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PROPERTIES OF WC-Cu ELECTRO SPARK COATINGS SUBJECTED TO LASER MODIFICATION

WŁAŚCIWOŚCI POWŁOK ELEKTROISKROWYCH WC-Cu PODDANYCH MODYFIKACJI LASEROWEJ

Key words: WC-Cu coating, tribology, electro-spark deposition, laser treatment.

Abstract The article presents the possibilities of using laser surface modification on the way EDM to better tribological properties. The paper tries to expand knowledge in the fields of the application of electrospark deposition. Surface treatment by applying a coating by electrospark deposition has many advantages (e.g., local interface or applying thin layers); therefore, this technology is used in the industry. Concentrated streams of laser beams can effectively modified the state of the electrospark coating, WC-Cu, and improve its performance. The aim of the study is to evaluate the influence of laser treatment on the properties of electrospark coatings. Evaluation of the properties of the coatings after laser treatment was carried out by observation of the microstructure, surface geometry analysis, and tribological test.

Słowa kluczowe: powłoki WC-Cu, tribologia, obróbka elektroiskrowa, modyfikacja laserowa.

Streszczenie: Artykuł prezentuje możliwości wykorzystania modyfikacji laserowej powierzchni na drodze obróbki elektroiskrowej do uzyskania lepszych właściwości tribologicznych. Przedstawione w pracy zagadnienie może posłużyć do rozszerzenia wiedzy w zakresie obszarów zastosowania obróbki elektroiskrowej. Obróbka powierzchni poprzez nanoszenie powłok metodą elektroiskrową cechuje się wieloma zaletami (np. możliwością lokalnego oddziaływania czy nakładania cienkich powłok), dlatego też technologia ta jest wykorzystywana w przemyśle. Skoncentrowanym strumieniem wiązki laserowej można skutecznie modyfikować stan warstwy powłok elektroiskrowych, WC-Cu i wpływać na poprawę ich właściwości użytkowych. Celem pracy jest ocena wpływu obróbki laserowej na właściwości powłok nanoszonych elektroiskrowo. Ocenę właściwości powłok po obróbce laserowej przeprowadzono na podstawie obserwacji mikrostruktury, analizy struktury geometrycznej powierzchni oraz testów tribologicznych.

INTRODUCTION

There are many methods for producing surface coatings, such as electroplating, plasma spraying, etc. Very thin layers can be deposited by vapour deposition. Various surface treatment techniques have been developed to improve the desired properties of the deposited layers. Some of these methods are expensive and should only be used for special applications, where the high cost is justified. For most applications, however, there is a need for inexpensive coatings having good properties. Electrospark deposition (ESD) is a cheap and efficient way to improve the performance properties of the metal. Electrospark deposition is mainly used in the automotive, aerospace, and shipbuilding industries. Metallic coatings applied on the metal surfaces increases the corrosion resistance surface of the substrate and extend the service life treated materials.

The technology uses the phenomena of electrode material erosion and spark discharge between the electrodes, leading to the formation of a surface layer with characteristics different from those of the substrate. This method makes it possible to deposit ultra-thin and slightly thicker coatings made of any metal. The high temperature and high pressure induced by the pressure shock wave from the electrical discharge determine the shape of the top layer of the coating.

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Electro-spark deposited coatings have also some disadvantages, but these can be easily eliminated by laser beam machining (LBM), which can be used for polishing the surface, sealing and modifying its topography, and chemical homogenization of coatings **[L. 1–3]**. Deposition of protective layers on machine components is economically reasonable when small parts of them or surface layers are worn, and when the surface layer is required to have characteristics that are different from the mechanical and physical properties of the core. The layers typically deposited on objects prior to putting them to operation are called *technological surface layers* **[L. 4–9]**.

MATERIALS AND METHODS FOR SURFACE LAYER PRODUCTION

The coatings were deposited on C45 carbon steel by ESD using the portable device shown in **Figure 1**. Three types of electrodes were used with different compositions rates:

- WC 75%-Cu 25%;
- WC 50%-Cu 50%;
- WC 25%-Cu 75%.

