TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
MECHANICS | MECHANIKA
4-M/2016

NORBERT RADEK*, JACEK PIETRASZEK**, AGNIESZKA SZCZOTOK***

PROPERTIES OF ANTI-WEAR ELECTRO-SPARK DEPOSITED COATINGS

WŁAŚCIWOŚCI POWŁOK PRZECIWZUŻYCIOWYCH NANOSZONYCH OBRÓBKĄ ELEKTROISKROWĄ

Abstract

The paper is concerned with the performance properties of electro-spark deposited coatings. The properties were assessed by analyzing the coating microstructure, X-ray diffraction, microgeometry, microhardness, and corrosion tests. The studies were conducted using WC-Co-Al_2O_3 electrodes produced by the sintering of powders. The anti-wear coatings were electro-spark deposited over C45 carbon steel by means of an EIL-8A. These coatings are likely to be applied in sliding friction pairs and as protective coatings.

Keywords: electro-spark deposition, *coating*, *properties*

Streszczenie

W artykule przedstawiono wyniki badań właściwości powłok nanoszonych elektroiskrowo. Ocenę właściwości przeprowadzono na podstawie obserwacji mikrostruktury, analizy składu fazowego oraz pomiarów mikrotwardości, chropowatości i badań korozyjnych. Badania przeprowadzono, wykorzystując elektrody WC-Co-Al_2O_3, które zostały wytworzone przez spiekanie proszków. Przeciwzużyciowe powłoki zostały naniesione elektroiskrowo na próbki ze stali C45 za pomocą urządzenia EIL-8A. Ze względu na swoje właściwości powłoki tego typu mogą być stosowane w ślizgowych węzłach tarcia oraz jako powłoki ochronne.

Słowa kluczowe: obróbka elektroiskrowa, *powłoka*, *właściwości*

DOI: 10.4467/2353737XCT.16.241.5990

* D.Sc. Ph.D. Eng. Norbert Radek, Assoc. Prof., Centre for Laser Technologies of Metals, Faculty of Mechatronics and Machine Design, Kielce University of Technology.

** D.Sc. Ph.D. Eng. Jacek Pietraszek, Assoc. Prof., Institute of Applied Informatics, Faculty of Mechanical Engineering, Cracow University of Technology.

*** Ph.D. Eng. Agnieszka Szczotok, Institute of Materials Science, Faculty of Materials Science and Metallurgy, Silesian University of Technology.

1. Introduction

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 electro-thermal reactions [1, 2]. Today, different electro-spark deposition techniques are used; they are suitable for coating formation and surface microgeometry formation [3, 4].

The EDS process is depicted schematically in Fig. 1.

Coatings produced by electro-spark deposition are applied:

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

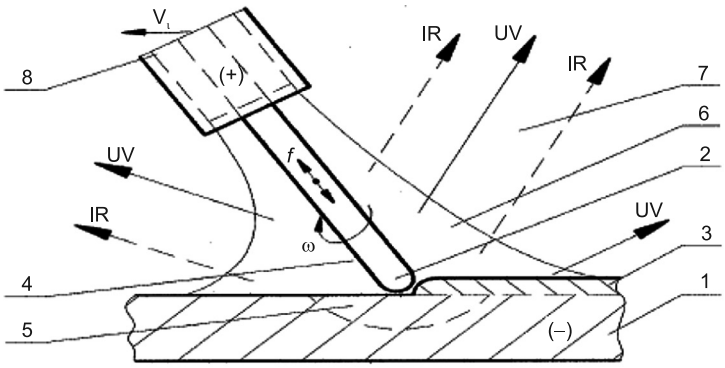

Fig. 1. Scheme of surface layer forming by electro-spark deposition method: 1 – material of base (cathode), 2 – working electrode (anode), 3 – created coating with established operational features, 4 – plasma, 5 – diffusive or reactive-diffusive zone, 6 – nearer surrounding (shielding gas), 7 – further surrounding (air), 8 – electrode holder with channels supplying gas, IR – infrared radiation, UV – ultraviolet radiation [2]

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.

2. Experimental

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 [5].

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 allowed for obtaining electrodes of porosity $<$ 10% and strength sufficient to maintain integrity when installed in the electrode holder.

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.

The electro-spark deposition equipment is illustrated in Fig. 2.

Fig. 2. EIL-8A electro-spark deposition – equipment

3. Results and discussion

3.1. Microstructure and X-ray diffraction analysis

A microstructure analysis was conducted for WC-Co-Al_2O_3 coatings, using the Joel JSM-5400 scanning electron microscope.

Fig. 3 illustrates the microstructure of an ESD WC-Co-Al_2O_3 coating. It is clear that the thickness of the obtained layers ranged from 34 to 64 μm, whereas the heat affected zone (HAZ) ranged approximately from 23 to 31 μm into the substrate. Fig. 3 also depicts a clear boundary between the coating and the substrate, pores and microcracks.

