THE EFFECT OF LASER TREATMENT ON OPERATIONAL PROPERTIES OF ESD COATINGS

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Abstract

A characteristic feature of the beam technologies is that the treatment of materials occurs as a result of the impact of the concentrated energy flux. By controlling the energy flux, the selected areas of the surface can undergo the treatment process. The diameter of the energy beam varies from a fraction of nanometers to several tens of centimeters. It depends on the basic physical phenomenon occurring in a given technology. The smallest field of impact is typical of the methods which use a stream of electrons or a laser beam. The energy streams, occurring here, are focused and controlled by optical or magnetic lens systems or mirrors, while the size of the spot in the focal point depends only on the wavelength of the electron or laser radiation. There are many methods for producing surface coatings, such as electroplating and plasma spraying. The use of laser treatment to improve the properties of electro-spark coatings is very interesting. The main objective of the present work is to determine the effects of laser treatment on properties of WC-Co coatings electro-spark deposited (ESD) on steel substrates. The microstructure and properties of laser treated/melted coatings were evaluated by means of: scanning electron (SEM) microscopy, X-ray diffraction (XRD), surface roughness measurements, hardness and corrosion resistance tests. The obtained experimental data show that the laser-treated ESD WC-Co coatings are characterised by lower hardness, higher resistance to seizure and roughness, and better adhesion to the substrate. The laser treatment homogenizes the chemical composition, refines the microstructure and heals microcracks and pores of ESD coatings. The laser treated ESD WC-Co coatings can be used in sliding friction pairs and as protective layers.

Keywords: Electro-spark coatings, laser treatment, properties

1. INTRODUCTION

Sintered carbides are cermets composed of 70-96% of refractory metal carbides (such as tungsten, niobium, tantalum) as well as the binding matrix. This matrix is typically made of cobalt, more rarely of molybdenum, nickel, or even iron. Cemented carbides are currently very commonly used as a material for the production of cutting blades, mostly in milling and turning devices [1]. We can divide sintered carbides into individual grades depending on their chemical composition or the size of WC particles. WC-Co carbides are divided according to the WC particle size into the groups listed below [2]:

- coarse-grained (mean diameter of 3 ÷ 30 μm),
- standard (mean diameter of 1.5 ÷ 3 μm),
- fine-grained (mean diameter of 0.5 ÷ 1.5 μm),
- ultra-fine grained (mean diameter below 0.5 μm).

The application of ceramic tool materials in comparison to sintered carbides is small, but still shows a dynamic growth. According to estimates, about five percent of cutting tool blades are manufactured of this group of materials. The most popular materials for the production of ceramic tool materials are:

- single-phase aluminum oxide Al2O3,
- silicon nitride Si3N4,
- multi-phase mixtures of Al2O3 and Si3N4 with hard carbides, oxides as well as nitrides.

The possibility of producing anti-wear carbide-ceramic coatings using electro-spark deposition with electrodes made by powder metallurgy methods is quite interesting [3-7]. Super-hard coatings may be applied onto the cutting edges of tools, e.g. turning knives, cutters, chisels and taps. It is assumed that the above-mentioned coatings could be successfully used on machine elements which operate in extreme conditions, such as intense abrasive wear, impact loads. An additional advantage encouraging the use of super-hard electro-spark deposited coatings is the ecological aspect. Electro-spark deposition is characterized by the lack of any harmful impact on the environment. In as-deposited condition the ESD coatings usually have flows which can be easily eliminated by laser beam processing (LBP), wherein a laser beam is used for pore/crack sealing and surface polishing as well as for homogenizing the chemical composition of the coating [8, 9]. Additionally, the laser-treatment aids the coating's adhesion to the substrate, wear and seizure properties, resistance to corrosion, and fatigue strength due to formation of compressive stress in the sub-surface layer. The work discusses the properties of electro-spark deposited WC-Co coatings subjected to laser treatment. The properties were established basing on the results of a microstructure analysis, corrosion resistance tests, roughness and hardness measurements. The methodology and results shown in this article by modifying the surface layer [10,11] may be useful for many industries, including corrosion protection in construction [12] and the production of agricultural machinery [13,14], strength improvement in railways [15-17], quality improvement in the automotive industry [18-20], metallurgy [21] and general production organization [22,23]. The results may have a particularly strong impact in the research area, including material [24-26], coating [27] and corrosive [28], but also mechanical [29,30]. Finally, the importance of such research for the purposes of military technology should not be forgotten [31].

