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Production and properties of electro-spark deposited coatings modified via LBM

Wytwarzanie i właściwości powłok elektroiskrowych modyfikowanych obróbką laserową

Abstract
The paper is concerned with determining the influence of laser treatment process on the properties of electro spark coatings. The properties were assessed after a laser treatment by analysing microstructure and X-ray diffraction and measuring surface geometric structure and microhardness. The studies were conducted using WC-Cu electrodes produced by powder metallurgy of nanostructural powders. The coatings were deposited by means of the EIL-8A model and they were laser-treated with the Nd:YAG, BLS 720 model.
Keywords: electro-spark deposition (ESD), laser beam machining (LBM), coating, properties

Streszczenie
W artykule badano wpływ obróbki laserowej na właściwości powłok nanoszonych elektroiskrowo. Ocenę właściwości powłok po obróbce laserowej przeprowadzono na podstawie obserwacji mikrostruktury, analizy składu fazowego oraz pomiarów struktury geometrycznej powierzchni i mikrotwardości. Badania przeprowadzono, wykorzystując elektrody WC-Cu, które zostały wytworzone przez spiekanie nanostrukturalnych proszków. Do nanoszenia powłok elektroiskrowych użyto urządzenie model EIL-8A. Obróbkę laserową nałożonych powłok elektroiskrowych wykonano laserem Nd:YAG, model BLS 720.
Słowa kluczowe: obróbka elektroiskrowa, obróbka laserowa, powłoka, właściwości

1. Introduction

A number of modern surface processing methods use an energy flux. The examples include electro-spark deposition and laser treatment. Electro-spark deposition (ESD) is a cheap, high-energy process. Developed in the post-war period, this technology has been frequently modified. Its main advantages are the ability to select precisely the area to be modified, ability to select coating thickness, which may range from several to several dozen micrometers, good adhesion of a coating to a substrate, and finally, cheap and simple equipment for coating deposition. ESD has been known under several other terms such as spark hardening, electric spark toughening and electro-spark alloying (ESA).

The processes of coating formation on metal parts including electro-spark deposition involves mass and energy transport accompanied by chemical, electrochemical and electrothermal reactions [1]. Today, different electro-spark deposition techniques are used, which are suitable for coating formation and surface microgeometry formation [2-4].

Electro-spark deposited coatings have some disadvantages but these can be easily eliminated. One of the methods is laser beam machining (LBM); a laser beam is used for surface polishing, surface geometry formation, surface sealing or for homogenizing the chemical composition of the deposited coatings [5, 6].

It is envisaged that the advantages of laser-treated electro-spark coatings will include lower roughness, lower porosity, better adhesion to the substrate, higher wear and seizure resistance, higher fatigue strength due to the occurrence of compressive stresses on the surface and higher resistance to corrosion.

2. Materials and treatment parameters

The working electrode (a stationary) was made from C45 carbon steel. The elemental composition of the steel was as follows: (wt.%): C: 0.42-0.50, Mn: 0.50-0.80, Si: 0.10-0.40, P: 0.04, S: 0.04.

In the experiment, the coatings were electro-spark deposited using a WC-Cu (50% WC and 50% Cu) electrode with a cross-section of 4 x 6 mm (the anode) – onto samples made of carbon steel C45 (the cathode). The main characteristics of the powders used in this work are included in Table 1.

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 equipment used for electro-spark deposition was an EIL-8A model. Based on our previous work and instructions given by the equipment manufacturer, the following parameters were assumed to be optimal for ESD voltage U = 230 V, capacitor volume C = 150 μF, current intensity I = 0.7 A.

Table 1. Powders used to manufacture WC-Cu electrodes

Powder	Particle Size, μm	Producer
WC	~0.2*	OMG
Cu	~0.04*	NEOMAT

* measured using Fisher Sub-Sieve Sizer

Then, the coatings were treated with an Nd:YAG laser (impulse mode), model BLS 720. The samples with electro-spark deposited coatings were laser-modified using the following parameters: spot diameter $d = 0.7$ mm, power $P = 60$ W, laser beam velocity $v = 250$ mm/min, nozzle-workpiece distance $\Delta f = 6$ mm, pulse duration $t_i = 0.4$ ms, pulse repetition frequency $f = 50$ Hz, beam shift jump $S = 0.4$ mm, nitrogen gas shield $Q = 25$ l/min.