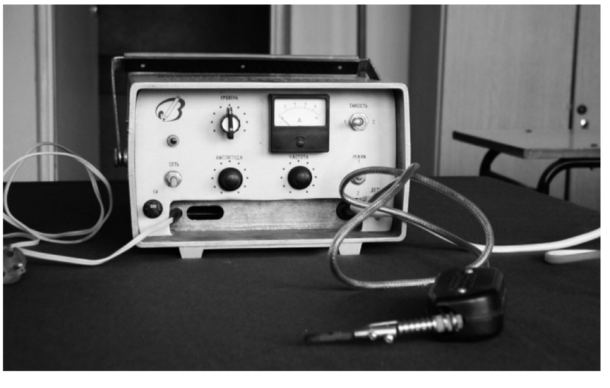

Fig. 1. Portable EIL-8A electro-spark deposition facility (TRIZ, Ukraine)
Rys. 1. Urządzenie do nanoszenia powłok elektroiskrowych EIL-8A produkcji ukraińskiej

The electrodes were produced using hot metallurgical powder presses **[L. 10]**. The powders were mixed for 30 minutes in a Turbula type chaotic mixer. The mixture was then poured into rectangular graphite cavities of 6 x 40 mm and consolidated by passing the electric current through the mould with a single axial compression load. Holding for 3 minutes at 950°C and under 40 MPa allows the electrodes with a porosity of <10% and a sufficient strength to maintain integrity when installed in the electrode holder.

The equipment used for the electrostatic precipitator was the EIL-8A **[L. 11–14]**. Based on the results of the previous studies and the instructions provided by the manufacturer, the optimum parameters for the ESA were as follows:

- Voltage U = 230 V,
- Capacitor capacity C = 150 μF,
- Current intensity I = 0.7 A,
- Deposition time τ = 2 min/cm^2.

The coatings were subjected to laser treatment at the Centre for Laser Technology of Metals. Then the coatings were treated with Nd: YAG (pulse mode) laser BLS 720 Nd:YAG laser capable of generating 150 W maximum average power, operating in the pulse mode, manufactured by BAASEL LASERTECHNIK. The samples with electrolysis-coated coatings were laser-modified using the following parameters:

- Point diameter d = 0.7 mm,
- Variable power P = 50W, 60W, 70W,
- Laser beam speed v = 250 mm / min,
- Nozzle distance – workpiece Δf = 6 mm,
- Pulse duration ti = 0.4 ms,
- Frequency of pulse repetition f = 50 Hz,
- Beam travel stroke S = 0.4 mm.

TRIBOLOGICAL TEST

Friction resistance tests were performed on ring-shaped specimens made of higher quality carbon steel C45, with WC-Cu coatings deposited by electrospark deposition before and after laser-based modification. A ϕ 6.3 mm diameter ball made of 100Cr6 steel was the counter-specimen. The following friction parameters were used in the tests:

- Linear velocity V = 1 m/s,
- Time t = 3600s,
- Load change range Q = 4.9 N; 9.8 N; 14.7 N.

Table 1 shows the average coefficient friction for different electrospark coatings modified by laser treatment.

As you can see from the results placed in the table, the highest average coefficient friction was found with coating WC 25% Cu 75% modified by laser power P-50W. On the other hand, the smallest average coefficient friction was found with coating WC 75% Cu25% modified by laser power P-70W. To illustrate this result, a graph of time relative to the coefficient friction is presented below.

The graph in **Fig. 2** compiles examples of the results and illustrates the changes in friction coefficient value as a function of time under the different loads of 4.7 N; 8.9 N and 14.7 N. In dry friction, the technological surface layer of the coating (abbreviated to TWP in Polish) transformed into the operational surface layer (abbreviated to EWP in Polish). As you can see from **Figure 2**, the coefficient of friction is lowest at the lowest load and stabilizes after 2500 seconds, and its value is about 0.61 to 0.64.