2. MATERIALS AND TREATMENT PARAMETERS

WC-Co coatings were manufactured by the ESD method. Cylindrical electrodes, 5 mm in diameter and 20 mm high (**Figure 1**), were used to deposit coatings on C45 plain carbon steel.

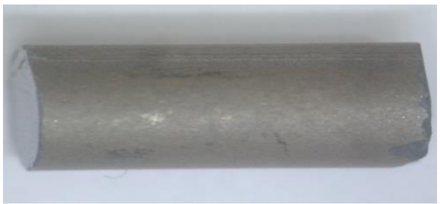

Figure 1 WC-Co electrode (mag. 12.5x)

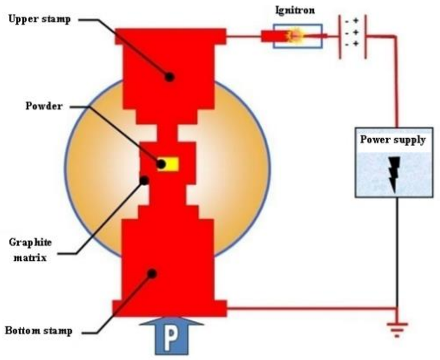

Figure 2 Scheme of the device for PPS

Electrodes containing 95 wt.% WC (OMG; FSSS=0.2 μm) and 5 wt.% Co (Umicore; FSSS=0.4 μm), were produced by means of pulse-plasma sintering (PPS), by holding the powder mix for 5 minutes at 1100^{o}C and under a pressure of 50 MPa. PPS uses high-current pulses generated through continual discharging a capacitor battery of 300 µF, thereby inducing several tens of kA current which flows through the consolidated powder within each millisecond pulse. **Figure 2** shows a schematic of a pulse-plasma sintering device. The coatings were deposited in argon by means of an EIL-8A pulse generator with manual electrode displacement. Following the manufacturer's guidelines and using prior experience, the voltage, capacitor volume, current intensity and deposition time were set to 230 V, 300 µF, 2.2 A and 2 min/cm^2, respectively.

The coatings were subsequently subjected to LBP at the Centre for Laser Technology of Metals, University of Technology, Kielce. The Basel Lasertechnik BLS 720 Nd:YAG laser generated a beam having 0.7 mm spot diameter and 20 W power was operated in the pulse mode. The laser treatment conditions were: pulse duration time: 0.4 ms, pulse repetition frequency: 50 Hz, beam shift jump: 0.4 mm, nozzle-workpiece distance: 1 mm, specimen movement rate: 250 mm/min.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Microstructure analysis

The microstructure of the WC-Co coatings was observed using a scanning electron microscope (SEM) in both as-deposited and laser-treated condition. A typical microstructure of the WC-Co coating is illustrated in (**Figure 2**)**.** From the SEM analysis it is evident that the as-deposited coating is porous and have a thickness of between 30 and 40 µm. The heat affected zone (HAZ) within the substrate ranges from 15 to 20 µm beneath the clearly seen coating-substrate interface. As seen in (**Figure 3**) the laser-modified outer layer is free from microcracks and porosity The coating is 40-50 µm thick and perfectly adhere to the substrate, wherein the carbon-enriched HAZ extends from 30 down to 40 µm beneath the coating. The Philips PW 1830 X-ray diffractometer with CuKα radiation was used for phase identification. The analysis of the phase composition of the WC-Co coating revealed that the surface layer of the coating consisted mainly of WC and W_2C before and after the laser treatment. The laser treatment renders the WC-Co coating to melt together with part of the substrate, resulting in formation of complex M_6C carbides, primarily Fe_3W_3C.

