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WEAR RESISTANCE OF MULTI-COMPONENT COMPOSITE COATINGS APPLIED BY CONCENTRATING ENERGY FLOWS

M. KANDEVA[1,3*], T. PENYASHKI[2], G. KOSTADINOV[2], M. NIKOLOVA[4], T. GROZDANOVA[1]

[1]Faculty of Industrial Technology, Technical University, Sofia, Bulgaria
[2]Institute of Soil Science Agrotechnologies and Plant Protection "N. Pushkarov", Sofia, Bulgaria
[3] South Ural State University, Chelyabinsk, Russia
[4] University of Ruse "A. Kanchev", Russe, Bulgaria
*Corresponding author: e-mail: kandevam@gmail.com

Abstract: *In this work are presented the results of comparative tests of the abrasion wear characteristics and the wear resistance of new coatings from multi-component composite materials. The main objective of the study is to reveal the mechanisms of wear and optimization of the composition of multi-component materials to obtain high wear resistant coatings under conditions of abrasion and erosion. The coatings are applied by electrical spark deposition and gas-fuel spraying on carbon steel substrates. Composite mixtures of Cr-Ni-Co-B-Si-C, reinforced with micro-sized particles of boron and tungsten carbides, and titanium diboride in varying proportions are used for layering. Results were obtained for the influence of microgeometric parameters, the composition and microstructure of coatings on their wear resistance and on the characteristics of the wear at different loads under dry abrasive friction. It has been found that the resulting coatings have a 20-50% higher wear resistance than the conventional materials used. The compositions of layering materials and the process parameters of the two methods have been determined, at which maximum wear resistance of the coated samples is obtained.*

Keywords: *tribology, coatings, composite materials, carbides, abrasion wear, structure, wear resistance*

1. INTRODUCTION

One of the most promising directions for enhancing the reliability and durability of equipment and technique is the modification of the working surfaces of the rapidly wearing parts and products and the creation of surface layers with high mechanical and tribo-technical characteristics. The diversity and complexity of the processes and operating conditions and friction in which wear takes place have led to the creation of numerous methods and means of coatings, on the basis of which various apparatus and equipment were developed [1,2,3]. Each of these methods has certain drawbacks and advantages that make it more or less suitable for the various specific uses.

Gas Flame Spraying (GFS) [4,5,6,7,8] and Electrical spark deposition (ESD) [9-12] are of the most versatile, lightweight and affordable methods for applying wear-resistant coatings. Both methods are realized by converting the layering material into molten particles, which are applied at high speed to the surface of the coated article and bonded thereto. The coatings applied by these methods have lower characteristics and properties as compared for example with the Physical and Chemical vapor deposition - PVD or CVD methods, but the latter require significant investments in expensive equipment and technologies and specially trained operators. ESD and GFS are simple, environmentally friendly methods with simple, affordable and portable equipment easy technology that does not require pre-treatment and are universal - they allow the local application of coatings from any and on any all conductive materials, and GFS - and on non-conducting - wood, plastics and others.

Because of their simplicity and universality versatility, ESD and GFS are not only more widespread but also significantly cheaper and fully accessible to most consumers.

One of the main problems of gas thermal spray coatings is their porosity, lack of homogeneity on account of poor agglomeration of powder particles, high roughness of surface and low adhesion to substrate. These result in insufficient corrosion and wear resistance of such coatings [4,5,7,9]. Increasing the efficiency of the GFS and ESD coatings is related to the development of new materials and technologies to increase adhesion, uniformity and wear-resistance of coatings, as well as the hardness of the contact surfaces. In this connection, the aim of the present work is to develop new materials for GFS and ESD coatings, to study of the nature and the regularities of the wear of coatings obtained with these materials and to optimize of the materials composition and of the processes parameters for obtaining new coatings with increased wear resistance and triboefficiency.

2. EXPERIMENTAL. MATERIALS AND METHODS

2.1. Apparatus for applying coatings

GFS is carried out using a Super Jet-S-Eutalloy oxy-acetylene thermal spray torch which provides very precise anti-wear protective coatings thanks to its sensitive controls- Fig. 1 [6].

