TECHNOLOGY AND APPLICATION OF ELECTRO-SPARK DEPOSITED COATINGS

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Abstract

The paper described properties of electro-spark deposited coatings. The processes of coating formation on metal parts including electro-spark deposition involve mass and energy transport accompanied by chemical, electrochemical and electrothermal reactions. The tests were conducted to analyze the operational properties of steel beaters used in a hammer mill for waste paper recycling. The degree of wear and the development of wear processes were studied for specimens with and without electro-spark deposited coatings. The studies were conducted using WC-Co-Al_2O_3 electrodes produced by sintering powders. The anti-wear coatings were electro-spark deposited over C45 carbon steel by means of an EIL-8A.The operational properties of the specimens were assessed by analyzing their micostructure, microhardness, surface geometric structure, corrosion resistance and tribological properties. The results show that more effective methods are required to increase the durability of beaters for hammer mills.

Keywords: Electro-spark deposition, coating, properties, steel beater

1. INTRODUCTION

The process of material growth resulting from electroerosion is known as electro-spark alloying (ESA) or electro-spark deposition (ESD). The erosion of the anode and the spark discharges between the electrodes result in the formation of a surface layer with properties different from those of the base material [1, 2].Electro-spark alloying is one of the methods that require concentrated energy flux. The method was first used in the USSR in the 1940s almost simultaneously with the destructive electrical discharge machining.The ESA technique was studied intensively in the 1960s. In the next decade, it was commonly applied to deposit hard-melting materials on selected metals and alloys, mainly steel. Polish scientists became interested in electro-spark alloying of coatings as early as in the 1980s. Electro-spark deposition (ESD) is a cheap high-energy process. Developed in the post-war period, the technology has been frequently modified. Its main advantages are the ability to select precisely the area to be modified, the ability to select the coating thickness, which may range from several to several dozen micrometers, good adhesion of a coating to the substrate, and finally, inexpensive and simple equipment for coating deposition. The processes of coating formation on metal parts including electro-spark deposition involve mass and energy transport accompanied by chemical, electrochemical and electrothermal reactions [1]. Today, different electro-spark deposition techniques are used; they are suitable for coating formation and surface microgeometry formation [3-5].Coatings produced by electro-spark deposition are applied:

- to protect new elements,
- to recover the properties of worn elements.

Electro-spark alloying is becoming more and more popular as a surface processing technology. Electro-spark deposited coatings are frequently applied in industry, for example, to produce implants or cutting tool inserts. The coatings are deposited with manually operated equipment or robotized systems. As electro-spark coatings are reported to be resistant to wear and corrosion, they can be applied, for instance, to:

- ship propeller components,
- casting moulds,

- fuel supply system components,
- exhaust system components.

Analysis of properties of coating systems requires many methods [6-9] even with the dimensionality reduction (the large number of attributes mapped into the smaller subset of attributes with the highest significance e.g. principal component analysis, cluster analysis etc.) [10, 11], the image analysis techniques [12-14] and the subjective assessment of the coating quality [15] and this assessment repeatability [16]. There are many alternative technologies for producing coatings in relation to ESD technology [17, 18].

2. MATERIALS AND TREATMENT PARAMETERS

Coatings were deposited on the C45 grade plain-carbon steel by the ESD method using a portable EIL-8A electro-spark deposition facility (TRIZ, Ukraine). Electrodes containing 85% WC, 10% Co and 5% Al_2O_3, were produced using the powder metallurgy hot pressing route. The main characteristics of powders used in this work are included in **Table 1**.

Table 1 Powders used to manufacture electrodes

Powder	Particle size (μm)	Producer
WC	~0.2	OMG
Co	~1.4	Umicore
Al2O3	18 ÷ 60	Sulcer-Metco

The powders were mixed for 30 minutes in the chaotic motion Turbula T2C mixer. The mixture was then poured into rectangular cavities of a graphite mould, each 6 × 40 mm in cross section, and consolidated by passing an electric current through the mould under uniaxial compressive load. A 3 minute hold at 950 °C and under a pressure of 40 MPa permitted obtaining electrodes of porosity <10 % and strength sufficient to maintain integrity when installed in the electrode holder. The hot pressing of powders, or green compacts, is generally realised in high-resistance graphite moulds by passing electrical current directly through the mould, as schematically shown in **Figure 1**.