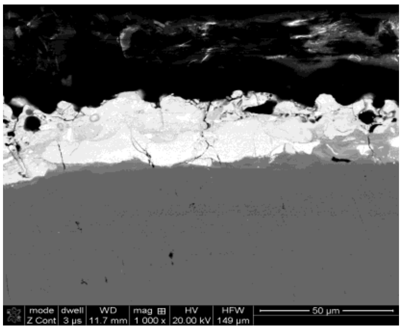

Figure 2 As-deposited microstructure of WC-Co coating

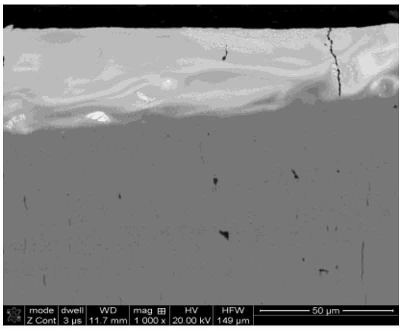

Figure 3 Microstructure of WC-Co coating after laser treatment

3.2. Roughness measurements

The roughness of WC-Co coatings was measured in two perpendicular directions. The first measurement was made according to the movement of the electrode, while the second measurement was perpendicular to the scanning stitches. The average value of the Ra parameter for a given coating was calculated from the two measurements. Measurements of WC-Co coatings treated with laser were made in perpendicular and parallel direction to the axis of the paths made with laser beam, and then the mean value of roughness for the given coating was calculated. In most of the works, the results of roughness measurements are given for profiles measured along the axis of the tracks obtained by laser, which does not reflect the actual picture of the surface microgeometry after this treatment, because the maximum height of irregularities occur in the direction perpendicular to the axis of the tracks. WC-Co coatings were characterized by the value of the parameter Ra = 1.35-2.01 μm, while after laser beam machining the arithmetic mean value of the profile ordinates was from 3.15-4.46 μm. Samples made of C45 steel to which coatings were applied were characterized by the value of the parameter Ra = 0.36÷0.40 μm. Examples of measurement profiles of microgeometry parameters of the tested samples are presented in (**Figure 4**).

On the basis of the measurements carried out, it can be concluded that LBP increases the roughness of WC-Co coatings. The higher roughness of WC-Co coatings after laser treatment is the result of the movement of liquid metal caused by surface tension forces. The heterogeneous temperature distribution in the laser beam (mod TEM_{00}) causes that the surface profile after clotting is also heterogeneous and in a sense reflects the energy distribution in the melt area.

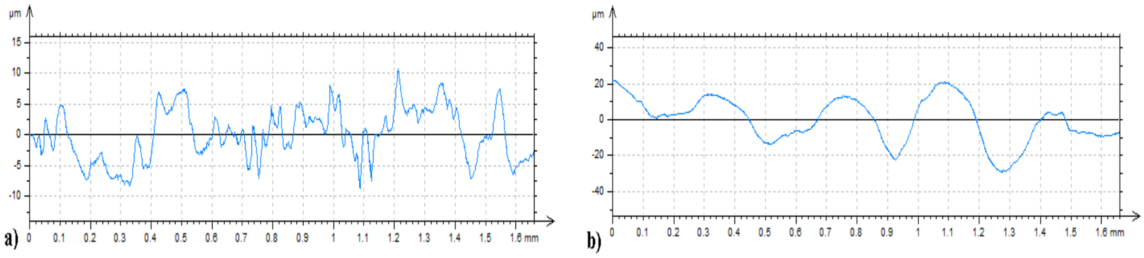

Figure 4 Example of roughness profile of WC-Co coating: a) before laser treatment, b) After laser treatment

3.3. Microhardness testing

The Vickers microhardness tests were carried out on polished cross-sections at three different locations, i.e. in the coating, in the heat affected zone (HAZ) located close to the coating, and in the substrate. An uncoated C45 steel substrate was also tested. The obtained results are presented in (**Table 1**). The results indicate minor decrease in microhardness of both the coating and HAZ after laser treatment, whereas the steel substrate remains unaffected. The slight decrease in the coating microhardness due to the laser treatment may potentially improve its elastic properties, thereby aiding field application behaviour under heavy-duty conditions, e.g. in rock and earth drilling, pressure moulding of ceramics, etc.