Figure 1. Device for manual gas fuel deposition (Reproduced by permission of Castolin Eutectic [6]

Parameters of application modes: Combustion gases: Acetylene, Oxygen
Fuel / Oxygen ratio (/ O_2),% - 45-55
Pressure of O_2 -4 bars
Acetylene pressure - 0.7 bar
Spray distance, mm – ≈ 20-30 mm
Angle of impact, degree - 90;
Powder flow rate, g / min - 20-25
Preheating –to 300-350 degrees C^0
Flame temperature: ≈3000 °C

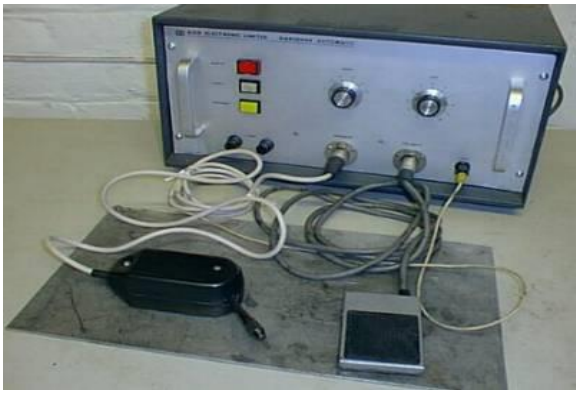


Figure 2. Device for Manual electrical discharge deposition with vibrating electrode “Harddege” - England, USA

The ESD is performed by a hand-held apparatus with vibrating movement of the electrode “Hardedge” (Fig.2) with the following parameters: Short circuit current - 0.2÷2A, Voltage - 80V, Capacity -5-100μF, oscillation frequency of the vibrator - 100 Hz. The individual layering modes are numbered from 1 to 6 in order of increase of pulse energy. In this work were used regimes with single pulse energy $E_i=C.U^2/2=0.03\div0.3J$. The individual layering modes are numbered from 1 to 6 in the order of increase of pulse energy given in Table 1.

Table 1. Regimes for ESD whit vibrating electrode

№ of regimes	Single pulse energy, J
1	$E_1 \approx 0.02$
2	$E_2 \approx 0.03$
3	$E_3 \approx 0.05$
4	$E_4 \approx 0.06$
5	$E_5 \approx 0.16$
6	$E_6 \approx 0.3$

2.2. Materials and Methods

Substrate.

Model plates of carbon steel with 0,45%C - (45) with hardness 190-210HB, and of steel 210Cr12 heat treated to a hardness of HRC 59–61 with sizes 10×10×4 mm and polished to a roughness *Ra*=0.63µm are used for substrate. The chemical composition of these steels is given in Table 2.

Table 2. Chemical composition of substrate plates.

Element,%	Steel 210Cr12	steel 45
C	1.9-2.2	0.42-0.5
Cr	11-12	Up to 0.25
Si	0.1-0.4	0,17-0,37
Mn	0.15- 0.45	0,5-0,8
Ni	up to 0.35	up to 0.25
Mo	up to 0.2	-
W	up to 0.2	-
Ti	up to 0.03	-
Cu	up to 0.3	up to 0.25
V	up to 0.15	-
P	up to 0.03	up to 0.04
S	up to 0.03	up to 0.04

Table 3. Chemical composition of the bonding metal powder mixtures and of initial compositions whit addition of WC.

Designation/Element %	NW	KW
C	0.6	1.5
S	2.9	1.5
Cr	12	23
Fe	3.9	0.5
B	3.6	1.5
Ni	Balance	30
Co	-	42
∑ %	55	45
WC	45	55

Coating materials

Two types of metal powder compositions Ni-Cr-B-Si-Fe-C and Co-Cr-Ni-B-Si-C with trademarks NP60 [6] - based on Ni, and 10612[6] - based on Co as bonding phases of the powder compositions are defined and used. To these has been added tungsten carbide in the proportions and with the inscriptions NW and KW given in Table 3.

The introduction into the composition of the materials of the self-fluxing additives (B, Si, C, etc.) is one way to maximize the storage of the beneficial properties of the individual components of layering material in the coating [13-17]. The securing the necessary performance characteristics and adhesion of the surface layer in the present work is solved by the using of Co, Ni, Cr forming unlimited solutions in the iron [14-16,18,19]. According to the data for the mutual solubility of the metals and the compounds [14-16,18-20], taking into account the principles established for the selection of the bonding and wear-resistant components and using the wettability data of the difficult compounds and alloys, the following compositions of powder mixtures were having selected and formulated to provide the effective forming a wear-resistant layers on the steel surfaces:

(1)NWT10B10 - 80%NW+ 10%B_4C+10%TiB_2.

