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INVESTIGATION OF THE PROPERTIES OF NON-TUNGSTEN ELECTRO-SPARK COATINGS ON HIGH SPEED STEEL

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Abstract: In this work contactless local electro spark deposition (LESD), has been used to received wear resistant coatings from hard alloys based of TiC, TiN, TiCN onto high speed steel HS6–5–2. The influence of the operating electric parameters and the electrode materials on the roughness, thickness, microhardness, phase composition, and on the structure of resulting coatings was studied. The impact of different electrode materials on the quality characteristics, the composition and structure of the resulting coatings has been found. The technological parameters of the LESD process for the formation of coatings with a predefined roughness, thickness, composition and structure has been determined.

Keywords: coatings, electrode materials, microhardness, phase composition.

1. INTRODUCTION

The creation of new protective and highly wear resistance coatings from new composite materials and the development of economical, resource-saving technologies for their application is the latest scientific trend in modern tribology and materials science. Electrical spark deposition is one of the simple, cheap, universal and effective tribotechnologies decisions for locally deposition of single and multilayer wear-resistant coatings on the work surface of wearing parts and tools.

Contact-less local electro-spark deposition LESD, [1], is a variation of the classical electrical spark deposition with a vibrating electrode, wherein the coatings are applied by rotating cylindrical electrode at a controlled rate up to 1500 rpm. At the deposition of the coating work piece is moved with a controlled rate of axes X and Y. Automatic regulator of inter-electrode distance maintains the necessary gap in which the spark discharges run and it ensures high stability of the process. This method allows mechanization, automation, increasing productivity of the process and of quality of the coatings [1–4]. The resulting coatings are of high density, uniformity, repeatability of the quality characteristics and low roughness, which in most cases does not require further processing. This ensures of LESD certain advantages that give him priority over the vibration methods for stratification of all tools and parts with high requirements on the quality of the work surface, for example, obtaining of thin, dense and smooth coatings on the cutting edges of tools and dies [3–6].

For the electrodes in the LESD mainly hard alloys based on WC–K10, K20, P10, P25 are used [5, 7–9], which in many cases limits the obtaining of the desired effect of the applied coatings. In this respect, the hard-alloy electrodes based of TiC, TiN, TiCN are also of interest.

The objectives of the present work is to compare and evaluate the quality characteristics, structure and the phase composition of the coatings from non-tungsten hard alloys and to determine the LESD processes parameters for obtaining such coatings with increased properties compared to the existing ones.

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2. METHODOLOGY

2.1. Materials and Methods

2.1.1. Apparatus for LESD

Deposition is performed on machine type "Elfa 541" [2] with single pulse energy up to 0.03 J. The application of the coatings is carried out with cylindrical rotating electrode with a diameter of 1÷1.5 mm. The performance of the deposition is 0.5÷0.6 mm/s.

During the experiments the following adjustable parameters of the regime for LESD were used:

– Pulse current amplitude – I = 8–16 A;
– System voltage /Circuit voltage/ – U = 90 V;
– Pulse duration – Ti = 3, 5, 8, 12, 20 μs;
– Capacity – C = 0.2, 0.5, 0.7, 1 μF;
– Coefficient of filling of the pulses – τ = 0.1and 0.2, τ = Ti/T, where T = Ti + Tp is the period of the pulse, and Tp – pause between the pulses; 1/T = f – frequency of the pulses;
– Number of passages of the electrode – n = 2.

2.1.2. Electrode materials

The present work uses non-tungsten hard alloys with soldering metals Ni, Cr, Mo and various technological additives such as Cu, Al_2O_3, B, etc., with the following designations and composition:

TNM10 – TiC + 10% Ni+Mo;
TN10 – TiN + 10% Ni+Cr;
KNT16 – TiCN + 16% Ni+Mo;
TNM20 – TiC + 20% Ni + Mo;
TC – TiC + 14% Ni, Mo, + 1% Cu, B, Al_2O_3;
TN – TiN + 14% Ni,Cr,+ 1% Cu,B, Al_2O_3;
TC–TN – TiC+TiN + 12% Ni, Mo + 1% Cu, B, Al_2O_3.
WC – WC+6% Co
TiC – TiC + 2% technological additives

Layering electrodes with a diameter of 1–1.5 mm are obtained by electrically discharge cutting from monolithic plates, prepared by the methods of powder metallurgy.

