amount of iron oxides and oxides of alloyed elements at the slats.

It is determined that the coating with microvises on the basis of chromium and aluminum oxides resist abrasive grinding and act as the edges of cutting in friction vapors, causing intense wear, which at the same time accelerates the process of grinding surfaces stabilizing the coefficient.

The addition of ferromanese or ferrotitane to the composition of powder wires, forms finely dispersed oxides with low microhardness, which are easily subjected to wear, which leads to low surface roughness and improving tribological characteristics.

A means of assessing the resistance to the wear of the coatings in the form of the ratio of the depth of the projections (H) to the radius of its acute tip (r) was developed. When h/r < 0,02, there is only elastic interaction, with the material of counteraction elastic. In the range of 0,02 < H/r <0.7, the projections induce plastic deformation of the countertel. If h/r> 0.7, sharp projections are cut to the surface, generating microchips.

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Поверхнева топографія електродугових покриттів з різних композицій порошкових дротів та її вплив на механізм зносу

Робота присвячена дослідженню впливу компонентів складу порошкових дротів на поверхневі характеристики відшліфованих електродугових покриттів. Для нанесення покриттів застосовувався електродуговий розпилювач та порошкові дроти діаметром 1,8 мм, що містять порошки FeSi, FeTi, FeMn, чисті метали Al і Cr та карбід B_4C з коефіцієнтом наповнення досяг 24%. Параметри розпилення: струм – 150 А, напруга – 32 В, тиск повітряного струменя – 0,6 МПа, відстань розпилення – 120 мм.

Топографія поверхні виявила пластинчасту структуру покриття з ламелями різного хімічного складу і мікротвердості, наявність карбідів та боридів, значну кількість оксидів заліза та оксидів легованих елементів на межах ламелей. Виступи з значної висоти сприяють інтенсивному зносу через зменшення поверхні пари тертя. Западини слугують резервуарами для мастила, посилюючи товщину плівки змащення. Взаємодія регулюється співвідношенням глибини виступів (H) до радіуса його гострого наконечника (r). Коли $H/r < 0{,}02$, відбувається лише еластична взаємодія, при цьому матеріал протидії еластично відновлюється. В діапазоні $0{,}02 < H/r < 0{,}7$ виступи індукують пластичну деформацію контртіла. Якщо $H/r > 0{,}7$, різкі виступи врізаються на поверхню, генеруючи мікрорізання. Зменшення кількості та розміру включень та збільшення їх радіусів округлення є критично важливими для поліпшення стійкості до зносу.

Покриття містять складні суміші оксиду Fe-C-Cr. З'єднання хрому та оксиди алюмінію протистоять різанню, вони або зламаються, утворюючи виразки поверхні, або залишкові виступи. Додавання феромангацю до складу дротів виробляє оксиди марганцю з низькою мікротвердістю, які не утворюють різання країв під час тертя. Додатки титану, який швидко реагує з киснем, призводить до тонко утворення дисперсних оксидних включення на основі Ti (7 ГПа). Ці оксиди на основі марганцю та титану не генерують різких країв різання, зменшують шорсткість поверхні роблячи покриття більш придатними для використання в парах тертя.

Покриття з мікровиступами на основі оксидів, протистоять абразивному шліфуванню та діють як краї різання у парах тертя. Включення феромангацю або феротитану в склад дротів, утворює дрібно дисперсні оксиди з низькою мікротвердістю, які легко піддаються зносу, що призводить до низької шорсткості поверхні та покращення трибологічних характеристик.

електродугові покриття, порошкові дроти, шорсткість поверхні, оксиди елементів, механізм зносу

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