(2)NWW15T20- 65% NW +15% WK8 + 20% TiB_2. (WK8 is hard alloy with 92%WC and 8%Co).

(3)NWW15B10T20 - 55%NW +15%WK8 + 10%B_4C + 20%TiB_2;

(4)NWW10T10B10 - 70%NW+10%WK8 +10%B_4C + 10%TiB_2.

(5)NWW10T20B20 - 50% NW + 10% WK8+ 20% B_4C+ 20%TiB_2.

(6)NWT20B20 - 60% NW +20%B_4C+ 20%TiB_2.

(7)KWB10- 90% KW + 10%B_4C.

(8)KWT10B10-80%KW + 10%B_4C + 10%TiB_2.

The high hard components B_4C, TiB_2, and WC [9,10,14] are selected for to provide both high wear resistance, such and obtaining of new additional wear-resistant compounds and phases in the process of forming the coatings.

Boron carbide B_4C is a super hard material with extremely high wear resistance and abrasion resistance but is brittle. The introduction of the less fragile and rigid components titanium diboride - TiB_2 and tungsten carbide- WC eliminates this issue. It's very high hardness, wear resistance and chemical resistance distinguishes TiB_2.

By literature data compared with the carbide, the boride bonds are more difficult to decompose and is expected TiB_2 to be stored in the layer to a higher degree than of WC or TiC. TiB_2 and WC, in addition to abrasive wear, are also resistant to impact loads.

Carbide mixtures of WC + 8% Co - WK8 are added in order to increase the amount of WC and of Co in the composition of the powder compositions and of the electrodes. Composite materials of B_4C, TiB_2, and WC are selected for to provide both high wear resistance, such and obtaining of new additional wear-resistant compounds and phases in the process of forming the coatings.

Initially, base mixtures with designations "NW and KW" according (Table 2), were milled to a 45±5 µm and are homogenized. After this the wear-resistant compounds B_4C, WK8 and TiB_2 with grain size 20 ± 5 µm in respective weight ratios were added to base mixtures.

Laminating electrodes for ESD with a diameter of 1÷1.5mm are obtained by electrically discharge cutting from monolithic plates, prepared by the methods of powder metallurgy. Coatings of carbide composite electrode materials from 16%TiC +4.5 %(Ta, Nb) C +10.5%Co +WC, studied and developed earlier [21,22] with indications respectively P25 were used as reference for comparison with the resulting coatings from the new electrodes.

Appropriate ratios between the base phases NW and KW and the composition and amount of the wear-resistant phases in the powder compositions should be established based on the results obtained from the tribological tests.

Methodology of measurements.

- Balance WPS 180/C/2, which has 0.0001g sensitivity, was used to determine the mass loss of tested samples.
- The surface roughness Ra, µm and thickness B, µm of the resulting coatings are measured by using profilometer - AR-132B (China) and Pocket Leptoskop 2021 Fe (Germany). Density, uniformity and morphology of coatings were monitored by a VT-300 (Germany) digital microscope.
- The initial indicative determination of the surface hardness of the coatings was performed with hardometer Al 150A (Germany).
- The microstructure of the coatings has been studied by optical microscopy on cross-sectional sections by metallographic Optical microscopy (Epytip 2, Carl Zeiss Jena).
- The tribological properties and wear resistance of the coatings are investigated by comparative tests of friction with tribotester type "Thumb -disk" under dry surface friction with hard-fixed abrasive particles – Fig.3. The wear characteristics test method consists in measuring the mass wear m of the samples for a specific friction path L (friction cycles) under constant conditions - load P and glide speed V.

