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Wear-resistant electric spark Colmonoy-WC coatings with high tungsten carbide content

V.G.Khristov, V.E.Sheludko, M.A.Vasilkovskaya

Frantsevich Institute for Problems of Materials Science, National Academy of Sciences of Ukraine, 3 Krzhyzhanovsky Str., 03142 Kyiv, Ukraine

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The article is devoted to the study of the properties of electrode materials of the Colmonoy-WC system with a high content of the carbide component (up to 94 wt. %), which are used for electrospark deposition of coatings on Steel 45. The coatings were deposited using an EFI-46A unit in mode III: oscillation frequency ν = 100 Hz, short-circuit current $I_{sh.c}$ = 4 A, operating current $I_{o.c.}$ = 1.5 A, discharge energy E = 0.28 J. To study the kinetics of mass transfer of these materials, the mass transfer coefficient K, the cathode mass gain Δk, and the anode erosion Δa were determined. The effect of the electrode sintering temperature on these kinetic characteristics has been established. Phase composition and structures of the coatings were studied with a DRON-3M diffractometer and a Neophot-21 metallographic microscope, respectively. The ESA-coating of NV-94 material is shown to have the best characteristics (thickness h ~ 80–85 μm, microhardness H_μ = 13 GPa, wear rate I = 6.1 μm/km, friction coefficient f = 0.3). The ESA-coatings of NV-85 and NV-90 materials also have quite good properties. A conclusion is made about the prospects of using these electrode materials for electrospark hardening of Steel 45.

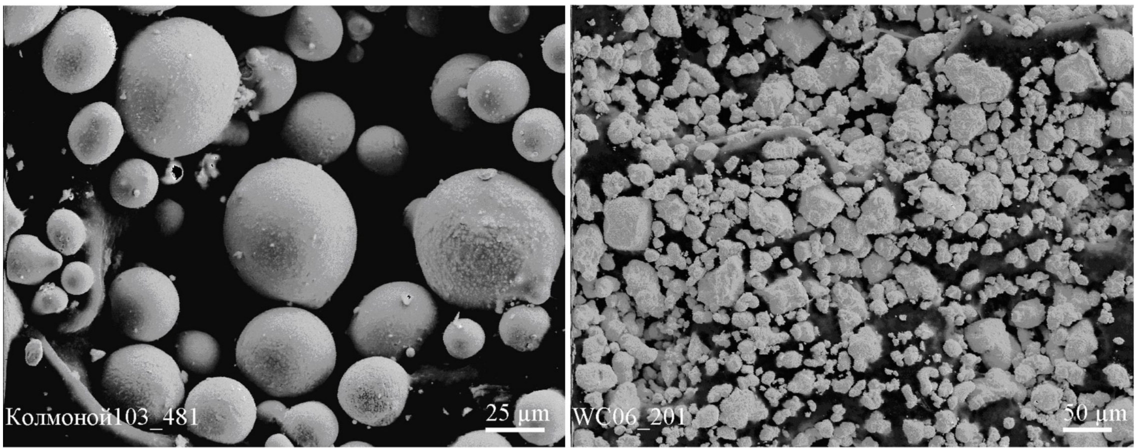
Keywords: Colmonoy-WC system, ESA, mass transfer kinetics, structure, microhardness, wear rate.

Зносостійкі електроіскрові покриття системи "Колмоной-WC" з високим вмістом карбіду вольфраму. *В.Г.Христов, В.Є.Шелудько, М. А. Васильківська*

Статтю присвячено дослідженню властивостей електродних матеріалів системи "Колмоной- WC" з підвищеним вмістом карбідної складової (до 94 мас.%), що використовуються для нанесення електроіскрових покриттів на Сталь 45. Покриття наносили на установці ЭФИ-46А на III режимі: частота коливань ν = 100 Гц, струм короткого замикання $I_{к.з}$ = 4 А, робочий струм I_p = 1,5 А, енергія розряду E = 0,28 Дж. Вивчено кінетику масопереносу цих матеріалів: визначено коефіцієнт масопереносу K, приріст маси катода Δk та ерозію аноду Δa. Встановлено вплив температури спікання електродів на ці кінетичні характеристики. Фазовий склад покриття вивчено за допомогою дифрактометра ДРОН-3М, а структуру покриттів — на металографічному мікроскопі Neophot-21. Показано, що ЕІ-покриття з матеріалу НВ-94 має найкращі характеристики (товщина h ~ 80–85 мкм, мікротвердість H_μ = 13 ГПа, інтенсивність зношування I = 6,1 мкм/км та коефіцієнт тертя f = 0,3). ЕІ-покриття з матеріалів НВ-85 і НВ-90 також мають непогані властивості. Зроблено висновок про перспективність застосування даних електродних матеріалів для електроіскрового зміцнення Сталі 45.