2.1.3. Substrate

For substrate model plates of steel HS6–5–2 (1.3343) –(6% W, 5% Mo, 4.2% Cr, 1.8% V, 0.9% C) with hardness HRC 61–63 are used – with size 10×10×3 mm, and polished to a roughness Ra=0.63μm.

2.2. Methods of measurements

The surface roughness Ra, μm and thickness δ, μm of the resulting coatings by using profilometer – "Pertometer S5P" (Germany) are measured.

The microstructure and microhardness HV of the coatings on cross-sectional and micro-hardness tests under indentation load of 5 and 10g by optical metallographic microscopes "Neophot 2" and "Metaval" (Germany) have been studied.

Phase identification of the coatings along with the interface region with the X-ray diffractometer "Drone–2" – (Russia) in cobalt "Kά" and copper radiation tube were performed.

3. RESULTS AND DISCUSSION

3.1. Coating characterization – Roughness Ra and thickness δ of coatings

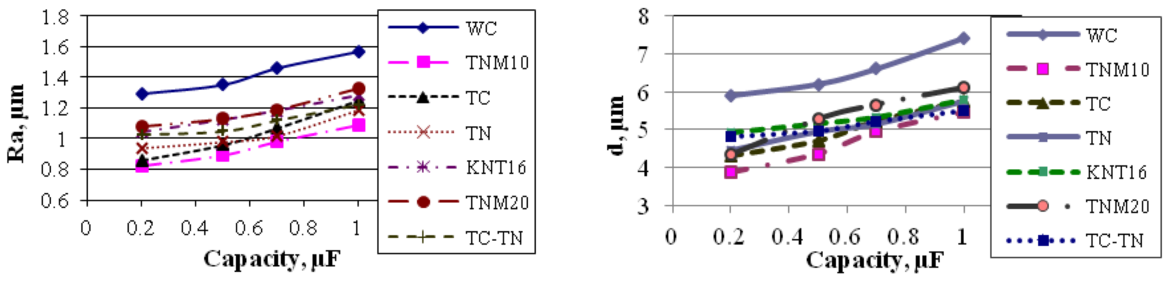
The results of the study showed that the surface layers are dense and smooth; there are no pores and cracks without shells. The minimum and maximum values (borders) of the thickness δ, of surface roughness Ra, and microhardness HV of coatings, obtained from the studied electrodes at the different used values of parameters of regimens for LESD is shown in Table1. From the data presented in the table it seen that the roughness values Ra are significantly lower than those obtained with the vibrating apparatus [7, 8], even with the use of nano-electrode materials [9], but the thickness δ is also lower. Moreover, the higher the content of soldering materials in the composition of the layering electrode, the higher are the values of roughness Ra and the thickness δ of the obtained coatings and micro-hardness slightly decreases.

Fig. 1a,b, displays the amendment on surface roughness Ra and the thickness δ of coatings, depending on capacity C. Similar dependences are obtained and of about the impact of the other electrical parameters of the regime of LESD – I and Ti.

Table1. The range of variation of values of roughness Ra, the thickness δ and microhardness HV of coatings.

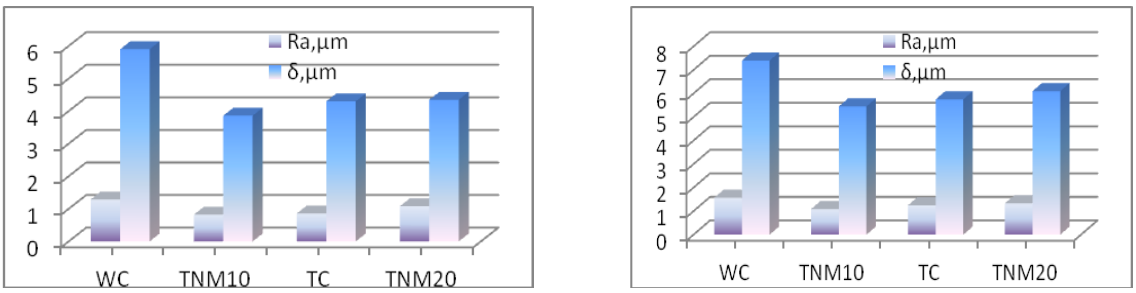
Electrode	Coating			
	Ra, μm	δ, μm	HV, GPa	Coeff. of hardening
WC+6% Co	0.95–1.6	4.5–8	13.6	1.58
TNM10	0.6–1.19	3.5–5.5	13.3	1.54
TC	0.7–1.3	4–6	13.0	1.51
TNM20	0.85–1.3	3–6.5	12.7	1.48
TN10	0.65–1.2	2,5–5	13.2	1.53
TN	0.63–1.25	2.5–5.5	13	1.51
KNT16	0.7–1.25	3.5–5.8	12.5	1.45
TiC–TiN	0.8–1.35	3.5–6	13.35	1.55
Substrate	0.63		8.6	1.0