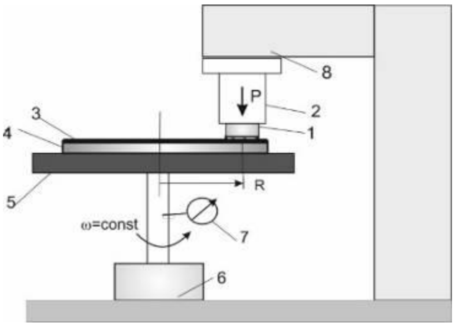


Figure 3. Tribotester type 'Thumb –disk'

Calculated are the following wear characteristics:

- *mass loss*, [mg]:

$$m=m_o - m_i \qquad (1)$$

- *wear rate,* [mg/min]:

$$\gamma = m/t \qquad (2)$$

- *wear intensity*, [mg/m]:

$$i_e = m/L \qquad (3)$$

- *wear resistance*, [m/mg]:

$$I=1/i_e = L/m \qquad (4)$$

Table 4 gives the experimental conditions for testing the wear of the test coatings.

Table 4. Parameters of the experiment in studying the wear of the tested GFS and ESD coatings

№	Parameter	Value (GFS)	Value (ESD)
1	Normal load	100 N	5N
2	Nominal contact area	2.25 cm^2	2.25 cm^2
3	Nominal contact pressure	44.4 N/cm^2	2.22 N/cm^2
4	Speed of rotation	95 min^{-1}	212 min^{-1}
5	Distance between the axis of rotation and the center of the contact site	80 mm	-
6	The friction path of the center of the contact site	238.64 m	42.68 m
7	Friction time	5 min	-
8	Sliding speed of the contact center site	0.8 m/s	0.8 m/s
9	Ambient temperature	20°C	21°C
10	Abrasive surface	Corund P 120	Corund P 320

3. RESULTS AND DISCUSSION

3.1 Coating characterization

Initially, in a wide range of values of technological parameters with each of the tested materials were applayed coatings on steel substrates. After visual comparative evaluation of the uniformity, density, roughness, grain size of porosity of the resulting coatings, for each test material were selected conditions suitable for deposition, in which hard are obtained dence, uniform and fine-grained coatings.

ESD Coatings

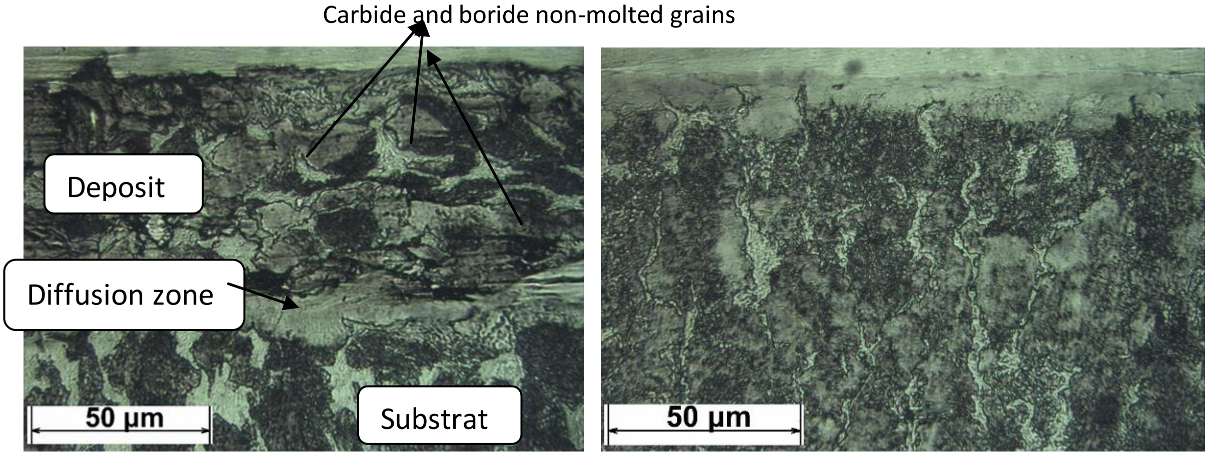
With the various materials used were obtained similar in structure and composition coatings, but with a different quality characteristics and properties. The results obtained show that at ESD with the multi-component carbide alloys the coatings have high density and uniformity and with acceptable for the practical use roughness, which in many cases do not require further processing. A transfer coefficient by 12-18% higher than that at ESD with the conventional hard alloys type P25 was achieved, and the mass gain of the cathode is up to 1.8 times higher than that of the electrodes based of tungsten carbide. 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 ESD is shown in Tables 5 and 6. The obtained results of vibration ESD show that the increase of the energy of the impulses (in the direction from mode 1 to mode 6 - Table 2) leads to an increasing in the thickness of the obtained coatings, but significantly increase and their roughness and unevenness. The maximum thickness at which is obtained a relatively uniform coating with surface roughness up to $Ra=3\div4\mu m$ is in the range of $45\div50\mu m$ at regime № 5 with pulse energy $E5 = 0.16J$. From the results obtained at ESD and onto the both steels it was found that at the NWW15T20 electrodes, the thickness of the coatings is higher. Moreover, the increase in the amount of bonding metals in the electrode composition allows us to create coatings with a greater thickness. The higher thickness of the coatings can be explained by the presence of bonding metals forming unlimited solid solution with the substrate material and by the presence of boron and silicon, which slows down the formation of oxide films and have a positive effect on the continuity and the increase of the thickness of the coating. In addition, the introduction of the boron reduces the erosion resistance of the alloying electrode, as a result of which the transport of electrode material to the surface to be processed is increased [14]. In all investigated coatings, the hardness of the white layer is higher than that of the substrate and varies too widely (Tables 6 and 7). However, the microhardness of coatings applied by vibration ESD with the new electrodes is up to 10-15% higher than that obtained with P25 electrodes. The highest values of HV to 18GPa were obtained at coatings from electrodes KWB10T10 and NWW15B10T20 in ESD on steel 210Cr12. The highest coefficient of increase in the hardness after the ESD, however, was observed in the unhardened steel 45 - K=3.8÷6 times increase in HV, while for hardened tool steel 210Cr12 the coefficient is 1.4÷2.