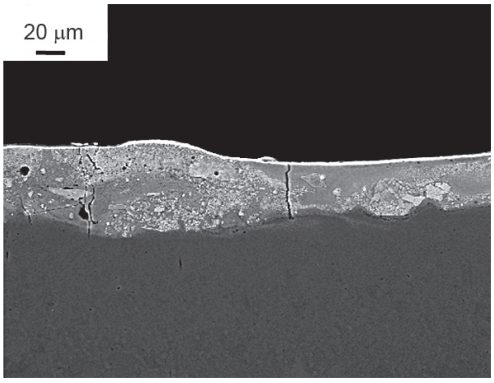

Fig. 3. WC-Co-Al_2O_3 coating microstructure after electro-spark alloying

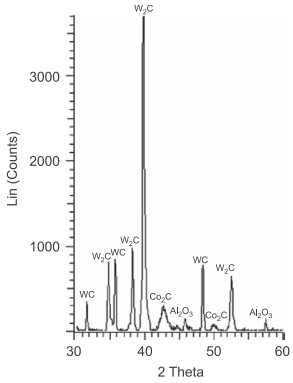

Fig. 4. X-ray diffraction pattern of the WC-Co-Al_2O_3 coating

A Philips PW 1830 X-ray diffractometer with CuKα radiation, operating at 40 kV and 30 mA, was used for identification phase (s). As shown in Fig. 4, the superficial layer of the coating consists of WC and W_2C as well as a small amount of Co_2C and Al_2O_3. W_2C is known to appear as an intermediate during the formation and dissolution of WC. Moreover, it has been found that peaks from the W_2C phase are most intense.

3.2. Microhardness and roughness measurements

The microhardness of the specimens with WC-Co-Al_2O_3 coatings was analyzed 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 the one 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.

The roughness of the WC-Co-Al_2O_3 coatings was quantitatively assessed using the Topo L120 surface profiler.

The roughness was measured in two directions, perpendicular to each other. Then, the average value was calculated: Ra = 6,16 − 7,79 μm.

The steel specimens without coatings (C45) had the roughness from 0.42 to 0.44 μm.

Figure 5 presents an example of the two-dimensional surface microgeometry measurement of the WC-Co-Al_2O_3 coatings.

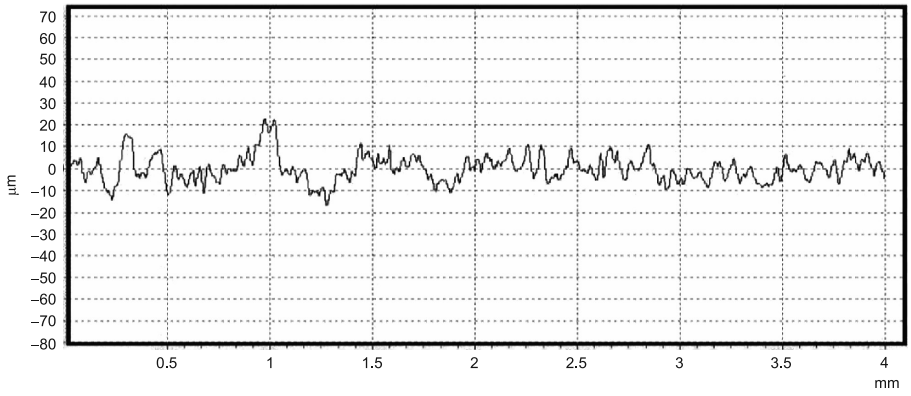

Fig. 5. Surface microgeometry of the WC-Co-Al_2O_3 coating deposited

3.3. Corrosion resistance tests

The corrosion resistance of the WC-Co-Al_2O_3 coatings and the underlying substrate were analyzed by using a computerized system for electrochemical tests, Atlas'99, produced by Atlas-Sollich. The potentiodynamic method was applied, which 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 the 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 results are summarised in Table 1.

Table 1

Corrosion current densities of the tested materials

Material	Corrosion current density (I_k), μA/cm^2
C45	35.4
WC-Co-Al_2O_3	16.8

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 52%. 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 the intensification of the corrosion processes.

4. Summary

The following conclusions can be drawn from the analysis and test results:

1. The microstructure analysis revealed that the coating thickness was 34−64 μm, whereas the heat affected zone ranged approximately from 23 to 31 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 increases 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 52% increase in corrosion resistance of the ESD coated sample compared to the uncoated C45 steel substrate.
5. The coating surface is composed of WC and W_2C besides a small amount of Co_2C and Al_2O_3.

References

[1] Galinov I.V., Luban R.B., *Mass transfer trends during electrospark alloying*, Surface & Coatings Technology, 79, 1996, 9-18.

[2] Ozimina D., Scholl H., Styp-Rekowski M., *Formowanie przeciwzużyciowych warstw wierzchnich obróbką elektroiskrową. Wybrane zagadnienia obróbek skoncentrowaną wiązką energii*, rozdział 2, 2003, 104-109.

[3] Radek N., *Determining the operational properties of steel beaters after electrospark deposition*, Eksploatacja i Niezawodność – Maintenance and Reliability, 4, 2009, 1016.

[4] Chang-bin T., Dao-xin L., Zhan W., Yang G., *Electro-spark alloying using graphite electrode on titanium alloy surface for biomedical applications*, Appl. Surf. Sci., 257, 2011, 6364-6371.

[5] Konstanty J., *Powder metallurgy diamond tools*, Elsevier, Oxford 2005.