3. Results and discussion

3.1. Microstructure and X-ray diffraction analysis

A microstructure analysis was conducted for WC-Cu coatings before and after laser treatment using a scanning electron microscope Joel JSM-5400.

Figure 1 shows the microstructure of an ESD WC-Cu coating. It is clear that the thickness of the obtained layer varied from 36 to 60 μm, whereas the heat affected zone (HAZ) ranged from 20 to 30 μm into the substrate. Figure 1 also reveals a clear boundary between the coating and the substrate and pores within the coating. The ESD WC-Cu coatings were modified by laser treatment, which caused changes in their composition. The laser treatment homogenizes the coating chemical composition, causes structure refinement, and crystallization of non-equilibrium phases due to the occurrence of temperature gradients and high cooling rates.

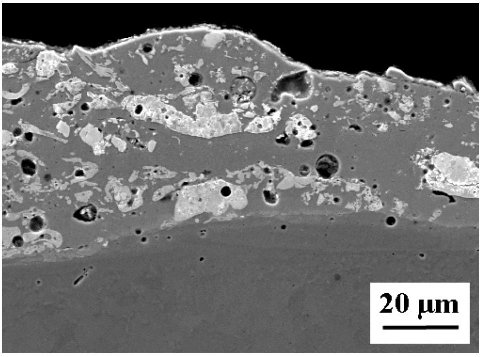

Fig. 1. WC-Cu coating microstructure after electro-spark alloying

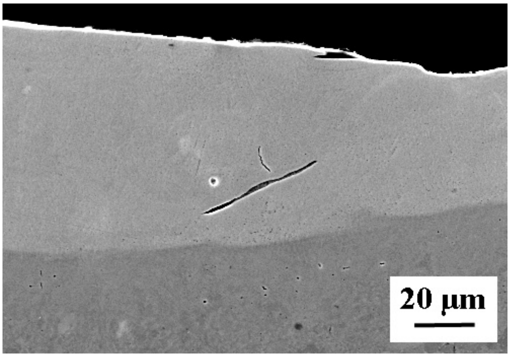

Fig. 2. Microstructure of the electro-spark alloying WC-Cu coating after treatment with an Nd:YAG laser

The laser-modified outer layer does not possess microcracks or pores (Fig. 2). There is no discontinuity of the coating-substrate boundary. The thickness of the laser-treated WC-Cu coatings ranges from 40 to 62 μm. Moreover, the heat affected zone (HAZ) is in the range of 25 to 35 μm, and the content of carbon in the zone is higher.

Using the X-ray diffraction method, the analysis of the phase composition of the examined coatings was performed with Philips PW 1830 instrument. Cu Kα filtered radiation was employed. Tests were carried out for the 2θ angle in the range 30-60° and the scanning velocity of 0.05°/3 seconds.

a) a)

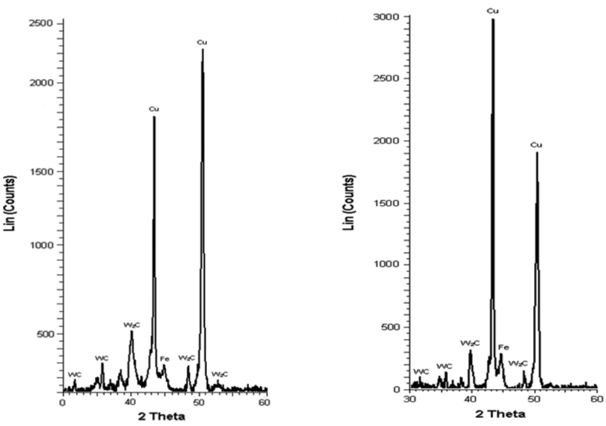

Fig. 3. X-ray diffraction pattern of the WC-Cu coating: a) before laser treatment; b) after laser treatment

The analysis of the phase composition of the WC-Cu coating (Fig. 3a) revealed that the surface layer of the coating consisted mainly of Cu and W_2C and a small amount of WC and Fe. Laser treatment did not cause the melting of the WC-Cu coating to penetrate into the substrate material (Fig. 3b). The surface layer of the WC-Cu coating after the laser treatment has the same composition as that of the coating before the treatment. The most intense peaks originate from Cu (Fig. 3a and 3b).