The increase in current, capacity and duration of the pulses results in a monotonic increase in the roughness and thickness of the coatings, and there is a proportional relationship between Ra and δ, with increase in thickness grows and roughness and vice versa. The most significant influence on changes of roughness and thickness of the resulting coatings provide the capacity, followed by duration of pulses Ti, current amplitude I and τ.



a) Ra=f(C)   b) δ = f(C)

Figure 1. Amendment in surface roughness Ra and the thickness δ of coatings deposited from investigated electrodes on high speed steel in function of the capacity C. I = 14.4 A, Ti = 12 μs, U = 90 V, τ = 0.1, V = 0.6 mm/s, n = 2 passes of the electrode.



a) LESD at capacity 0.2 μF   b) LESD at capacity 1 μF

Figure 2. Roughness and thickness of coatings from TiC based electrodes with at varying amounts of bonding metals – LESD Process parameters: I = 14.4 A, Ti = 12 μs, τ = 0.1, n=2 passes of the electrode

From the results obtained it is found that the specific values of the roughness and the thickness of the coatings under the same other conditions are different for the different electrodes – Figures 1 and 2. The lowest values of Ra and δ are obtained for the coatings deposited with the electrodes TNM10 and TN10, and the highest – at LESD with electrode TNM20, respectively, we can expect that they have the greatest coefficients of friction. It is obvious that the increase in the quantity of solder metals in the composition of the electrode materials leads to an increase of Ra and δ – Fig. 2. The lower values of Ra and δ of obtained coatings than those obtained from tungsten electrodes, are due to the lower erosion resistance of TiC, TiN and TiCN, and to the higher degree of brittle destruction of these carbides under the action of spark discharges. [5,6,7,8]. Lowering the fraction of fragile destruction of these carbides is possible by introducing of plastic additives in the composition of the electrode materials which help reduce the consumption of anode material and increase cathode growth. As can be seen from Fig. 3, the dependence of the consumption of anode material ΔA on the amount of solder metals passes through a minimum. Based on these results for the current studies, the amount of the solder metals in the composition of the TiC based electrodes was chosen be in the field of the minimum – 10, 15 and 20%.

3.2. Structure and Micro-Hardness of Coatings

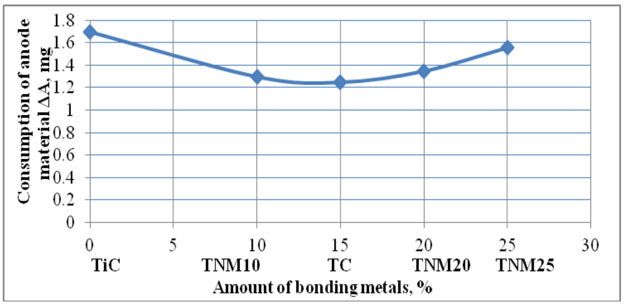
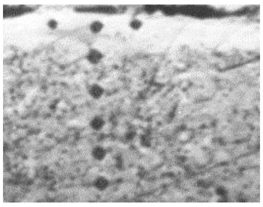
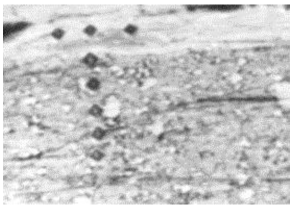


Figure 3. Dependence of the consumption of anode material ΔA on the amount of bonding metals.

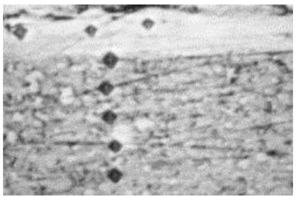
The structure of the surface layer – Fig. 4 obtained with different electrodes under different modes is not significantly different. The structure consists of an upper-white layer and a substrate material. Sublayer and transient heat affected zone, characteristic for vibrational methods [5, 7–9] at LESD are not registered.