Figure 2 of the untreated coating WC50% - Cu50% with a load of Q = 14,7 N indicates that the friction coefficient stabilizes after about 2000 seconds with

Table 1. Average coefficient friction at different loads
Tabela 1. Średni współczynnik tarcia przy różnych obciążeniach

Laser modified coatings	Average coefficient Friction		
	Q-4.9N	Q-9.8N	Q-14.7N
WC 75%-Cu 25%	0.68	0.48	0.41
WC 75% -Cu 25% P-50 W	0.74	0.46	0.39
WC 75% Cu 25% P-60 W	0.57	0.56	0.41
WC 75% Cu25% P-70 W	0.58	0.41	0.38
WC 50% Cu 50%	1.09	0.67	0.58
WC 50% Cu 50% P-50 W	1.35	0.74	0.65
WC 50% Cu 50% P- 60 W	0.74	0.7	0.57
WC 50% Cu 50% P-70 W	0.82	0.69	0.58
WC 25% Cu 75%	0.86	0.6	0.47
WC 25% Cu 75% P-50 W	1.39	0.82	0.68
WC 25% Cu 75% P-60 W	0.90	0.78	0.69
WC 25% Cu 75% P-70 W	0.85	0.82	0.65

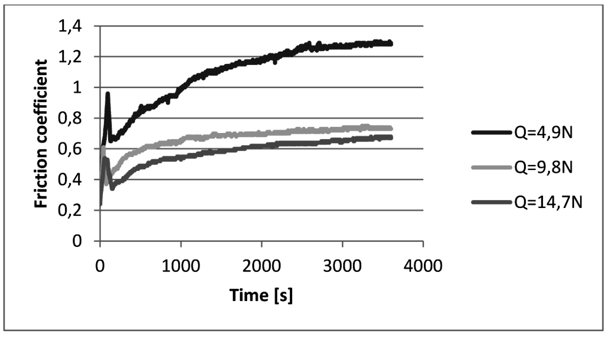

Fig. 2. Friction coefficient versus time for 50%WC--50%Cu coating with different loads
Rys. 2. Wykres zmian współczynnika tarcia w funkcji czasu dla powłoki 50%WC-50%Cu przy różnych obciążeniach

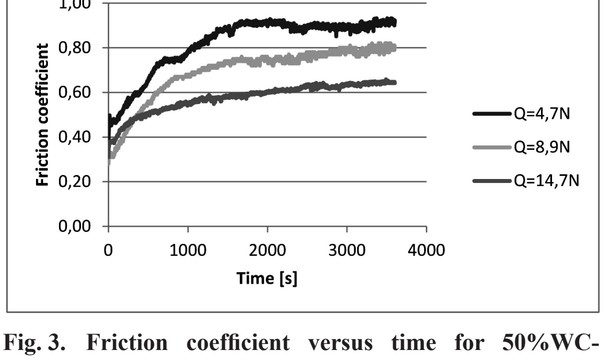

Fig. 3. Friction coefficient versus time for 50%WC--50%Cu coating modified with a laser beam P-70 W with different loads
Rys. 3. Wykres zmian współczynnika tarcia w funkcji czasu dla powłoki 50%WC-50%Cu zmodyfikowanej wiązką lasera o mocy P = 70 W przy różnych obciążeniach

the value oscillating at the level of 1.2 to 1.22. In the case of the laser treated WC50%-Cu50% coating with a load of Q = 14,7 N, the friction coefficient stabilizes after about 2000 seconds with the value oscillating at the level of 0.90 to 0.93. The mean friction coefficient is lower than that after laser irradiation (at the moment of their stabilization). This effect might be induced by the elimination of defects (microcracks and pores) in laser treated coatings.

MICROGEOMETRY MEASUREMENTS

The geometric structure of the surface is one of the main determinants of its quality. It has a significant influence on many processes occurring in the surface layer. The geometry of the (SGP) surface is defined as the set of all inequalities resulting from the processes of material consumption. Operational data shows that approximately 90% of all manufacturing defects originate in the surface from various types of mechanical damage. One of the main disadvantages of the coatings produced by electrospark 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 the erosion of the base material and the formation of micro-craters 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. Electrospark alloying allows producing surfaces with enhanced roughness called surface relief.

The roughness of the WC-Cu coatings was measured at the Laboratory for Measurement of Geometric Quantities of the Kielce University of Technology using TALYSURF CCI equipment. Three-dimensional surfaces and their analysis using the software TalyMap Platinium allowed thoroughly investigating the geometric structure of the surface tested. **Figure 4** presents an example of three-dimensional surface microgeometry measurement of the WC50%-Cu50% coatings after and before laser treatment.

