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HETEROGENOUS SURFACES FORMED BY HIGH ENERGY TECHNIQUES

POWIERZCHNIE NIEJEDNORODNE KSZTAŁTOWANE TECHNOLOGIAMI WYSOKOENERGETYCZNYMI

A b s t r a c t

The paper concerns testing Cu−Mo coatings deposited over carbon steel C45, which were then eroded with a laser beam. The analysis involved the measurement of macrogeometry and microhardness of selected areas after laser treatment. The coatings were deposited by means of an ELFA-541 device and they were laser treated with a Nd:YAG laser, the parameters being variable.

Keywords: electro-spark deposition, laser treatment, coating

S t r e s z c z e n i e

W artykule przedstawiono wyniki badań powłok Cu−Mo nałożonych na stal węglową C45, które zostały poddane procesowi erodowania wiązką laserową. Wykonano pomiary makrogeometrii i mikrotwardości na wybranych obszarach po obróbce laserowej. Powłoki nanoszono za pomocą urządzenia ELFA-541, które zostały poddawane obróbce laserem Nd:YAG przy różnych parametrach.

Słowa kluczowe: obróbka elektroiskrowa, obróbka laserowa, powłoka

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1. Introduction

During tribological investigations it was found that employed heterogeneous surfaces models into boundary interaction of solid surfaces make significant improvement [1–4]. Surfaces described as heterogeneous consist of areas which differ one from another in geometrical, physicomechanical or physicochemical properties. The heterogeneity of surfaces is frequently due to application of more than one technology, and can be constituted by:

– shaped surface features such as grooves, pits or channels resulting from milling, eroding, etching, laser-beam forming, etc.;
– areas with different physicochemical and physicomechanical properties, e.g. areas with diversified hardness and mechanical strength accomplished by local surfacing or selective surface hardening (e.g. electron-beam machining, laser-beam forming or thermochemical treatment);
– areas with diversified surface microgeometry, e.g. areas eroded at the points of focus (laser treatment or electro-spark deposition), or areas with formed surface microgeometry, for instance, in terms of desired microroughness directivity or load capacity (laser and ESD technologies).

Heterogeneous surfaces can be measured by different methods [5], the laser treatment of electro-spark deposited coatings being one of them [6]. Electro-Spark Deposition (ESD) is one of the methods that require concentrated energy flux. The method which developed into a number of varieties allows us not only to produce coatings but also modify their surface microgeometry [7, 8]. Steels with different properties are an alternative to the use of ESD technologies [9].

The electro-spark deposition coating is characterized by a non etching structure. It remains white after etching. The surface layer is constituted in the environment of local high temperature and high pressure. It has been suggested that ESD coating quality can be improved by applying laser technologies. A laser beam used for surface smoothing, surface geometry formation and surface sealing is able to reduce surface roughness and change the profile form of the irregularities. For smoothing purposes, it is recommended that power density should be small and laser beam diameters big so that the melting process affects the coating at a small depth. The aim of laser concentration is to reduce coating porosity and dispose of scratches, cracks and delaminating, and, in consequence, to improve coating density. The predicted advantages of laser treatment of ESD coatings include: better smoothness, smaller porosity, better adhesion to substrate material, better resistance to wear and seizure, more compressive stresses resulting in better resistance to fatigue, better resistance to corrosion, shaping of surface.

2. Experimental

Two investigation stages were carried out. First of all, Cu-Mo coatings were electro-spark deposited on C45 steel coupons and after that they were modified by a Nd:YAG laser beam. The copper inside coatings is a fundamental material to the creation of low-friction surface layers. It is itself also a compensator of internal stresses. This material is characterized by good thermal conductivity, which can be very helpful in highly loaded contacts – heat can be taken away into material core from the friction zone. The other selected element was molybdenum as it significantly strengthens the surface content. Mo is also helpful in the creation of hard phase compounds, e.g.: MoC. In the practical meaning, this compound will improve durability of tools of kinematics pairs. The electro-spark deposition of Cu and Mo wires with a diameter of 1 mm was performed by means of an ELFA-541, a modernized device made by a Bulgarian manufacturer. The subsequent laser treatment was performed with the aid of a BLS 720 laser system employing a Nd:YAG type laser operating in the pulse mode.