GFS coatings

The thickness of GFS coatings is in the range 150÷350μm, the roughness Ra - 5÷15μm, and the hardness HRC of the various materials varies within the range 60÷75.

The results of the study showed that the surface layers are a inhomogeneous, non uniforms, similar in form and structure with acceptable repeatability of the qualitative characteristics. All layers are to some extent porous. The reason for this is the presence of non melted particles of the hard phases remaining in the lamellae of the coating obtained, as well as of the unfilled spaces between the lamellae due to their incomplete bonding to each other in the heat-sealing process. Figure 4 shows the microstructure of the coatings from KWT10B10 compositions on st.45.

In the middle (Fig.4a) (which divides the image into two parts) is visible a diffusion white layer - a mixture of the layers and the substrate - and is most likely amorphous. Above it, in most areas of the coating, dark (almost black) spherical phases are visible - grains of approximate size of 15-30μm, which are undissolved and non-melted carbides and borides.



a) GFS - Coating material KWT10B10 b) ESD - coating material KWT10B10

Figure 4. Cros- section microphotographs of microstructure of coatings applied by GFS – a), and by ESD – b) on steel 45

Table 5. Range of change of parameters of tested coatings obtained with ESD with vibrating apparatus on 210Cr12 steel, E_i=0.03 ÷0.3J

№	Electrode	Ra, μm	δ, μm	Hv, GPa	Coeff. of hardening
1	P25	1.8 ч4.2	10- 40	10ч16	1.2÷1.9
2	NWW15T20	2.5ч6.5	15ч80	11ч15	1.4÷1.7
3	NWW15B10T20	2.5ч7.2	15ч80	12ч17	1.4÷2
4	KWB10	2- 6.2	12-80	12-17	1.4÷2
5	KWT10B10	2.5-6.5	15-70	12-18	1.4÷2.1

Table 6. Range of change of parameters of tested coatings obtained with ESD with vibrating apparatus on 45 steel, E_i=0.03ч0.3J

№	Electrode	Ra, μm	δ, μm	Hv, GPa	Coeff. of hardening
1	P25	1.8÷4.2	13- 40	6÷13	3÷6.5
2	NW15T20	2.5÷6.5	20÷90	6÷13	3÷6.5
3	NW15B10T20	2.5÷6.5	20÷70	6÷14	3.5÷7
4	KWB10T10	2.6÷6.5	16÷80	7÷15	3.5÷7

The bright areas between them are probably a multi-metal solid solution based on Co- Ni-Cr-B-Si and the larger long grey areas at the top of the surface form a metal matrix incorporating part of the melted carbides and borides during the transfer.

The ESD coating - Fig. 4b represents a white uniform and homogeneous layer with a thickness to 20-25 microns.