The analysis of the results in **Table 2** and the topography images of the surface of the specimen shown in **Figure 3** indicate that the laser modification with a 60 W laser power positively influenced almost all the tested parameters, which included observed reduced value *Sa*, which is the arithmetic average deviation of the surface roughness. This is the basic amplitude parameter for the quantitative evaluation of the analysed surface. A similar trend was observed for the quadratic surface roughness *Sq*.

Additional information about the surface configuration of the examined elements gives the amplitude parameters: the slope coefficient – Syk asymmetry and the concentration coefficient – Ssk kurtosis. These parameters are sensitive to the occurrence of local inclinations, recesses, or defects on the surface. The laser treatment of 70 W and 60 W resulted in the increase of the major values of the surface geometry parameters of the electrospark deposition coatings (*Sa, Sq, Sp, and Sz)*, in relation to the SGP parameters of the coatings before laser treatment, which may be due to the movement of liquid metal due to surface tension forces.

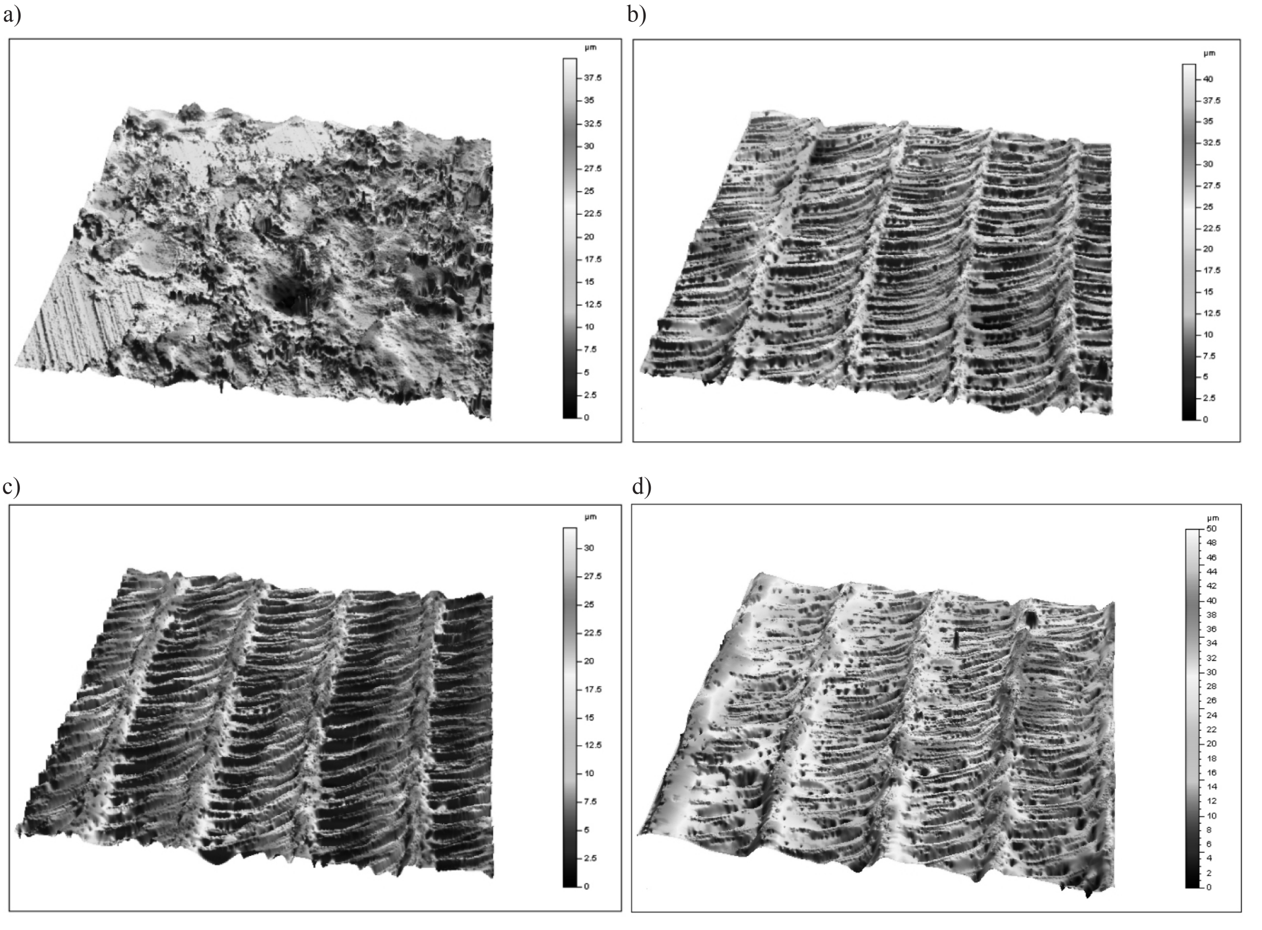

Fig. 4. Three-dimensional microscopic surface area of WC 50%-Cu 50% coating: a) no laser; b) laser beam modified P = 50 W; c) laser beam modified P = 60 W; d) laser beam modified P = 70 W

Rys.4. Trójwymiarowa mikroskopowa powierzchnia elektroiskrowej powłoki WC50%-Cu50%: a) bez lasera; b) zmodyfikowana wiązką laserową P = 50 W; c) zmodyfikowana wiązką laserową P = 60 W; d) zmodyfikowana wiązką laserową P = 70 W

Table 2. Parameters of the surface geometry of WC 50%-Cu 50% before and after laser treatment

Tabela 2. Parametry struktury geometrycznej powłoki WC 50%-Cu 50% przed i po modyfikacji laserowej

Parameters of the surface geometry	Coatings			
	WC 50%-Cu 50%	WC 50%-Cu 50% + laser P-50 W	WC 50%-Cu 50% + laser P-60 W	WC 50%-Cu 50% + laser P-70 W
Sa, [µm]	3.98	4.08	3.80	5.36
Sq, [µm]	5.25	5.11	4.69	6.75