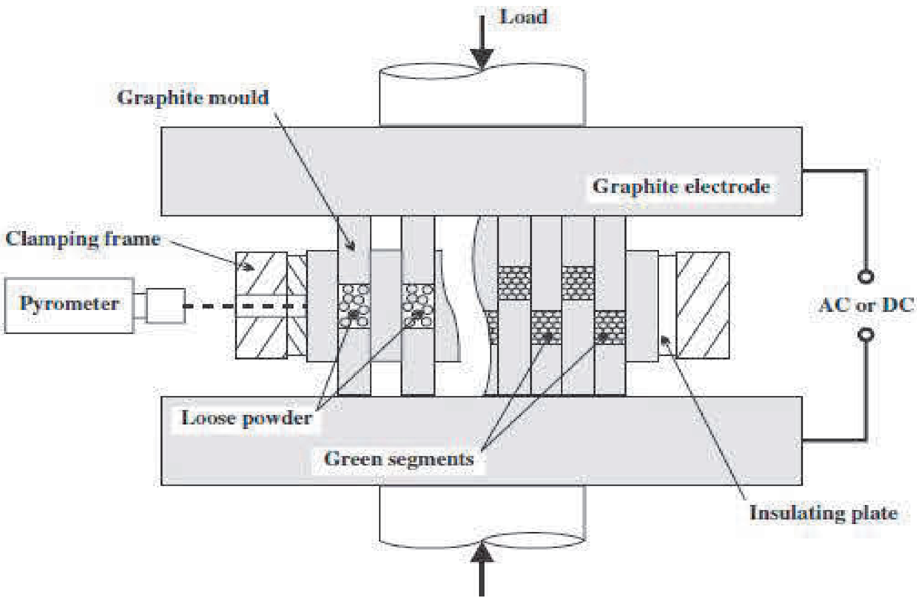

Figure 1 Schematic representation of the hot pressing process [19]

The equipment used for electro-spark alloying was an EIL-8A model. Basing on the results of previous research as well as instructions given by the producer, the following parameters were assumed to be optimal for ESA:

- voltage, U = 230 V,
- capacitor volume, C = 150 μF,
- current intensity, I = 2.4 A.

3. RESULTS OF INVESTIGATIONS AND DISCUSSION

3.1. Microstructure and microhardness tests

A microstructure analysis was conducted for WC-Co-Al_2O_3 coatings using the Joel JSM-5400 scanning electron microscope and the Neophot 2 light microscope. In **Figure 2** the microstructure of an ESD WC-Co-Al_2O_3 coating is illustrated. It is clear that the thickness of the obtained layers was from 60 to 70 μm, whereas the heat affected zone (HAZ) ranged approximately from 30 to 40 μm into the substrate. **Figure 2** also reveals a clear boundary between the coating and the substrate, pores and microcracks.

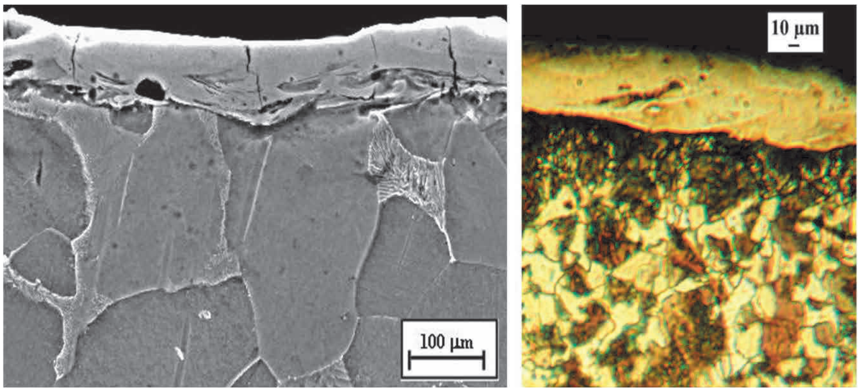

Figure 2 SEM (left) and LM (right) micrographs of the polished cross section through a WC-Co-Al_2O_3 ESD coating on C45 steel substrate

The microhardness of the specimens with WC-Co-Al_2O_3 coatings was analysed applying a load of 0.4 N and using the Vickers method. The indentations were made consecutively in three zones: the coating, the heat affected zone (HAZ) and the base material. The average microhardness of the base material after ESA was 279 HV0.4. The value was the same as that at the initial state. The average microhardness of the WC-Co-Al_2O_3 coating was 906 HV0.4. Thus, there was a 225 percent increase compared to that of the base material. The microhardness of the heat affected zone after electro-spark alloying was 38 % higher in relation to that of the base material.

