UDC 621.9.048.4:621.95

EFFECT OF ELECTRODE MATERIAL ON FORMATION OF ELECTROSPARK COATINGS ON CUTTING TOOLS AND EQUIPMENT PARTS

V. I. Shemegon[1]

Translated from *Metallovedenie i Termicheskaya Obrabotka Metallov*, No. 9, pp. 34 – 39, September, 2007.

The effect of the material of the alloying electrode on formation of electrospark coatings on blade cutting tools and equipment parts produced from high-speed steel is studied.

INTRODUCTION

A condition for effective use of domestic and foreign equipment in all branches of industry in recent years is its fast and quality repair. This is possible when domestic blade cutting tools and repair equipment have a high operating capacity and when worn parts are replaced by high-quality ones. Specifically, blade cutting tools and processing equipment meeting these requirements can be obtained by depositing coatings by the method of electrospark alloying (ESA) on their surfaces [1 – 4].

Correct choice of material for the alloying electrode is a requirement that guarantees reliable operation and high working capacity of blade cutting tools and equipment parts.

The aim of the present work consisted in studying the effect of the material of the alloying electrode on formation of ESA coatings on blade cutting tools and equipment parts produced from high-speed steel for choosing the most suitable grade of electrode material and in determining the operating properties of tools and the parts and comparing the quality of surfaces treated by blade cutting tools with ESA coating and without it.

METHODS OF STUDY

We studied ground ($R_a = 1.25$ μm) square specimens with an area of 1 cm^2 from high-speed steel R6M5 (0.82% C, 5.10% Mo, 6.00% W, 3.88% Cr, 0.58% Mn, 0.56% Si, 1.75% V). The hardness of the specimens after heat treatment in a salt bath (hardening from 1230°C + triple tempering at 560°C) was 62 – 64 *HRC*. After such treatment the microstructure of the high-speed steel R6M5 was represented by martensite reinforced by carbides located individually or combined into streaks and by retained austenite. The alloying electrodes were made of hard alloys T15K6, VK8, VK6M based on tungsten carbide. The properties of these materials are presented in Table 1. Electrospark alloying of the specimens was performed in an ÉFI-54A device in air at short-circuit current $I_{sh} = 10$ A, open-circuit current of $U_{op} = 20$ V, and operating current $I_o = 5$ A.

The kinetics of formation of a coating was studied by weighing with the help of a VLA-200M analytical balance. The specimens were weighed every minute of the deposition of the coating.

The roughness of the surface layer was determined with the help of a profilograph-profilometer.

The laps were prepared using a 3V456 universal grinder. The specimens were ground by AS4-63/50-B1-4 wheels without applying lubricating and cooling facilities. The structure of the coatings obtained was determined with the help of successive etching in a 4% alcoholic solution of nitric acid. In order to remove the surface contamination the specimens were polished chemically in a solution of hydrofluoric acid.

The phase composition was determined with the help of a DRON-4.0 x-ray diffractometer in copper K_α radiation

TABLE 1. Properties of the Materials of Alloying Electrodes

Electrode material*	Basic composition, wt.%	HV_{30}, kgf/mm^2	ρ, tons/m^3	λ, W/(m · K)
T15K6	79WC – 15TiC – 6Co	1577	11.3	12.50
VK8	92WC – 8Co	1478	14.6	5.02
VK6M	94WC – 6Co	1360	14.8	4.80

* All the materials were fabricated at the IPM NAN (Ukraine).

[1] Khabarovsk Fleet Repair and Maintenance Base, Khabarovsk, Russia.

0026-0673/07/0910-0457

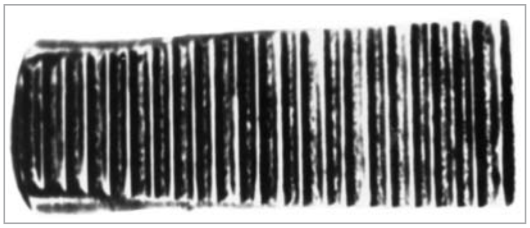

Fig. 1. A wedge for mechanical stud driver.

