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PRACTICAL USE OF THE SURFACE LAYERS OF LASER MODIFIED WC-Cu COATINGS

PRAKTYCZNE WYKORZYSTANIE WARSTW POWIERZCHNIOWYCH WC-Cu MODYFIKOWANYCH LASEROWO

Key words:

electro-spark deposition, laser processing, coating

Słowa kluczowe:

obróbka elektroiskrowa, obróbka laserowa, powłoka

Abstract

The article presentsthe study of the effectof laser treatmentonthe microhardnessof WC-Cu coatingsappliedbyelectro spark deposition. Observations offriction resistancetest results allowed the evaluation of the coatingsafterlaser treatment. The studies were conducted using WC-Cu electrodes, produced by sintering of nanostructural powders. The anti-

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wearcoatingswere electro spark deposited over C45 carbon steel by means ofEIL-8A, while the laser processingwas performedby electrocoats appliedusing a Nd:YAG, BLS720. Model tests were carried on test mechanical seals for rings made of SiC and WC- Cu coatings before and after laser treatment.

INTRODUCTION

Significant developments in the field of material technologies resulting from the need to enhance mechanical properties of the materials are pushing towards the search for new solutions in terms of protection against corrosion, the improvement of wear characteristics or the restoration of worn components to original dimensions. One of the solutions is electro spark alloying (ESA), the technology is also referred to as electro spark deposition (ESD) **[L. 1–6]**. 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 technology offers both an inexpensive and efficient method of metal component performance enhancement, being environmentally friendly at the same time. The use of these protective layers provides optimum resistance to corrosion, abrasive wear, and erosion, along with high fatigue strength.

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. 7–12]**.

MATERIALS AND METHODS FOR SURFACE LAYER PRODUCTION

The tests were performed on the WC-Cu (50%-50%) coatings produced on the normalized C45 grade steel specimens by electrospark deposition. The coatings were deposited in an argon atmosphere with the use of an EIL-8A pulse generator for triggering spark gaps, with manual electrode displacement. The following parameters were established in compliance with the manufacturer's guidelines and the previous experience of the authors: voltage U=230 V, capacitor volume C = 150 μF, current intensity I = 0.7 A, and deposition time $\tau = 2\ min/cm^2$.

The coatings were subjected to laser treatment at the Centre for Laser Technology of Metals. The laser used was a BLS 720 Nd:YAGlaser capable of generating 150 W maximum average power, operating in the pulse mode, manufactured by BAASEL LASERTECHNIK. The laser treatment was performed in ambient air atmosphere. The tests used a focusing head. The TEM_{00} beam defined the radiation energy distribution. The parameters used were as follows: spot diameter d = 0.7 mm, laser power P = 60W, specimen movement rate V = 250 mm/min, nozzle-workpiece distance Δl = 1 mm, pulse duration t_i = 0.4 ms, pulse repetition frequency f = 50 Hz, and beam shift jump 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 ϕ6.3 mm diameter ball made of 100Cr6 steel was the counter-specimen. The following friction parameters were used in the tests: linear velocity V = 0.8 m/s, time t = 3600s, and load change range Q = 4.9 N, 9.8 N, and 14.7 N.

The graph in **Fig. 1** compiles examples of the results and illustrates the changes in friction coefficient value as a function of time under the load of 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).