3.2. Measurements of the surface geometric structure

Surface geometric structure (SGS) substantially influences many processes that occur in the outer layer. A lot of publications deal with measurement methods and the assessment of surface roughness and waviness [20, 21]. Measurements of surface geometric structure were carried out at the Laboratory of Computer Measurements of Geometric Quantities of the Kielce University of Technology. Those were performed using Talysurf CCI optical profiler that employs a coherence correlation algorithm patented by Taylor Hobson Company. The algorithm makes it possible to take measurements with the resolution in the axis *z* below 0.8 nm. The result of measurements is recorded in 1024 x 1024 measurement point matrix, which for the x10 lens yields the 1.65 mm x 1.65 mm measured area and the horizontal resolution 1.65 μm x 1.65 μm. One of the main disadvantages of the coatings produced by electro-spark alloying is high surface roughness. By reviewing the literature and analysing the latest developments in this technology, one can notice that the surface generation process involves erosion of the base material and formation of microcraters and ridges by particles leaving the electrode. The surface is regular with rounded microroughness peaks. The effect of the process parameters on the formation of surface roughness has been described in numerous publications. By controlling these parameters, it is possible to obtain surfaces with pre-determined microgeometry. Electro-spark alloying allows producing surfaces with enhanced roughness called surface relief. The roughness of the WC-Co-Al_2O_3 coatings was measured at the Laboratory for Measurement of Geometric Quantities of the Kielce University of Technology using a TALYSURF CCI equipment. The roughness was measured in two directions perpendicular to each other. Then, the average value was calculated: Ra = 4.99 ÷ 5.66 μm. The without coatings steel specimens (C45) had a roughness from 0.46 to 0.53 μm.

3.3. Corrosion resistance tests

The corrosion resistance of the WC-Co-Al_2O_3 coatings and the underlying substrate was analyzed using a computerized system for electrochemical tests, Atlas'99, produced by Atlas-Sollich. The potentiodynamic method was applied, because it is reported to be one of the most effective methods of electrochemical testing. The cathode polarization curve and the anode polarization curve were determined by polarizing the samples with a potential shift rate of 0.2 mV / s in the range of ±200 mV of the corrosive potential, and with 0.4 mV / s in the range of higher potentials. Samples with a marked area of 10 mm in diameter were polarized up to a potential of 800 mV. The polarization curves were drawn for samples exposed for 24 hours to a 3.5 % NaCl solution so that the corrosive potential could be established. The tests were performed at 21±1 °C. The WC-Co-Al_2O_3 coating was reported to have the highest corrosion resistance. The corrosion current density of the coating was 16.8 μA / cm^2, while that of the C45 steel substrate was 35.4 μA / cm^2. Applying the WC-Co-Al_2O coating improved the sample corrosion resistance by approx 100 %. The fusion of the coating and the substrate resulted in a considerable heterogeneity of electrochemical potentials on the coating surface. The microcracks in the surface layer also contributed to intensification of the corrosion processes.

3.4. Wear resistance of beaters

In the experiment, the coatings were electro-spark deposited on hammer faces made of carbon steel C45 - the cathode - using a WC-Co-Al_2O_3 electrode. Sixteen specimens were tested: eight with electro-spark deposited WC-Co-Al_2O_3 coatings and eight uncoated ones.

Table 2 Mass of the beaters with WC-Co-Al_2O_3 coatings

Specimen number	Measurement number			Mass loss
	I (g)	II (g)	III (g)	(g)
1 N	936.43	936.49	936.31	0.18
2 N	947.62	947.66	947.43	0.23
3 N	969.13	969.15	969.03	0.12
4 N	949.87	949.92	949.71	0.21
5 N	937.69	937.71	937.47	0.24
6 N	929.75	929.79	929.64	0.15
7 N	958.32	958.37	958.21	0.16
8 N	967.28	967.32	967.11	0.21
		average value		0.19

Table 3 Mass of the beaters without coatings

Specimen number	Measurement number		Mass loss
	I (g)	II (g)	(g)
1 W	937.72	937.48	0.24
2 W	934.19	933.54	0.65
3 W	948.86	948.64	0.22
4 W	965.72	965.29	0.43
5 W	953.78	953.31	0.47
6 W	943.33	942.89	0.44
7 W	921.18	920.45	0.73
8 W	972.83	972.62	0.21
	average value		0.42

