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Laser Processing of WC-Co Coatings

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Abstract. The main objective of the present work was to determine the influence of laser beam processing (LBP) on the microstructure, microhardness, roughness, and corrosion resistance of coatings produced on C45 carbon steel by the electro-spark deposition (ESD) process. The studies were conducted using WC-Co electrodes produced by the Pulse Plasma Sintering method (PPS) of nanostructural powders. The coatings were deposited by means of the EIL-8A and they were laser treated with the Nd:YAG, BLS 720 model.

Introduction

Carbide coatings have numerous industrial applications. Characterized by high abrasion, sliding, and erosion resistance, they can be used as a substitute for hard chrome plating. Cemented carbides are cermets containing between 70 and 97 wt.% of refractory metal carbides (e.g. WC, TiC, TaC) and a metal binder which is most often cobalt, sometimes nicke,l and occasionally an iron-base alloy. At present, cemented carbides find numerous applications as wear parts as well as in all kinds of machining operations outperforming the conventional high-speed steel tools [1].

Cemented carbides are classified into categories depending on their chemical composition and WC grain/particle size. The latter parameter can vary widely, therefore cemented carbides are divided into four main groups [2]:

- coarse-grained - 3÷30 µm,
- standard - 1.5÷3 µm,
- fine-grained - 0.5÷1.5 µm,
- ultrafine-grained - < 0.5 µm.

ESD technology can be an alternative to other techniques for the production of engineering materials, e.g. sinters [3-5]

We can produce carbide-based coatings using various technologies. Among the beam techniques, we observe a dynamic development of laser processing [6] and a well-established position among surface treatments using the ESD method [7].

To date, a number of alternative ESD techniques have been developed to suit various coating deposition conditions and meet surface topography requirements. ESD coatings may serve as both technological and functional surface layers and can be deposited using portable, manually operated equipment or fully automated systems.

ESD coatings have some disadvantages, such as high roughness and the presence of porosity and discontinuities but these can be eliminated by laser treatment. The laser beam is used for surface sealing, removing surface irregularities, homogenizing the chemical composition of the coating, and changing its phase composition [8]. Therefore laser-treated ESD coatings show lower porosity, better adhesion to the substrate, higher resistance to wear and seizure, higher fatigue strength due to the presence of compressive stress, and good resistance to corrosion. Analysis of properties of WC-Co coating systems requires many methods [9, 10].

This paper reports on the effects of laser treatment on microstructure, microhardness, roughness, and corrosion resistance of electro-spark WC-Co coatings.

Experimental Procedure

The coatings were deposited on the C45 grade plain-carbon steel by the ESD method. The electrodes, of composition 95% WC and 5% Co, were produced using the Pulse Plasma Sintering method.

The powders were mixed together in the right proportions and consolidated by means of a pressure-assisted, pulse-plasma sintering (PPS) method at the Faculty of Material Engineering, Warsaw University of Technology (Poland). The powder mix was held for 5 minutes at 1100°C and 50 MPa. PPS uses high-current pulses generated through continual discharging of a capacitor battery of 300 μF, thereby inducing several tens of kA current which flows through the consolidated powder within each millisecond pulse.

To deposit the WC-Co coatings the EIL-8A apparatus was operated at voltage, current, and capacitance of 230 V, 2.1 A, 300 μF, and 2 min/cm^2, respectively. The coatings were afterward treated with the Baasel Lasertechnik *720* Nd:YAG laser run in pulsed mode at a power level of 25 W, a spot size of 1 mm, and pulse duration of 0.5 ms and a pulse repetition frequency of 45 Hz. The sample movement rate and beam shift jump were set to 230 mm/min and 0.35 mm, respectively.

Results and Discussion

The morphology of WC-Co coatings was analyzed before and after laser treatment by means of the Quanta 3D FEG (SEM/FIB) scanning electron microscope, equipped with an integrated EDS/WDS/EBSD system (energy dispersion spectrometer EDS, wavelength dispersion spectrometer WDS and electron backscattered diffraction EBSD). The microstructures of ESD WC-Co coatings in both as-deposited and laser-treated conditions were observed by SEM.

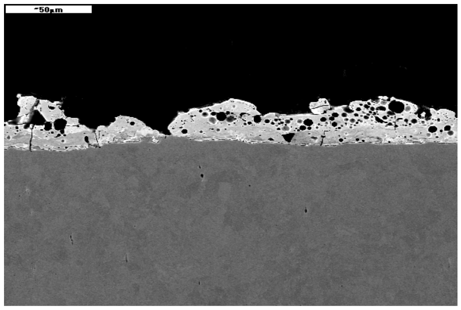

Fig. 1. *Microstructure of the WC-Co coating.*

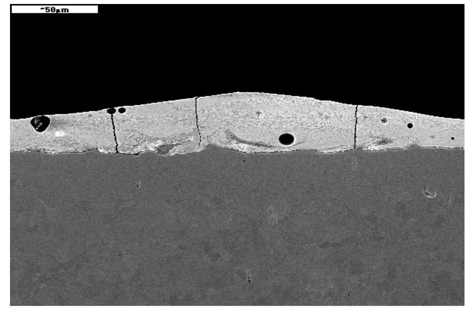

Fig. 2. *Microstructure of the WC-Co coating after laser treatment.*

A typical microstructure of the WC-Co coating is illustrated in Fig. 1. From the SEM analysis, it is evident that the as-deposited coating is porous and cracked, and has a thickness of between 25 and 35 µm. The heat-affected zone (HAZ) within the substrate ranges from 14 to 21 µm beneath the clearly seen coating-substrate interface. The ESD treatment homogenizes the chemical composition of the coatings and refines their microstructure. As seen in Fig. 2, the laser-modified outer layer is free from cracks and porosity The coating is 30-40 µm thick and perfectly adheres to the substrate, wherein the carbon-enriched HAZ extends from 25 down to 31 µm beneath the coating.