3.2 Wear resistance of the coatings obtained

GFS Coatings

In Tables 7 and Fig. 5-7 are given the results of the comparative experimental studies of the influence of the composition powder materials on the tribo-technical properties of the resulting GFS coatings.

The results obtained show that the wear of the layered samples is 5-12 times lower than that of the uncoated steel 45 and on coated steel 210Cr12 – 3 -6 times lower.

Similar is the amendment in wear rate, wear intensity and wear resistance of coatings – Table 7 and 8.

The comparison of the wear of the layered specimens shows that coated with the materials KWB10 and KWT10B10 specimens from steel 45 have 1.2 to 1.7 times lower wear than that at the analogous materials NWT10B10 and NWW10T10B10 and respectively higher wear resistance. Coated with this materials specimens from steel 210Cr12 have 1.1 to 1.3 times lower wear than that at the analogous materials NWT10B10 and NWW10T10B10. The good wetting of carbide in the cobalt matrix contributes to the high cohesion strength of the resulting metal ceramics. Wear analysis shows that the presence of B_4C, TiB_2 and WC in the powder compositions is the main reason for the higher wear resistance of these coatings. Apparently, the combination of TiB_2 and B_4C and WC additives in the powder composition allowed to use the full advantages of each of the individual component and to receive higher wear resistance of the layered surfaces compared to that obtained with only WC - TiB_2 or with WC-Co. However, with the increase of the B_4C and TiB_2 content from 10% to 20%, the difference in wear of the layered and non-coated samples sharply decreases.

Table 7. Parameters of wear of test samples with GFS coatings on steel 45 – s = 238.64m

№	Coating designation	Mass loss, mg	Wear rate mg/min	Intensity, mg/m	Wear Resistance, m/mg
1	NWT10B10	158.2	31.60	66.3×10^{-2}	1.50
2	NWW10T10B10	105.3	21.10	44.4×10^{-2}	2.30
3	NWW10T20B20	142.5	28.50	59.7×10^{-2}	1.70
4	KWB10	91.2	18.20	38.2×10^{-2}	2.60
5	KWT10	98.4	19.7	41.6×10^{-2}	2.42
6	KWT10B10	90.8	18.20	38.0×10^{-2}	2.60
7	Substrat steel 45	1089.5	217.90	456×10^{-2}	0.22

Table 8. Parameters of wear of test samples with GFS coatings on steel 210Cr12 – s = 238.64m

Coating designation	Mass loss, mg	Wear rate, mg/min	Intensity, mg/m	Wear resistance, m/mg
NWW10B10T10	91.8	18.30	0.386	2.60
NW B20T20	138.6	27.70	0.58	1.70
NWB10T10	107.8	21.60	0.45	2.22
KWB10	88.2	17.40	0.37	2.70
KWB10T10	83.7	16.70	0.35	2.85
Substratest.210Cr12	563.6	112.70	2.36	0.42

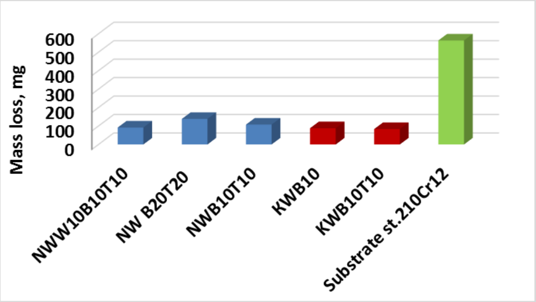


Figure 5. Wear of GFS coatings on steel 210Cr

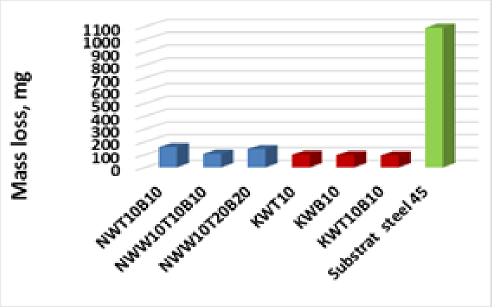


Figure 6. Wear of GFS coatings on steel 45

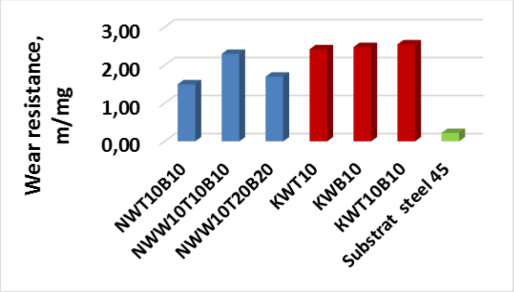


Figure 7. Comparative wear resistance of the GFS coatings on steel 45

Obviously, the higher concentration of these materials results in a weakening of the connections of the individual grains with the metal matrix in the coating, which results in tear, the more that, the breakaway high hard particles abrasively act on the surface of the coating, and further contributing to the increased wear.