All specimens were weighed for the first time before the tests. Then, eight of them were coated with WC-Co-Al_2O_3 and weighed again. It should be noted that only the working surfaces were strengthened. The next stage involved mounting the beaters in a hammer mill operating in Nordiska Ekofiber Polska Ltd. (**Figure 3**). The eighteen beaters were placed symmetrically along the mill shaft. After 250 hours of operation, all of them were weighed again. The data are shown in **Table 2** and **Table 3**.

Table 2 presents measurement results for the specimens with WC-Co-Al_2O_3 coatings. Column **I** shows the mass of the beaters before electro-spark alloying; in column **II** we have the mass of the beaters with electro-spark deposited WC-Co-Al_2O_3 coatings, and in column **III** the mass of the beaters after 250 h of operation in the mill. **Table 3** contains results for the uncoated specimens before use (column **I**), and after 250 hours of operation in the mill (column **II**).

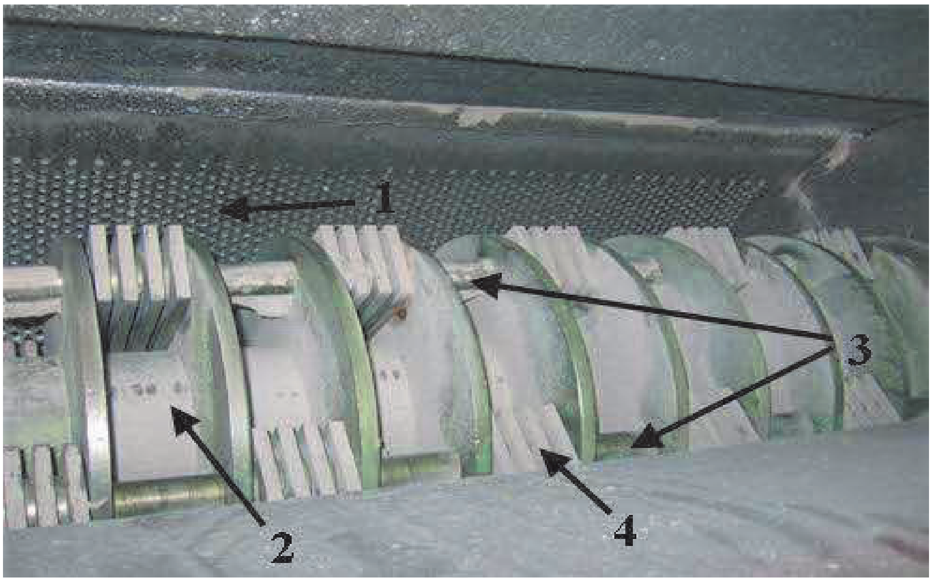

Figure 3 A view of the inside of the mill for waste paper grinding: 1 - sieve, 2 - main shaft, 3 - fixing pivots, 4 - beaters

The mass loss analysis showed that the beaters with the WC-Co-Al_2O_3 coatings had a lower wear rate than the uncoated beaters. The latter are predicted to operate for approximately 2-3 years. The investigations will be continued as there is not enough data confirming that the application of WC-Co-Al_2O_3 coatings improves the long-term wear resistance of beaters.

4. CONCLUSIONS

1) The microstructure analysis revealed that the coating thickness was 60 - 70 μm, whereas the heat affected zone ranged approximately 30 -40 μm. The coatings possessed microcracks and pores.
2) A significant increase in roughness Ra was reported for specimens with WC-Co-Al_2O_3 coatings. Higher roughness, however, is not always considered a disadvantage. Under certain circumstances, valleys in the roughness profile act as lubricant reservoirs, which increase the rate of heat transfer and that of catalysis.
3) The microhardness of the WC-Co-Al_2O_3 coating produced by electro-spark alloying was 906 HV0.4, while that of the base material - C45 steel - was 279 HV0.4.
4) The obtained I_k values indicate over 100 % increase in corrosion resistance of the ESD coated sample compared to uncoated C45 steel substrate.
5) The durability of beaters was studied under real conditions; the specimens with WC-Co-Al_2O_3 coatings were reported to be more wear resistant than the uncoated ones.

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