1. Introduction

When the tensile strength of materials is exhausted, different technologies of hardening and restoring working surfaces are used, mainly involving the application of coatings [1–5]. As a result, the service life of the base material increases. The most effective method is electrospark alloying (ESA) [6], in which the anode material



a) b)

Fig. 1. Powders used in the "Colmonoy-WC" system: a — C-225; b — WC.

eroded by a spark discharge is transferred and deposited on the surface of a workpiece (cathode); the formed hardened layer has improved physical and mechanical properties. Currently, standard hard alloys of the WC (WC-Co) and TC (WC-TiC–Co) types are most often used to harden the wear surfaces of machine parts and mechanisms by the ESA method [6–8].

The most effective direction of modern researches is the preparation of new electrode materials based on refractory carbides with a metal binder having an eutectic structure [9, 10]. Therefore, it seems promising to develop a technology of producing electrode materials of a system of refractory carbides (e.g. WC) with a binder of a Ni-based alloy from the Colmonoy® group [11–13], which is manufactured by Wall Colmonoy Inc. This is a world leader in the production of materials and equipment for wear-resistant coatings and compounds to develop.

Research conducted by A.V.Paustovsky et al. [14–18] at the Frantsevich Institute for Problems of Materials Science of NAS of Ukraine within the framework of the implementation of projects of the Target Complex Program of Scientific Research of NAS of Ukraine "RESOURCE" showed the following:

— An increase in the content of WC in the electrode up to 70 wt. % leads to a decrease in the mass transfer coefficient K (up to 20–30 %);

— Coating thickness depends on the mass transfer coefficient K and decreases with increasing WC content;

— The microhardness H_{μ} of the Colmonoy-WC ESA-coating constantly increases with increasing WC content in the electrode, especially after 40 wt. % of WC;

— The wear resistance of these coatings increases with increasing WC content.

The data presented indicate that it is possible to control the thickness of the coatings, their strength and tribological characteristics over a wide range by varying the WC content. Therefore, it is of interest to study such materials with an increased WC content (more than 70 wt. %).

The aim of this work is to study the influence of the composition of the electrode material with a high content of WC (85–94 wt. %) on the transfer kinetics and properties of ESA-coatings for hardening metal surfaces.

2. Experimental

The object of the study was a system of refractory tungsten carbide WC with a metal binder in the form of a Ni-based alloy of the Colmonoy®225 brand (hereinafter C-225) manufactured by Wall Colmonoy Inc. The powder of C-225 (B — 0.5 wt. %, Si — 2.2 wt. %, the rest is Ni [12]) consists of spherical particles with a diameter of 10 to 50 µm (Fig. 1a).

WC was prepared by carbonization of a tungsten powder in graphite crucibles in argon at T = 1400–1500°C. Chemical analysis of the obtained powder showed the carbon content in the range of 4.17–4.2 wt. %, which corresponds to the formula of WC. This is also confirmed by XRD data. Metallographic and electron microscopic studies indicate its "lamellar" shape with a length to width ratio of no more than 1.5–2 (Fig. 1b).

Colmonoy-WC electrode materials were fabricated by the powder metallurgy method (grinding, mixing, and introduction of a plasticizer, pressing, and sintering) according to the procedure [16]. Their compositions are given in Table 1.