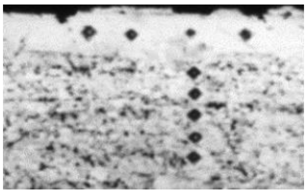
a) Electrode TNM10
δ = 5 μm



b) Electrode TN
δ = 5.3 μm



c) Electrode TC–TN
δ = 5.6 μm



d) Electrode TNM20
δ = 6.4 μm

Figure 4. Cross-sectional micrograph of the LESD coatings at LESD process parameters: I = 14.4 A, C = 1 μF, Ti = 12 μs, τ = 0.1, n = 2 passes.

The micro-hardness of the coatings varies in too broad a range, but hers average values for studied electrodes are similar. There is not established a clear dependence of HV on the LESD process parameters, but there is a tendency to increase with an increase in pulse energy. It is noticeable that it is lower than the micro-hardness of the coatings applied with WC–Co electrodes [10], but the differences are insignificant.

At coatings from TiC, TiN, THM20, and KNT16 electrodes, the HV values are slightly lower than those obtained with an electrode TNM10 which is probably due to the higher content of soldering metals in the composition of these electrodes.

a) Deposited with KNT16 electrode;
Scratch width = 123 μm

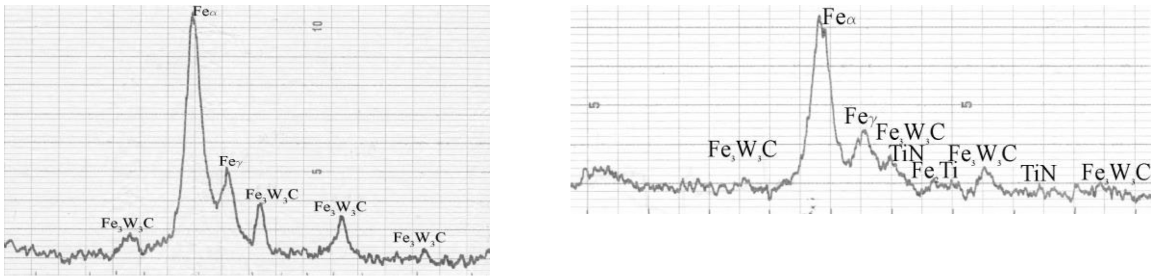
b) Deposited with TN10 electrode;
Scratch width =136 μm

Figure 5. Track from scratch to measure adhesion with the substrate of coatings deposited at regime: I = 14.4 A, C = 1 μF, Ti = 12 μs, τ = 0.1, n = 1 pass , δ = 4.3 μm.

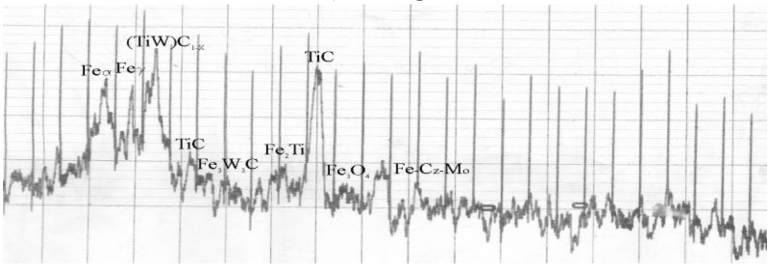
However, the increase in the quantity of the binding materials increases the range of possible regimes, where dense and even coatings are obtained. On the other hand, the increased amount of the binding materials contributes to better adhesion of the coating to the substrate, as seen in Fig. 5. At the same time, however, the increase in the quantity of the binding materials leads to higher values of the roughness and thickness of the coatings – Table 1.

3.3. Phase composition of coatings

Fig. 6 shows fragments of the X-ray diffraction patterns of coatings deposited with TC and TN electrodes. X-ray diffraction patterns differ in the intensity and width of the characteristic lines of austenite and carbides (carbonitrides and nitrides). The main phases in the composition of the coatings are given in Table 3. They are arranged sequentially in the intensity of the characteristic lines. The type and number of the phases is determined by the type of anode and cathode materials, and the ratios between them – by the energy for the processing.



a) high speed steel HS6–5–2 – Co–Kα radiation. b) coating from TN electrode I = 14,4 A, C = 1 μF,Ti = 12 μs.



c) Coating from TiC based electrode – I = 14.4 A, C = 0.68 μF, Ti = 8 μs – Cu radiation.