Powder compositions KWT10B10, KWB10 and NWW10T10B10 are emerging as promising materials for high-performance coatings.

ESD coatings

In Tables 9 and Fig. 8 are given the results of the comparative experimental studies of the influence of the materials and the ESD regimes on the wear of the resulting coatings.

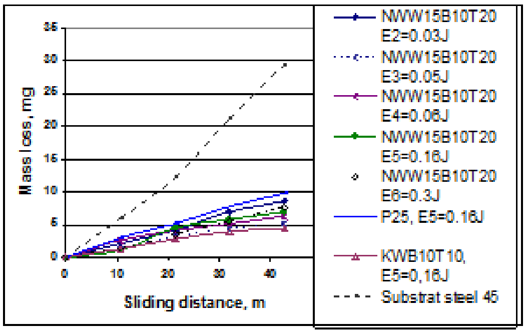
From the results it was established that the coated samples have 2-6 times lower wear than those of uncoated samples, and up to 1.5 times smaller than the deposited samples with electrode P25. Similar is the change in wear rate, wear intensity and wear resistance of coatings - Table 9. The lowest wear at ESD with electrode KWB10T10 and NWW15B10T20 samples is obtained in the pulse energy modes $E_i = 0.05\text{-}0.06$ J, while at electrode NWW15T20 the lowest wear is obtained at $E_6 = 0.3$ J.

Table 9. Parameters of wear of ESD test samples at 200 friction cycles (42.6m)

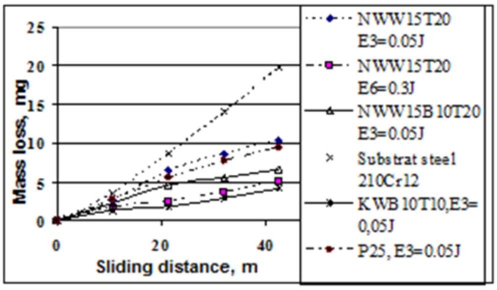
№	Pattern, Electrode / Designation, regime	Mass loss, mg	Wear rate, g/min	Intensity, mg/m	Wear resistance, m/mg
1	NWW15B10T20/steel 45, E_2=0.03J,	8.7	9.1	20.0×10^{-2}	5
2	NWW15T20/steel 210Cr12 hardened, E_3=0.05J	10.3	10.7	24.2×10^{-2}	4.13
3	NWW15T20/steel 45, E_3=0.05J	12.6	13.1	29.6×10^{-2}	3.3
4	NWW15T20 /steel 210Cr12 hardened, E_6=0.3J	5.1	5.3	12.0×10^{-2}	8.35
5	NWW15B10T20/steel 45, E_6=0.3J	7.6	7.9	17.8×10^{-2}	5.62
6	NWW15T20 /steel 45, E_6=0.3J	7.5	7.8	17.6×10^{-2}	5.68
7	NWW15B10T20/steel 45, E_3=0.05J	5.0	5.2	11.7×10^{-2}	8.87
8	NWW15B10T20/steel 45, E_5=0.16J	6.9	7.17	16.1×10^{-2}	6.21
9	NWW15B10T20 /steel 45, E_4=0.06J	6.5	6.8	15.2×10^{-2}	6.56
10	NWW15B10T20 /st.210Cr12 hardened, E_6=0.3J	6.5	6.8	15.3×10^{-2}	6.55
11	KWB10T10/st.210Cr12, E_5=0.16J	4.4	4,7	10.3×10^{-2}	9,7
12	KWB10T10/st.45, E_3=0.05J	4,8	5	11.4×10^{-2}	8,87
13	P25/st45, E_5=0.16J	9.8	10.2	23.0×10^{-2}	4.35
14	P25/steel 210Cr12, E_5=0.16J	8.9	9.2	20.8×10^{-2}	4.5
15	Conventional layering material 602P/steel 45, E_5=0.16J	10.4	10.81	24.8×10^{-2}	4.03
16	Steel 210Cr12 hardened	19.7	20.6	46.1×10^{-2}	2.17
17	Steel 45	29.3	30.68	68.7×10^{-2}	1.46