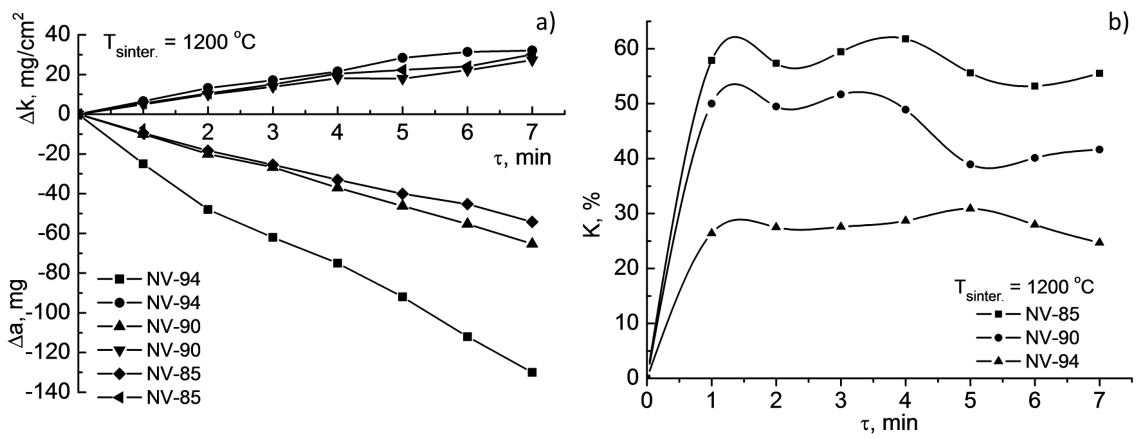


Fig. 2. Kinetic dependences of the mass gain of the cathode Δk, anode erosion Δa at ESA of 1 cm^2 of Steel 45 (a) and the mass transfer coefficient K (b). Tsint. of electrodes = 1200 °C.

ESA of the samples of Steel 45 (GOST 1050-88) of 1×1 cm in size was carried out on the EFI-46A installation (Pilot plant of the Institute of Applied Physics of the Academy of Sciences of Moldova, Chisinau, Moldova) in mode III: oscillation frequency ν = 100 Hz; short-circuit current $I_{sh.c}$ = 4 A; operating current $I_{o.c.}$ = 1.5 A; discharge energy E = 0.28 J. For each minute of the processing of 1 cm^2 of the sample surface, the specific anode erosion (Δa) and the specific gain in the cathode mass (Δk) were measured with an accuracy of 10^{-4} g on an electronic balance OHAUS Adventurer AR0640. The mass transfer coefficient $K = \Delta k/\Delta a$ was determined for each minute of alloying and the arithmetic coefficient was calculated for 7 minutes of alloying.

The microhardness of the coatings was measured on a PMT-3 microhardness tester at a load P = 0.5 N. The structure of the coatings was studied using a Neophot-21 metallographic microscope (Carl Zeiss, Jena, Germany). X-ray analysis of the coating surface was carried out on a DRON-3M diffractometer in CuK_{α} filtered radiation.

Tribotechnical studies of the coatings were carried out under conditions of dry sliding friction in air at room temperature on a MT-68 friction machine according to the shaft-plane scheme in the mode: V = 10 m/s, P = 98 N [19]. Hardened 65G steel (HRC 57-62) was used as a counterbody. The faceplates of the coatings were processed to a surface roughness of R_a = 0.2 μm. Friction coefficient and wear rate were determined.

Table 1. Compositions of Colmonoy-WC electrode materials

Composition	WC/C-225, wt.%
NV-85	85/15
NV-90	90/10
NV-94	94/6

3. Results and discussion

Based on the data obtained earlier, it can be assumed that the ESA-coating from the NV-94 alloy will have (at a thickness of up to ~ 100 μm) increased microhardness and wear resistance compared to the previously studied Colmonoy-WC ESA-coatings [14–18].

The kinetic dependences of the anode erosion Δa, the cathode mass gain Δk, and the value of the mass transfer coefficient K for the electrodes sintered at T = 1200°C are shown in Fig. 2a, b. These data indicate that the maximum cathode mass gain of NV-85, NV-90, and NV-94 alloys at T = 1200°C is 30–32 mg/cm^2. On the other hand, anode erosion is maximal for the NV-94 alloy (about 130 mg). This can be explained by the fact that the sintering temperature of hard alloys increases with an increase in the mass fraction of WC [20], i.e. at the same sintering temperature of 1200°C, the NV-94 alloy has the lowest mechanical strength. As is known [21], mechanical strength correlates with erosion resistance. Therefore, it is obvious that the NV-94 alloy is the least erosion-resistant.