Ssk	-0.22	-0.08	-0.28	0.01
Sku	3.87	2.98	2.70	2.93
Sp, [µm]	18.20	22.37	12.89	24.97
Sv, [µm]	21.52	19.44	18.96	25.05
Sz, [µm]	39.73	41.08	31.86	59.03

MEASUREMENTS OF ROUGHNESS

One of the main disadvantages of coatings coated with electro-erosion is their high-end finish. In-depth analysis of literature and previous studies show that surface formation occurs because of overlapping craters caused by erosion of the substrate as well as crests formed from the surface of the particles of the coating material (electrodes). This surface has a number of features: regularity, a lack of directionality, and a large radius of rounding of the micro connections. In many scientific studies, the impact of process parameters on the roughness of the surface is analysed. By controlling these parameters, one can obtain assumed changes in surface microgeometry.

Roughness measurements were performed at the Geometric Measurement Laboratory of the Kielce University of Technology using the Talysurf CCI optical profilometer using the patented Taylor Hobson coherence correlation algorithm, enabling measurement with an axial resolution of less than 0.8 nm. **Table 4** shows the values of the principal roughness parameters for the exemplary coating of WC 50%-Cu 50% before and after laser modification.

Sample graphs of the microgeometry parameters of the tested specimens are shown in **Fig. 5.** As you can see, all parameters of the P-60 W laser modified coating have been reduced. Both Ra (arithmetic deviation of the roughness profile) and Rc (height of the roughness profile components) have been reduced. On the other hand, with the modification of the P-70 W laser beam, all parameters were increased. Coatings WC-Cu before to laser treatment had an average roughness Ra = 3.85 μm, while after laser treatment P-60 W the average roughness was 3.01 μm. In this case, the laser power caused a decrease in roughness. In contrast, the modification coatings of the laser power P-70 W creased Ra to 4.15 μm.