The roughness of the WC-Cu coatings was quantitatively assessed using the Talysurf CCI optical profiler and was measured in two perpendicular directions. The first measurement was made parallel to the electrode movement direction, while the second measurement was perpendicular to the scanning stitches. The average value of the Ra parameter for a given coating was calculated from these two measurements. Measurements of WC-Co coatings subjected to LBP were made in perpendicular and parallel directions to the path of a laser beam, and then the mean value of roughness was calculated. In most research studies, the measurements of surface roughness are measured along the path of the laser beam. The obtained results do not reflect the actual surface micro-geometry because the maximum height of irregularities occurs in the perpendicular direction.

WC-Co coatings were characterized by the value of the parameter Ra = 2.64÷3.16 µm, while after laser beam machining the arithmetic mean value of the profile ordinates was from 9.87÷10.57 µm. C45 steel substrates to which coatings were applied were characterized by Ra = 0.38÷0.42 µm. Selected profiles of the tested samples are presented in Fig. 3.

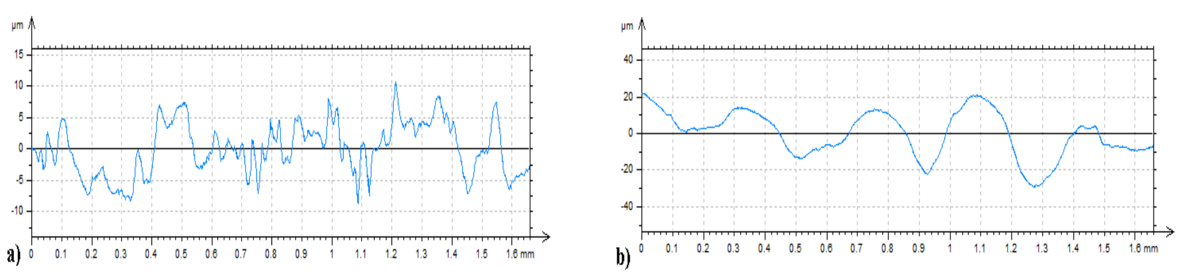

Fig. 3. *Examples of surface profiles of WC-Co coatings: a) before LBP, b) after LBP.*

Microhardness measurements were performed using the Vickers method. The microhardness was measured using the Microtech MX3 tester at a load of 0.4 N applied for 15 seconds. Indentations were made on perpendicular sections in three zones: in the coating (before and after LBP), in the heat-affected zone (HAZ) and in the substrate material. Each sample was subjected to 10 measurements. It was found that LBP caused a slight decrease in microhardness of the tested coatings. The microhardness of the WC-Co coating prior to LBP was ranging from 968 to 1065 HV0.4 and slightly decreased to between 937 and 995 HV0.4 after LBP. The C45 steel substrate of was not much affected by the laser treatment and its microhardness was ranging from between 461 and 528 HV0.4 in the HAZ to between 271 and 279 HV0.4 in the underlying substrate.

Corrosion resistance tests were carried out by the computerized Atlas'99 electrochemical analysis system using the potentiodynamic method. The cathodic and anodic polarization curves were acquired by polarizing the tested specimens at 0.2 mV/s (within the area of ±200 mV from the corrosion potential) and 0.4 mV/s (within the area of higher potentials). 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 Fig. 4.

After laser treatment of C45 carbon steel a martensitic structure was obtained, which has a higher resistance to corrosion as compared to the ferritic-pearlitic structure. LBP improved the corrosion resistance of ESD coatings by about 21% due to the sealing effect. As a result of laser processing a decrease in the corrosion current density, from 11.6 to 9.2 μA/cm^2, and increase in the corrosion potential, from -595 mV to -585 mV, were observed.

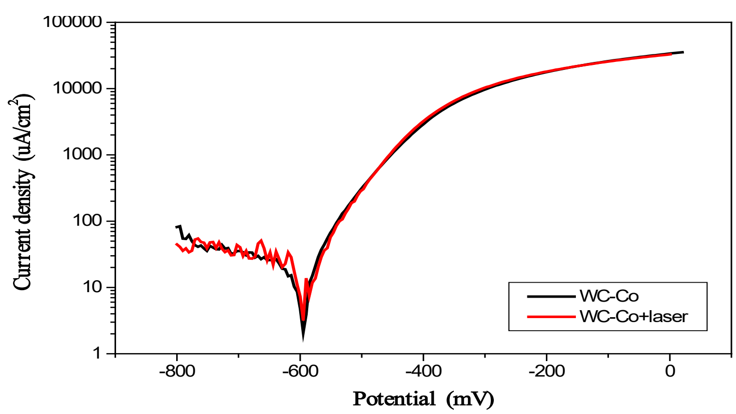

Fig. 4. *P*olarization curves of *WC-Co coatings in* as-deposited and laser treated *condition.*

Summary

1. The process of creating technological surface layers by the ESD method is associated with the transfer of mass and energy and the phenomenon of the formation of low-temperature plasma.
2. The laser beam can effectively modify ESD coatings and their functional properties.
3. Laser irradiation of coatings resulted in the healing of micro-cracks and pores.
4. The roughness of the ESD WC-Co coatings are more than tripled by the laser treatment.
5. The laser processed of electro-spark WC-Co coatings show improved resistance to corrosion (by ~21%) and slightly decreased microhardness (of ~6%).
6. The obtained results may of interests for industry branches using responsible parts of devices e.g. turbines [11], superheaters [12] or military equipment [13, 14].

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