The parameters of the electro-spark deposition established during the experiment include: current intensity $I = 16$ A (for Cu $I = 8$ A); table shift rate $V = 0.5$ mm/s; rotational speed of the head with electrode $n = 4200$ rev/min; number of coating passes $L = 2$ (for Cu $L = 1$); capacity of the condenser system C = 0.47 μF; pulse duration $T_i = 8$ μs; interpulse period $T_p = 32$ μs; frequency $f = 25$ kHz.

The main aim of the investigations was:
- observing the surface state by means of a stereoscopic microscope,
- analyzing the surface macrogeometry,
- measuring the microhardness with the Vickers method.

3. Results and discussion

The heterogeneous Cu–Mo coatings structure after electro-spark deposition on steel coupons and erosion by laser beam were investigated. The observation was done by an OLYMPUS SZ-STU2 stereoscopic microscope.

The erosion was performed with the point pulsed-laser technique by means of a Nd:YAG type laser under the following conditions:
- laser spot diameter, $d = 0.7$ mm,
- laser power, $P = 10$; 20; 30; 40; 50; 100 and 150 W,
- beam shift rate, $v = 1200$ mm/min,
- nozzle-sample distance, $h = 1$ mm,
- pulse duration, $t_i = 0.8$; 1.2; 1.48; 1.8; 5.5 and 8 ms,
- frequency, $f = 8$ Hz.

The investigations of the effects of the laser erosion involved measuring the diameters and depths of the cavities obtained at different laser powers. The results of the measurement performed with a PG-2/200 form surfer are presented in the form of graphs in Fig. 1 and 2. It was noticed that higher laser beam power gives a greater diameter and depth of the cavities. The cavity depth produced at 150 W is an exception. The value is smaller than the one obtained at 100 W (Fig. 1). This might have been due to a considerable pulse duration ($t_i = 8$ ms), the laser power being 150 W. However, if $P = 100$ W, the pulse duration t_i was 5.5 ms. In the case of lasers operating in the pulse mode, the power is averaged in time; thus, if pulse durations are long, the laser beam is less effective.

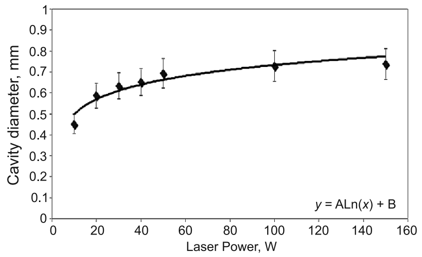

Fig. 1. Cavity diameter as a function of laser power

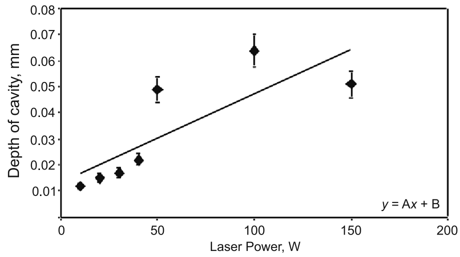

Fig. 2. Cavity depth as a function of laser power

A 3D macrogeometry of the developed heterogeneous surface eroded by the laser craters for the used specimens with A-A cross section built in 2-D crater is shown in Fig. 3a and 3b.

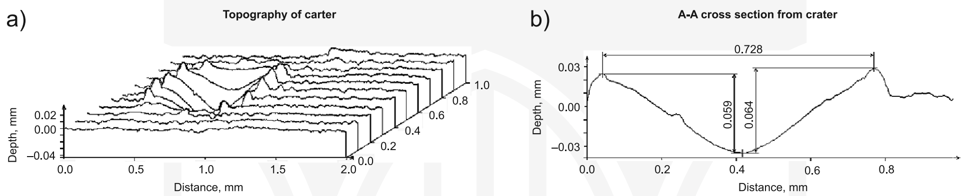

Fig. 3. Macrogeometry and cross section of a crater eroded by laser: a) 3D crater topography, b) A-A cross section on crater

As can be concluded from these graphs, crater edges are sharp and are protruding 0.03 mm above the average height, just treated by ESD surface, which is within the range of tolerances for the designed clearance fit. The average size of the crater shown on Fig. 1 produced by laser power of 100 W is about 0.7 mm in diameter and the total depth of about 0.06 mm. The crater is going below the so-called "ground zero level" by down to 0.030 mm. For instance, the crater displayed in Fig. 2, produced by laser power of 20 W, is about 0.05 mm in diameter and has a depth of 0.015 mm. The produced crater profile (picks and valleys) and also order of craters location, depending on the required or desired surface performance, could be controlled and adjusted to the acceptable level.