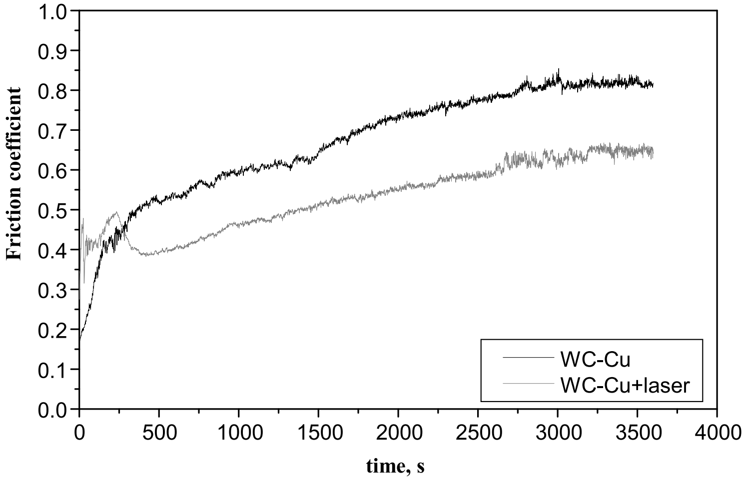

Fig. 1. Friction coefficient versus time: a) 50%WC-50%Cu coating, b) 50%WC-50%Cu coating + laser

Rys. 1. Wykres zmian współczynnika tarcia w funkcji czasu: a) powłoka 50%WC-50%Cu, b) powłoka 50%WC-50%Cu + laser

The graph of the untreated coating indicates that the friction coefficient stabilizes after about 3000 seconds with the value oscillating at the level of 0.80–0.82. In the case of the laser treated WC-Cu coating, the friction coefficient stabilizes after about 3200 seconds with the value oscillating at the level of 0.61–0.64. The mean friction coefficient is about 22% higher 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.

MICROHARDNESS TESTING

Microhardness testing was performed according to the Vickers method with a Microtech MX3 tester under a load of 40G. Penetrator indentations were made on metallographic sections in three zones: in the coating (white layer) and the melted zone of the coating (SPP), in the heat-affected zone (SWC), and in the base material (C45). **Figure 2** summarizes the microhardness test results.

Laser treatment slightly decreased the microhardness of the ESD coatings. Laser irradiation reduced the microhardness of the WC-Cu coatings by 9% relative to the untreated coatings. The minor microhardness reduction after the laser treatment may improve the plastic properties of the coatings, which is important for the tools or machine elements operating under large loads, for example, drilling equipment in the mining industry or press elements used for ceramic building material production. This effect may result from the dissolution of carbides.

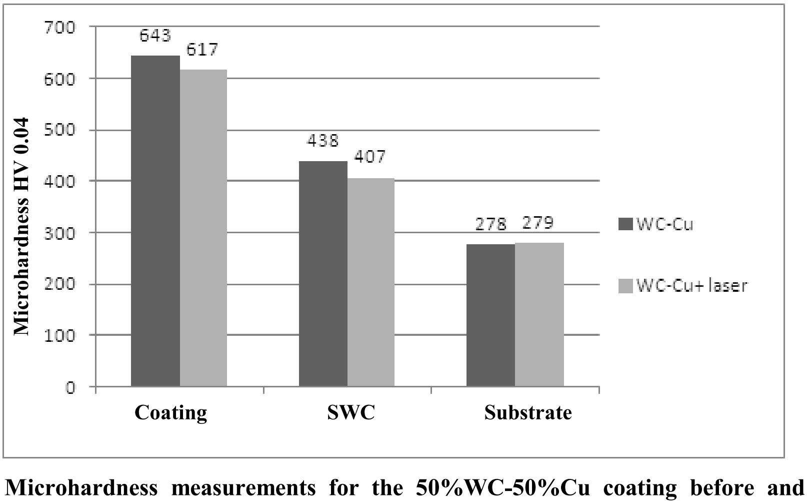

Fig. 2. Microhardness measurements for the 50%WC-50%Cu coating before and after laser treatment

Rys. 2. Pomiary mikrotwardości powłoki 50%WC-50%Cu przed i po obróbce laserowej

TESTS ON THE FACE SEAL SLIDE RING WITH AN ESD COATING

The slide ring of the face seal is specific because it can be treated as a universal model of a sliding pair **[L. 3, 4, 6]**. It operates under conditions similar to those of axial slide bearings (pressures from 1.5 to 2.0 MPa), similar sliding speed ranges from 0.1 to 100 m/s, film thickness from 10 to 15 μm, and a medium viscosity range from 0.01 to 0.015 [Pa s]. When seals are used, film thicknesses are noticeably lower (0.5 to 3.0 μm) and the medium viscosity range is considerably wider, from 0.0005 to 0.1 [Pa s].