As can be seen from Fig. 8 the effect of ESD differs according to the different sliding distances. The highest values of the effect of ESD were observed in the second part of the curve of wear - after the initial smoothing of the friction surfaces. High wear resistance is ensured by the homogeneous fine-grained structure of the electrical-spark coatings and of the combination of TiB_2 and B_4C and WC additives in the composition of the electrodes.

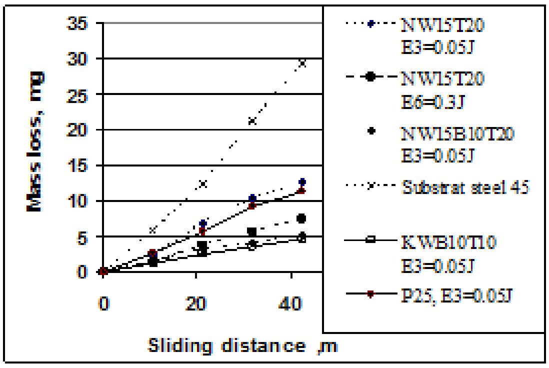
The comparison of the effect of using the new electrodes by both methods shows that at the vibration ESD the effect at both studied steels is lower than those at GFS.



a) Mass loss vs. sliding distance for coatings from electrode NW15B10T20 on 45 steel



b) Mass loss vs. sliding distance for coatings from electrode NW15T20 on 45 steel



c) Mass loss vs. sliding distance for coatings on 210r12 steel

Figure 8. Mass loss vs. sliding distance of the tested coatings

While at GFS the lowest wear for the two tested steels has the coatings from KWB10T10 and NWW10B10T10, then at the ESD lowest wear rates show the coatings with increased content of the high-hard components - NWW15B10T20 and KWB10T10.

Due to the lower roughness, better uniformity and the absence of thermal impact on the substrate the ESD is more suitable for the initial layering of parts and tools with high demands on surface accuracy and quality. GFS due to the higher coating thickness - is more suitable for restoring the shape and dimensions of worn out parts.

The resulting coatings from KWB10T10 and NWW10B10T10 show higher wear-resistance in friction and abrasion, than the others studied materials, than those obtained with conventional materials and then the substrate and they may be efficiently used to strengthen rapidly wearing parts and tools of steels 45 and 210Cr12 and for protection of steel parts for severe wear applications.

4. CONCLUSIONS

Carbide composite multiphase materials have been made based on mixtures of Co-Cr-Ni-B-Si with WC, TiB_2 and B_4C in varying percentages; by ESD and GFS are received dense coatings with wear resistance over five times higher than that of non-coated surfaces.

The influence of the energy parameters of the vibration ESD processes on the roughness, thickness and abrasion wear of coatings obtained was investigated.

Experimentally, the limit values of the energy of the pulses are determined by which dense and even coatings with acceptable roughness are obtained with the new electrode materials. The conditions and processing parameters for ESD, at which has been obtained the lowest wear of coated steel have been determined.

Increasing the content of B_4C and TiB_2 additives over 10 to 20% in the Ni based materials, at GFS coatings result to a reduction, and in ESD coatings - to an increasing of their wear resistance.

The least wear is at the ESD coatings from KWB10T10 and NWW15B10T20 electrodes, and at GFS - of coatings from KWB10T10 and NWW10B10T10 materials.

The resulting coatings show higher wear-resistance in abrasive friction than the substrate and then those obtained with conventional materials, and they may be efficiently used to strengthen rapidly wearing parts and for protection of steel parts for severe wear applications.

These coatings reduce the wear intensity to a greater extent than the coatings of conventional tungsten hard alloys, slow down of wear development over time, and can be used to increase the durability of friction steel surfaces as well as parts subjected to abrasion wear.

The resulting dependencies can be used to control and manage the basic parameters and the tribological properties of the molded wear-resistant coatings and to develop technologies for the lamination of specific details and articles.

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