At the next stage, the Vickers microhardness test was conducted using a load of 0.98 N. The measurement was carried out on Cu-Mo coatings laser-eroded at 20 W. The distribution of microhardness is shown in Fig. 4.

It was established that there was an increase in microhardness at the points of laser machining, the increase being strictly related to the changes in the coating structure, and therefore, to the method of laser treatment. The surface hardening at the points of laser interaction and in the heat-affected zone (HAZ) follows the phase changes occurring in the material first heated and then immediately cooled. The average microhardness of the C45 steel substrate was 300 HV, while that of the ESD coatings amounted to about 430 HV. The laser treatment of the ESD coatings caused an increase in microhardness to approximately 850–880 HV. In the heat-affected zone, the microhardness fluctuated around 580–630 HV.

The laser beam surface forming resulted in changes in the microhardness of electro-spark deposited Cu-Mo coatings.

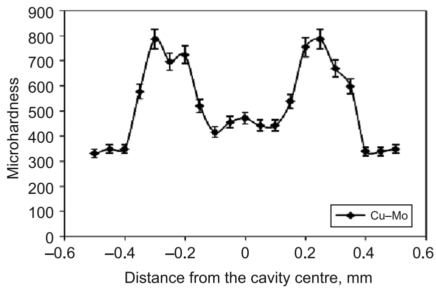

Fig. 4. Distribution of microhardness on the surface of a laser-treated Cu–Mo coating

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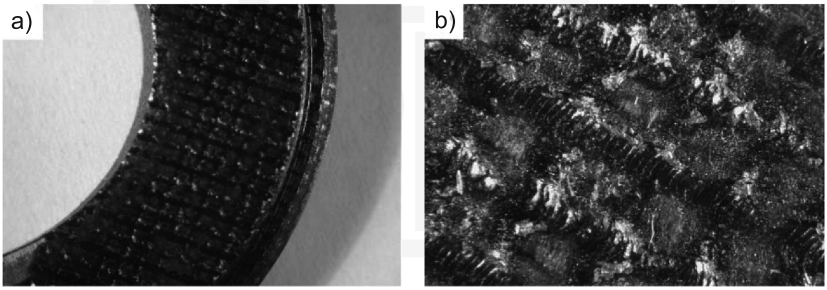

Fig. 5. Stereoscopic photographs of the laser-treated Cu-Mo surfaces: a) ×6 magnification, b) ×40 magnification

The next stage of the experiment involved analyzing the changes in the macrogeometry of Cu–Mo coatings. The laser treatment causing the formation of new surface geometry was performed with a Nd:YAG laser operating in the pulse mode, with the following process parameters: laser spot diameter, $d = 1.5$ mm, laser power, $P = 30$ W; beam shift rate, $v = 250$ mm/min, nozzle-sample distance, $h = 1$ mm, pulse duration, $t_i = 0.8$ ms, frequency, $f = 8$ Hz. Examples of the images obtained with a stereoscopic microscope for laser-treated Cu–Mo coatings are given in Fig. 5.

4. Summary

It is possible to diversify the surface of electro-spark deposited coatings, i.e. to obtain heterogeneous surfaces. The laser-affected areas are characterized by the occurrence of regular cavities, hardened areas and varied roughness.

Surface heterogeneity (i.e. the cavities) is desirable in sliding friction pairs. They may be used as reservoirs of lubricants as well as sources of hydrodynamic forces increasing the capacity of a sliding pair.

A concentrated laser beam can effectively modify the state of the surface layer, i.e. the functional properties of electro-spark coatings can be achieved.

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