The seals are used in all machines and devices in which there is a need of space separation. They are particularly important in rotating equipment where their required service life should not be shorter than that of the other machine components or should at least ensure correct operation of the sealing in the periods between the scheduled repairs.

Under normal operation, ring surfaces are in contact for a short time, which is only during the startup and rundown, which is why there is no need to manufacture the rings from costly materials. It is enough to focus on the resistance of their working surfaces to wear, for example, by strengthening or depositing wear resistant coatings.

TEST RIG

The test rig used **(Fig. 3)** was designed to test face-seal performance in terms of seal frictional resistance, leakage, and working temperature.

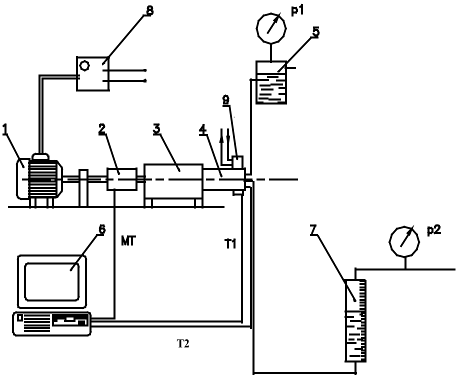

Fig. 3. Design of the test rig, schematically: 1 – motor, 2 – torque measuring shaft, 3 – spindle, 4 – test chamber, 5 – expansion tank, 6 – computer, 7 – leakage meter, 8 – power inverter, MT – frictional moment measurement path, T_1, T_2 – temperature measurement paths for the stationary ring and medium, p_1, p_2 – pressures on the inner and outer radius of the sealing ring

Rys. 3. Schemat stanowiska badawczego: 1 – silnik, 2 – momentomierz, 3 – wrzeciono, 4 – komora badawcza, 5 – zbiornik wyrównawczy, 6 – komputer, 7 – miernik wycieków, 8 – falownik, MT – tor pomiaru momentu tarcia, T_1, T_2 – tory pomiaru temperatury pierścienia stałego i medium, p_1, p_2 – ciśnienia odpowiednio na wewnętrznym i zewnętrznym promieniu pierścienia uszczelniającego

Leakage from the seals is measured with the volumetric leak test method to an accuracy of *1 ml*in a closed measuring system. Special software was developed to keep track of the test results (frictional resistance, temperatures $T_1$and T_2), record them in a form of data base files, and represent them as graphs of the measured quantities as functions of time. The accuracy of the frictional resistance measurements is a result of the class and measurement range of the MnI-20 torque-measuring shaft.

OBJECT OF STUDY

Modified type A1 seals manufactured by ANGA were used in the tests.

The tests involved replacing standard slide rings with those made with SiC and ESD WC-Cu coatings before and after laser treatment. The tests were performed on an unbalanced seal with a bellows. The elastomeric bellows prevents leakage on the secondary sealing.

Lapping and micromachining on a Minisupal lapping device provided adequate roughness and flatness of the ring sliding surfaces. An example of the profile is shown in **Fig. 4**.