Table 1 Results of Vickers microhardness test

Coating condition	**HV0.4 †**		
	Coating	**HAZ**	**Substrate**
As-deposited	1284 ± 56	419 ± 26	143 ± 4
Laser treated	1148 ± 49	403 ± 34	141 ± 5

†scatter intervals estimated at 90% confidence level

3.4. Corrosion resistance tests

Specimens with a 10 mm diameter separated area were polarized to 500 mV. In order to establish the corrosion potential the polarization curves were acquired 24 hours after exposure to the test solution (0.5M NaCl). All tests were carried out at 21±1°C. The corrosion resistance results are shown in (**Figure 5**).

The observed differences in potentials (between stationary and corrosive potentials) may have resulted from the fact that during slow changes of the potential during testing (0.2 mV/s), it was possible to form hydroxides on the tested surface, which alkalize (in the immediate vicinity of the sample) the environment and thus change the potential of steel (it is assumed that a change in pH by a unit changes the corrosive potential by 50 mV). Moreover, the cathode processes are under diffusional oxygen reduction control and therefore the slope angles of the cathode curves of the tested samples have such high values.

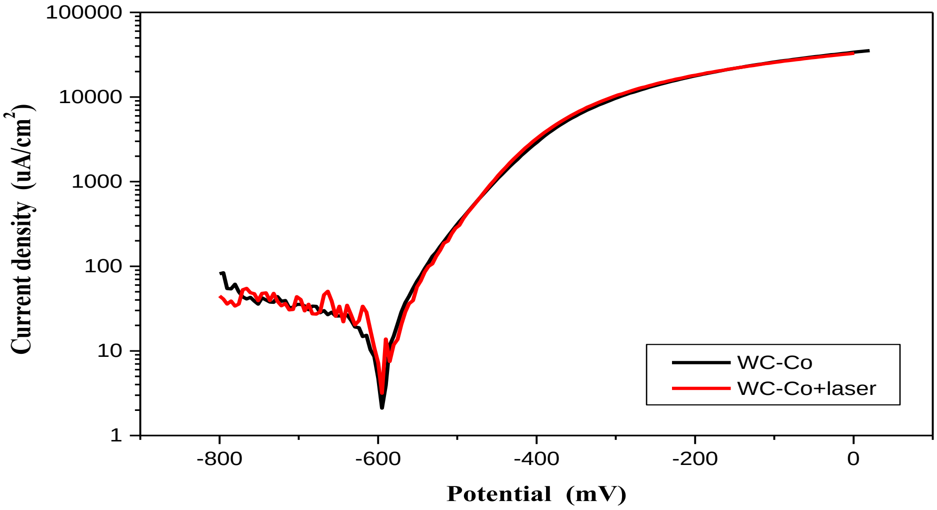

Figure 5 Polarization curves of WC-Co coatings in as-deposited and laser treated condition

Table 4 The values of current density and corrosion potential of the tested samples

Material	Corrosion potential (mV)	Corrosion current density ($\mu A/cm^2$)
C45	-630	15.9
C45+laser	-605	14.4
WC-Co	-595	11.6
WC-Co+laser	-585	9.2

4. CONCLUSION

The conclusions are as followings:

- The surface of C45 carbon steel can be modified by means of electro-spark deposition using WC-Co electrodes.
- A concentrated laser beam can be effective in modifying the state of the outer layer of electro-spark coatings and thus can modify their functional properties.
- The laser treatment refines the microstructure of ESD WC-Co coatings partially eliminates porosity and microcracks.
- Laser treatment of ESD WC-Cu coatings decreases their microhardness (by 6%).
- Laser radiation causes an improvement in the functional properties of the electro-spark deposited WC-Cu coating, i.e. they exhibit higher resistance to corrosion (by 26%).
- Laser treatment increases roughness of the ESD WC-Co coatings (more than twice).
- Coatings of that type can be applied to sliding friction pairs and can operate as protective coatings.
- Further experimental studies ought to focus on testing the resistance to abrasive and erosive wear of ESD coatings before and after laser treatment.

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