The dependences of the mass transfer coefficient K on the alloying time (Fig. 2b) indicate that as the WC content increases, K decreases, which is consistent with the

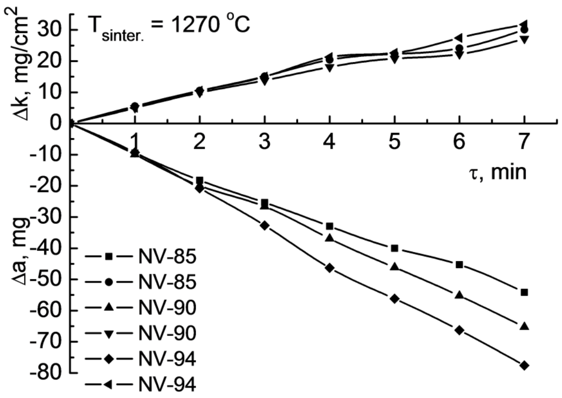


Fig. 3. Kinetic dependences of the cathode mass gain Δk, the anode erosion Δa at ESA of 1 cm^2 of Steel 45. Tsint. of electrodes = 1200 °C.

data of [14]. The average value of K for NV-85, NV-90 and NV-94 alloys is 57.26, 45.83 and 27.66 %, respectively.

The results of a study of the mass transfer kinetics of NV-type alloys sintered at T = 1270°C are presented in Fig. 3. The cathode mass gain reaches 27–32 mg/cm^2 for 7 min of alloying and it practically does not depend on the sintering temperature in the range of 1200–1270°C. On the other hand, anode erosion significantly decreases with increasing sintering temperature; this can be explained by a decrease in porosity. So, at T = 1200°C, Δa for the NV-94 alloy is more than 130 mg, and at T = 1270°C it is 1.6 times less (about 78 mg). It is noteworthy that as Δa decreased, the K value for NV-94 did not decrease, but even increased (from 27.66 % for T = 1200°C to 45.5 % for T = 1270°C). The average value of K for NV-85 and NV-90 alloys is 57.38 and 46.79 %, respectively.

The example of microstructure of the electrode material with an NV-94 alloy is shown in Fig. 4. It has been established that an increase in the WC content results in a heterophase structure consisted of a Ni-based solid solution, tungsten carbides and Ni borosilicides. X-ray analysis data indicate the presence of main phases of Ni and WC as well as traces of WC_{1-x}, W_3C, and Ni borosilicides such as $Ni_{9.2}Si_4B_2$, $Ni_3Si_{0.96}B$, Ni_6Si_2B.

The microstructure of the cross-section of the ESA-coating of the above mentioned alloy (dark phase — C-225, light gray phase — WC) is shown in Fig. 5. The coating thickness is h ~ 80–85 μm (for NV-85 and NV-90 alloys, h ~ 85–92 μm).

The microhardness of ESA-coatings is shown in Fig. 6a. These data indicate that microhardness increases with increasing WC content, which correlates with the data of [14–16]. The NV-94 alloy coating has the highest microhardness H_μ = 13 GPa (for NV-85 and NV-90 these values are 11 and 11.5 GPa, respectively); its distribution over the coating thickness is shown in Fig. 6b.

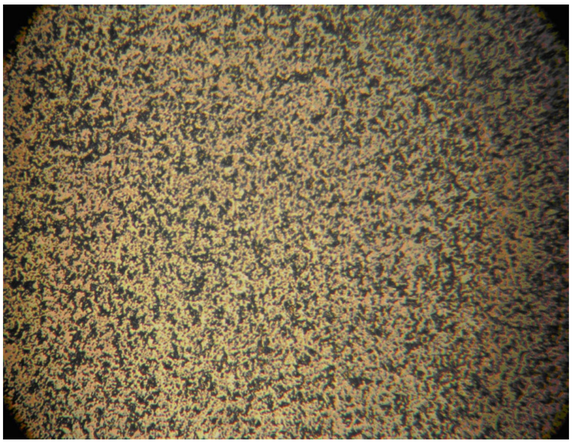


Fig. 4. Microstructure of the NV-94 alloy, ×300.