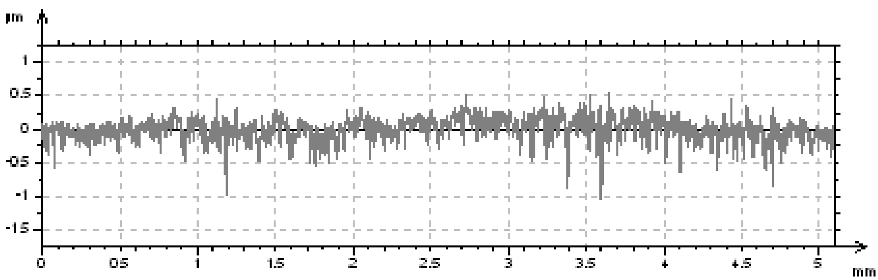

Fig. 4. Profile of a ring with a 50%WC-50%Cu coating after grinding and lapping
Rys. 4. Profil pierścienia z powłoką 50%WC-50%Cu po szlifowaniu i docieraniu

The surface micro-geometry was studied at the Laboratory for Geometric Quantities Measurements at the Kielce University of Technology. Three pairs of rings were prepared representing each option. **Tables 1** and **2** compile the averaged characteristics of the ring pairs.

Table 1. Microhardness results
Tabela 1. Wyniki pomiarów mikrotwardości

Coating	Before laser treatment		After laser treatment	
	Hardened layer	Transition layer	Hardened layer	Transition layer
50%WC-50%Cu	643 HV0.04	438 HV0.04	617 HV0.04	407 HV0.04

Table 2. Ring roughness results (Ra parameter)
Tabela 2. Wyniki pomiarów chropowatości pierścieni (parametr Ra)

Coating	Before laser treatment		After laser treatment	
	before grinding and lapping	after grinding and lapping	before grinding and lapping	after grinding and lapping
50%WC-50%Cu	2.16μm	0.12μm	2.87μm	0.19μm

EXPERIMENT DESCRIPTION AND RESULTS

Two cycles of tests were planned and performed:

- **Frictional resistance test** were performed with the use of a torque-measuring shaft, and initial testing involved evaluating frictional resistance for secondary seals. The measurements were performed three times for each set of materials and parameters. The resulting table shows the calculated and averaged values of the friction coefficient.
- **The leakage testing** procedure involved averaging the leak values from within three hours' measurement and converting the mean value into ml/min, and the technique used to eliminate the error resulting from liquid evaporation involved filling the space behind the seal with a liquid.

The testing programme assumed measuring frictional resistance and leakage depending on variable rotational speed and pressure. The following rotational speeds were used: n = 1500 rev/min, 3000 rev/min, and 4500 rev/min. The following pressure values were applied: p = 0.5 MPa, 1.0 MPa, and 1.5 MPa. This set of parameters allows defining the tendency of the measured parameters, i.e. Q and μ, to change from the pressure of the medium and rotational speed of the shaft. The test results are summarized in **Tables 3** and **4**.

The test results indicate that there is good cause to apply ESD coatings to the slide rings of face sealing. The values of the coefficient of friction and leakage were higher than were those measured in seals with rings made of SiC materials. The laser treatment of the coatings being studied did not bring a distinct improvement. Compared with the untreated specimens, the laser treated coatings had higher frictional coefficients within the range of low speeds. As for the entire range of the tests, reduced leakage was observed in the specimens after laser treatment, but this relationship was not systematic.

For all these reasons, this means of surface preparation can be proposed for the seals operating under fluid friction, for example, impulse seals or surface textured seals. This solution will provide satisfactory service life and high resistance to thermal and mechanical shocks.

Table 3. Summary of the results of frictional resistance and leakage for the rings without laser treatment

Tabela 3. Zestawienie wyników badań oporów tarcia i wycieków dla pierścieni bez obróbki laserowej