3.2. Measurements of the surface geometric structure and microhardness

Measurements of the 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.

Three-dimensional surfaces and their analysis with TalyMap Platinum software made it possible to precisely identify the geometric structure of the surfaces under consideration. Table 2 provides major parameters of the surface geometric structure of the examined specimens.

Table 2. Parameters of the surface geometric structure

SGS parameters	Coating	
	WC-Cu	WC-Cu + laser
Sa [μm]	4.02	6.95
Sq [μm]	5.24	8.48
Ssk	0.15	0.02
Sku	3.89	2.77
Sp [μm]	26.44	34.03
Sv [μm]	21.21	66.76
Sz [μm]	47.65	100.80

A greater value of the mean arithmetic deviation of surface roughness *Sa*, a basic amplitude parameter in the quantitative assessment of the state of the surface under analysis, was recorded for the specimen after the laser treatment. For the specimen before the laser treatment, the value of this parameter was almost 50% smaller.

A similar tendency is observed for the root mean square deviation of surface roughness *Sq*. Complementary information on how the surface of examined elements is shaped is provided by amplitude parameters, namely the coefficient of skewness (asymmetry) *Sku* and the coefficient of concentration (kurtosis) *Ssk*. Those parameters are sensitive to the occurrence of local hills or valleys, and also defects on the surface. *Ssk* parameter has a positive value for both specimens. The value is close to zero for the specimen before the treatment, which indicates the symmetrical location of the distribution of ordinates with respect to the mean plane. The values of kurtosis that were obtained are close to *Sku* = 3, which indicates that the distribution of ordinates for both specimens is close to normal distribution.

Before the laser treatment, the specimen had a random isotropic structure (*Iz* = 88.52%), whereas after the treatment, the structure became periodic, located in the transient area between isotropic and anisotropic structures (*Iz* = 55.32%). That is confirmed by the shape of the autocorrelation function of both surfaces. For the surface before the treatment, the shape is circular and symmetrical, whereas for the surface after the treatment, it is asymmetrical and elongated.

The microhardness was determined using the Vickers method (Microtech MX3 tester). The measurements were performed under the load of 0.4 N. The indentations were made in perpendicular microsections in three zones: the white homogeneous difficult-to-etch coating, the heat affected zone (HAZ) and the substrate. The microhardness of the substrate after the electro-spark deposition was 278 HV0.4; the same value was reported for the substrate before the process. There was a considerable increase in microhardness after depositing the WC-Cu coating. The microhardness of the WC-Cu coating was approx. 643 HV0.4. The microhardness of the WC-Cu coating in the heat affected zone (HAZ) after the electro-spark treatment was 58% higher than that of the substrate material. Laser treatment had a favourable effect on the changes in the microhardness of the electro-spark deposition of the WC-Cu coating. There was an increase of 122% in the microhardness of the WC-Cu coating.

4. Summary

1. Laser irradiation of coatings resulted in the healing of micro-cracks and pores.
2. Parameters of surface geometric structure of electro-spark coatings have lower values when compared to SGS parameters of coatings after the laser treatment.
3. The surface layer of the WC-Cu coating before and after the laser treatment consists mainly of Cu and W_2C and a small amount of WC and Fe.
4. Laser treatment caused a 9% decrease in the microhardness of the electro-spark alloying WC-Cu coatings.

References

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

[2] Antoszewski B., Evin E., Audy J., *Study of the effect of electro-spark coatings on friction in pin-on-disc testing*, Journal of Tribology – Transactions of the ASME, 3, 2008, 253-262.

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

[4] Radek N., *Determining the operational properties of steel beaters after electrospark deposition*, Eksploatacja i Niezawodność – Maintenance and Reliability, 4, 2009, 10-16.

[5] Radek N., Bartkowiak K., *Performance properties of electro-spark deposited carbide-ceramic coatings modified by laser beam*, Physics Procedia, 5, 2010, 417-423.

[6] Radek N., Antoszewski B., *Influence of laser treatment on the properties of electro-spark deposited coatings*, Kovove Materialy – Metallic Materials, 1, 2009, 31-38.