Table 3. Parameters of the roughness profile of the coating WC 50%-Cu 50% before and after the laser modification
Tabela 3. Parametry amplitudy profilu chropowatości powłoki WC 50%-Cu 50% przed i po modyfikacji laserowej

Amplitude parameters, [μm]	Coatings			
	WC 50%-Cu 50%	WC 50%-Cu 50% + laser P-50 W	WC 50%-Cu 50% + laser P-60 W	WC 50%-Cu 50% + laser P-70 W
Ra	3.85	2.59	3.01	4.15
Rp	9.73	8.85	6.41	11.50
Rv	8.02	9.08	8.18	10.27
Rz	17.74	17.93	14.60	21.77
Rc	12.76	8.36	9.16	15.08
Rt	17.74	17.93	16.78	21.77
Rq	4.47	3.42	3.58	5.11

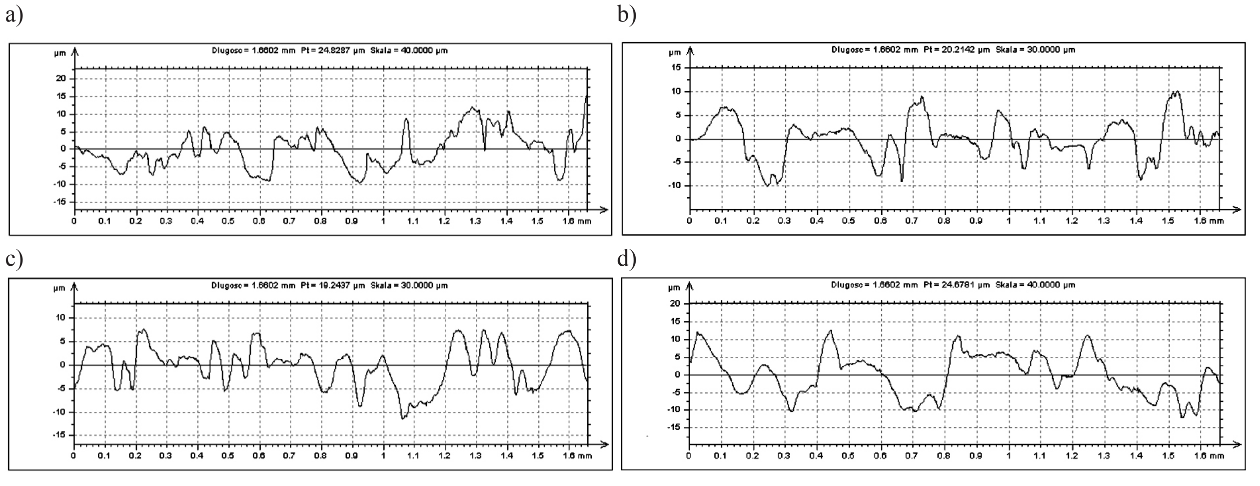

Fig. 5. Exemplary results of microscopy measurements of WC 50%-Cu 50%: a) without laser treatment, b) laser-modified P = 50 W, c) laser-modified P = 60 W; d) laser-modified P = 70 W
Rys. 5. Przykładowe wyniki pomiarów parametrów mikrogeometrii powłoki 50%WC-50% Cu: a) bez obróbki laserowej, b) modyfikowane laserem P = 50 W, c) modyfikowane laserem P = 60 W, d) modyfikowane laserem P = 70 W

MORPHOLOGY

The surface after electrospark deposition is clearly heterogeneous and rough, as shown in **Figure 6.** The surface roughness of the electrospark deposited coating can be several times higher when compared to the roughness of the substrate material. Unwanted surface effects obtained by electrospark deposition can be removed by laser treatment of the surface of the material. By appropriate selection of the exposure, it is possible to shape the surface geometry, change microhardness, and eliminate surface tension and the corrosion resistance of native material, which can be formed because of the elimination of delamination and microcracks. **[L. 1–4]**.

The microstructure was obtained by scanning electron microscope JSM-5400 with a sample of the test sites where chemical analysis was performed, shown in **Figure 6**. Spectral analysis for selected points is given in **Figure 7**. Results of chemical analysis of coatings WC50%-Cu50% before and after laser modification is shown in **Table 4**. The obtained data show that the composition of the coating after laser modification is more homogeneous.