Series	Material	p [MPa]	n [rev/min]	Q [ml/min]	ΔQ [ml/min]	μ [-]	Δμ [-]
1	WC-Cu	0.5	1500	8	0.5	0.14	0.03
2	WC-Cu	0.5	3000	8	0.5	0.13	0.03
3	WC-Cu	0.5	4500	8.5	0.5	0.11	0.03
4	WC-Cu	1	1500	9.2	1	0.16	0.03
5	WC-Cu	1	3000	10	1	0.14	0.03
6	WC-Cu	1	4500	9	1	0.11	0.03
7	WC-Cu	1.5	1500	10	3	0.16	0.05
8	WC-Cu	1.5	3000	10	3	0.12	0.05
9	WC-Cu	1.5	4500	15	3	0.1	0.05
19	SiC	0.5	1500	4	0.5	0.08	0.03
20	SiC	0.5	3000	4	0.5	0.06	0.03
21	SiC	0.5	4500	5	0.5	0.05	0.03
22	SiC	1	1500	6	1	0.1	0.03
23	SiC	1	3000	8	1	0.08	0.03
24	SiC	1	4500	10	1	0.08	0.03
25	SiC	1.5	1500	8	3	0.11	0.05
26	SiC	1.5	3000	9	3	0.09	0.05
27	SiC	1.5	4500	15	3	0.07	0.05

Table 4. Summary of the results of frictional resistance and leakage for the rings after laser treatment

Tabela 4. Zestawienie wyników badań oporów tarcia i wycieków dla pierścieni po obróbce laserowej

Series	Material	p [MPa]	n [rev/min]	Q [ml/min]	ΔQ [ml/min]	μ [-]	Δμ [-]
1	WC-Cu	0.5	1500	8	0.5	0.18	0.03
2	WC-Cu	0.5	3000	8	0.5	0.14	0.03
3	WC-Cu	0.5	4500	12	0.5	0.10	0.03
4	WC-Cu	1	1500	9	1	0.20	0.03
5	WC-Cu	1	3000	9	1	0.14	0.03
6	WC-Cu	1	4500	9	1	0.11	0.03
7	WC-Cu	1.5	1500	13	3	0.19	0.05
8	WC-Cu	1.5	3000	17	3	0.11	0.05
9	WC-Cu	1.5	4500	24	3	0.09	0.05
19	SiC	0.5	1500	4	0.5	0.08	0.03
20	SiC	0.5	3000	4	0.5	0.06	0.03
21	SiC	0.5	4500	5	0.5	0.05	0.03
22	SiC	1	1500	6	1	0.1	0.03
23	SiC	1	3000	8	1	0.08	0.03
24	SiC	1	4500	10	1	0.08	0.03
25	SiC	1.5	1500	8	3	0.11	0.05
26	SiC	1.5	3000	9	3	0.09	0.05
27	SiC	1.5	4500	15	3	0.07	0.05

CONCLUSIONS

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

- A focused laser beam can be used to effectively modify the electrospark deposited WC-Cu and SiC coatings and improve their performance.
- The application of electrospark deposited WC-Cu coatings enhanced performance, microhardness in particular.
- Laser modification reduced the coefficient of friction under various loads and increased the resistance to seizure.
- The tests performed on the face seal test rig for the rings with laser treated and untreated WC-Cu coatings showed higher coefficients of friction and leakage than those in the seals with rings made of SiC materials. The laser treated rings showed a reduced leakage tendency.

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Streszczenie

Artykuł przedstawia badania wpływu obróbki laserowej na mikrotwardość obrabianych powłok WC-Cu nanoszonych metodą elektroiskrową. Na podstawie obserwacji badań oporów tarcia dokonano oceny właściwości powłok po obróbce laserowej. Docelowe badania przeprowadzono, wykorzystując elektrody WC-Cu, które wytworzono poprzez spiekanie nanostrukturalnych proszków metodą metalurgii proszków. Przeciwzużyciowe powłoki zostały naniesione elektroiskrowo na próbki ze stali C45 przy pomocy urządzenia produkcji ukraińskiej, model EIL-8A, natomiast obróbkę laserową nałożonych powłok elektroiskrowych wykonano laserem Nd:YAG, model BLS 720. Przeprowadzone zostały także badania modelowe na stanowisku do badań uszczelnień czołowych dla pierścieni wykonanych z SiC oraz powłok WC-Cu przed i po obróbce laserowej.