Figure 6. Patterns of XRD spectra of the LESD coatings of TiN and TiC electrodes on steel HS6–5–2.

Table3. Phase composition of coatings.

Electrode	Phase composition of coated steel HS6–5–2
WC	Feα, Feγ, W_2C, Fe_3W_3C, Co_3W_3C, Fe_2O_3, Fe_3O_4.
TC	Feα, Feγ, Fe_3W_3C, TiC_{1-x}, $(TiW)C_{1-x}$, $TiCN_{1-x}$, Fe–Cr–Mo, Fe_2Ti, Fe_2O_3, Fe_3O_4.
TN	Feα, Feγ, Fe_3W_3C, TiN, Fe_2O_3, $TiCN_{1-x}$, Fe_2Ti.
KNT16	Feα, Feγ, W_2C, Fe_3W_3C, TiN–TiCN, Fe_2Ti, Fe_2O_3,Fe_3O_4.
TiC–TiN	Feα, Feγ, W_2C, Fe_3W_3C, TiN_{1-x}, TiCN, TiC_{1-x}, $(TiW)C_{1-x}$, Fe_2Ti, Fe_2O_3, Fe_3O_4.
Substrate	Feα, Feγ, Fe_3W_3C.

The results of X-ray analysis showed that at LESD with the studied electrodes in the coating composition the main phases are: α–Fe, γ–Fe, Fe_3W_3C and TiC_{1-x}, TiN_{1-x}, $Ti(CN)_{1-x}$. Traces of

$(TiW)C_{1-x}$ Cr_2N, Fe_2N, Fe_2O_3, and Fe_2Ti are observed. The amount of the iron-tungsten carbide is less than those obtained at WC–Co coatings [10] and is comparable to that of the substrate. The extension of the structural peaks of γ–Fe and α–Fe – and their displacement is less pronounced than those obtained with electrodes WC–Co, i.e. the presence of amorphous structures in the coatings is also lower. The comparison of the phase composition of the coatings obtained with the investigated electrodes indicates that the resulting with electrode TiC–TiN layers are richer in carbides, nitrides and carbonitrides, which also explains its higher single measured values of microhardness of the coatings obtained with the others electrodes.In the case of LESD with machines "Elfa", the obtained structure is analogous to the sublayer obtained by the vibration methods, but the latter often form defects and a relatively non-uniform thickness of the formed layer [5, 8, 9].

With the increase of energy for LESD increases the amount of transferred material accordingly increases the amount of carbides in the layer, increases the degree of dispersion and the degree of alloying of austenite with elements of the anode and the environment. In the regimes with the maximum energy for the "Elfa" machines, there is a decrease in the intensity and extension of the structural maximums of the characteristic lines of the phases, which can be taken as an indicator of the presence of solid solutions of the anode materials in the gamma iron and of increasing the dispersibility to the appearance of a structure close to the amorphous. At $I > 12.8$ A, $Ti > 8$ μs, and $C > 0.68$ μF for all examined electrodes, coatings with the highest content of carbides, degree of saturation of solid solutions, and the largest share of unstructured state are obtained.

Targeted use of different electrodes and regimes of contactless LESD allows for the realization of different processes on the surface layer in depending of the operating conditions and the function of the product and for the modification of the properties of materials within certain limits.

CONCLUSIONS

The increase in energy leads to an increase in roughness, thickness and microhardness of coatings and the amount of carbides obtained in the layer. The use a low energy and a low durability of pulses lead to obtain fine-grained and uniform coatings in comparison with the vibration methods.

It has been found the impact of different electrode materials on the quality characteristics, the composition and structure of the resulting coatings. The roughness and thickness of the resulting from hard alloys based on TiC and TiN are not significantly different and are lower than those obtained with WC–Co electrodes. The most promising in terms of the properties of the coatings are the TiC–TiN electrodes.

The technological parameters of the LESD process for the formation of coatings with a predefined roughness, thickness, composition and structure has been determined.

The results obtained in this paper show that the non-tungsten carbide electrodes can be effectively used for LESD of high-speed steels. Their improved quality compared to tungsten carbide-based electrodes coatings consists in increasing the continuity of coatings and forming a lightweight coating with lower roughness.

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