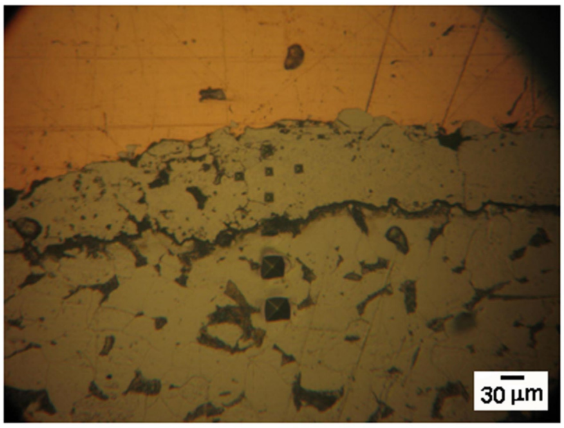


Fig. 5. Microstructure of the cross section of the NV-94 coating on Steel 45.

Wear resistance studies have shown (Table 2) that the wear rate of NV-85, NV-90, and NV-94 ESA-coatings is significantly less than that for uncoated Steel 45. The maximum wear resistance observed for the NV-94 ESA coating is 26 times higher than for uncoated steel 45.

This article completes the cycle of previous works on the Colmonoy-WC system. It is dedicated to the blessed memory of Alexander Vasilyevich Paustovsky, Raisa Andreevna Alfintseva, and Stepan Nikolaevich Kirilenko — who were Professionals in their field and just good People.

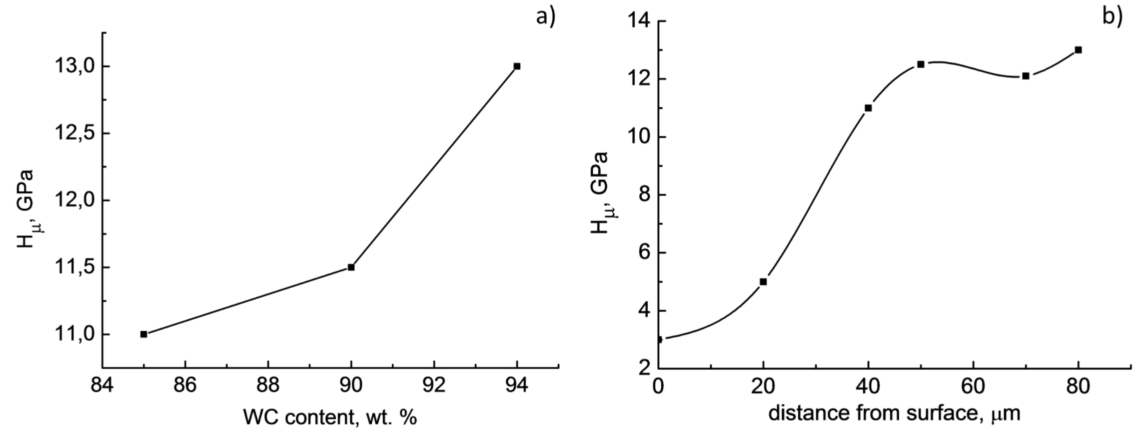


Fig.6. Dependence of coating microhardness H on the WC content in NV type electrodes (a) and microhardness distribution over the thickness of the NV-94 coating (b).

Table 2. Wear rates and friction coefficients of NV-85, NV-90, and NV-94 ESA-coatings

Composition	Wear rate, *I*, μm/km	Friction factor, *f*
NV-85	9.7	0.29
NV-90	7.3	0.31
NV-94	6.1	0.3
Steel 45 uncoated [15]	160	0.4

4. Conclusions

1. An analysis of the obtained experimental data showed that an increase in the content of tungsten carbide up to 94 wt. % and an sintering temperature up to 1270°C (NV-94 alloy) contributed to the production of ESA-coatings on Steel 45 with improved strength and tribological characteristics. At a thickness of 80–85 μm, the coatings have a microhardness H_μ = 13 GPa, a wear rate I = 6.1 μm/km, and a friction coefficient f = 0.3. In this case, the mass transfer coefficient K is 45.5 %.

2. Alloys with a lower content of the carbide phase (85 and 90 wt. %) also have a good strength and tribological characteristics and they can be also recommended for deposition of strengthening ESA-coatings on Steel 45.

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