Table 4. Percentage of elements calculated at each point marked on the coating
Tabela 4. Procentowy skład pierwiastków wyliczony w poszczególnych punktach zaznaczonych na powłoce

Points on the coating a)	Elements				
	C	Fe	Cu	W	Total
1	5.43	87.53	5.05	1.99	100
2	5.11	87.46	6.00	1.43	100
3	5.37	88.83	5.29	0.51	100
4	6.83	84.65	6.37	2.15	100

Points on the coating b)	Elements				
	C	Fe	Cu	W	Total
1	5.74	91.16	1.72	1.37	100
2	7.69	91.59	1.40	0.82	100
3	6.92	89.11	1.68	1.28	100
4	6.01	92.82	1.27	0.88	100

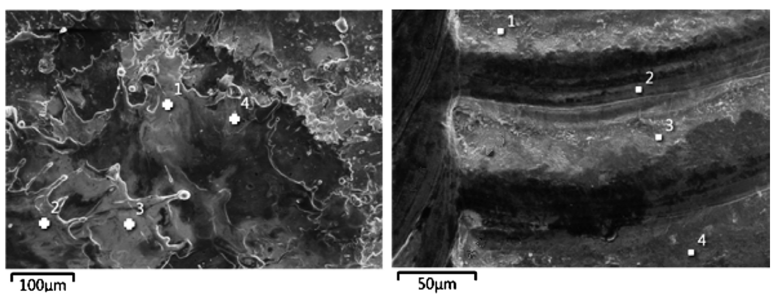

Fig. 6. Microstructure of coating WC 50%-Cu 50% before (a) and after (b) laser modification with power P-60 W. Magnification 1000x
Rys. 6. Mikrostruktura powłoki WC 50%-Cu 50% przed (a) i po (b) modyfikacji laserem o mocy P-60 W. Powiększenie 1000x

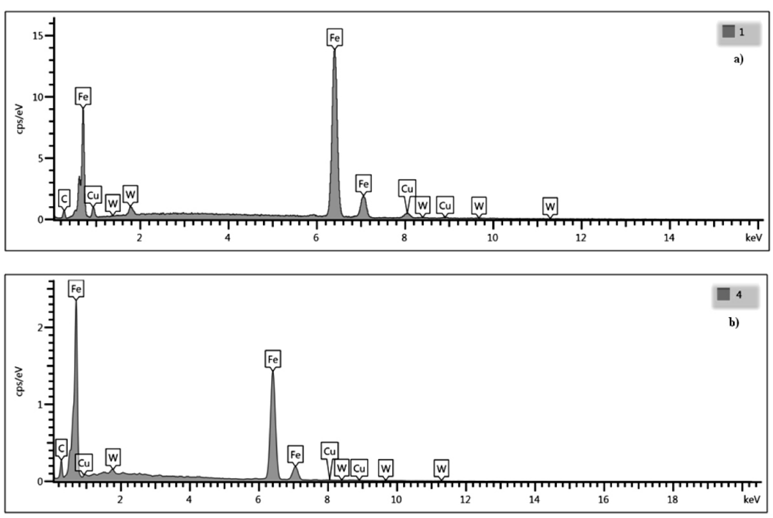

Fig. 7. Spectrum of EDS coating WC50%-Cu50%: a) before laser treatment in Point 1, b) after laser treatment P-60 W in Point 4
Rys. 7. Spektrum EDS powłoki WC50%-Cu50%: przed modyfikacją lserem w punkcie 1, b) po modyfikacji laserem P-60 W w punkcie 4

CONCLUSIONS

The following conclusions can be formulated based on the tests and analysis of the results:

- The carbon steel surface can be modified by electrospark deposition using WC-Cu electrodes with different percentages of both components.
- A concentrated laser beam can effectively modify the state of the electrospark coating, WC-Cu, and improve their performance.
- Laser treatment of WC-Cu coatings resulted in the homogenization of the chemical composition, fragmentation of the structure and the elimination of microcracks and pores.
- WC-Cu coatings after laser treatment had as little roughness Ra as the coatings without this treatment. This phenomenon is advantageous in terms of quality and usefulness under certain operating conditions.
- Laser modification reduced the coefficient of friction under various loads and increased the resistance to seizure.

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