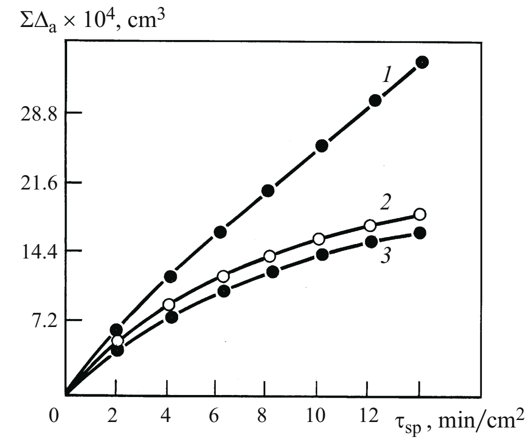

Fig. 2. Effect of the specific time of deposition of coating τ_{sp} on the erosion of the anode $\Sigma\Delta_a$ (here Δ_a is the erosion of the anode after 1-min alloying) for the case of alloying high-speed steel R6M5 with hard alloys: *1*) T15K6; *2*) VK6M; *3*) VK8.

with the counter moving at a rate of 2 K/min. The microstructure and the thickness of the coatings were estimated with the help of a MIM-8M metallographic microscope. The microhardness of the coatings was measured using a PMT-3 microhardness meter at a load of 0.98 N on the indenter.

The coatings were deposited on the wedges of stud drivers (Fig. 1) and twist drills with cylindrical shanks using ÉFI-54A and "Élitron-10" devices.

Industrial tests were performed at machining departments of an auto repair shop. Stud driver wedges were tested in operations of driving and removing of studs by automated stud drivers. The operating stability was evaluated in terms of the number of studs driven by one wedge. The twist drills were tested in a vertical drilling mill of model 2N118-1 and in a semiautomated multihead drilling mill. Drills with diameter $d = 6.0$ and 10.2 mm were used for drilling through holes of depth 3d in steel 12Kh18N10T and steel 45. Blind holes of depth 3d were drilled in steel U8 by drills with $d = 7.2$ mm. The drills with $d = 6.0$ and 7.2 mm were assumed to be dulled when the wear of the rear surface $h_{r.s} = 0.8$ mm; for the drills with $d = 10.2$ mm the criterion was wear to $h_{r.s} = 1.2$ mm. The wear of the drills was evaluated in equal time intervals over the rear surfaces with the help of a 10-fold Poldi magnifier and of a UIM-21 universal measuring microscope. The cutting modes used in the tests are presented in Table 2.

The worn surfaces of the blade tools were studied with the help of a BS-301 scanning electron microscope.

RESULTS AND DISCUSSION

A general notion on the kinetics of formation of coatings due to ESA of high-speed steel R6M5 with hard alloys T15K6, VK8, and VK6M (for comparison) can be obtained from the data presented in Figs. 2 – 4. It can be seen from Fig. 2 that the total erosion of the electrode materials changes in accordance with a nonlinear law with growth in the alloying time. This is especially obvious for the VK alloys. The time dependences of the erosion of these alloys (curves *2* and *3* in Fig. 3) decrease already after the first minute of alloying and stabilize at a specific time $\tau_{sp} \geq 10$ min/cm^2. Such a dependence is explainable by the fact that in alloying for $\tau_{sp} = 1$ min/cm^2 the erosion of the material of the alloying electrode is determined by the initial state that corresponds to the physicochemical properties of the alloying electrode. Upon growth in the alloying time a layer with a changed structure (different from the initial material) known as a se-

TABLE 2. Results of Testing of Drills

Drilled steel	d, mm	Drilling modes			Characteristics of coatings			$K_{o.s}$
		v, m/sec	S, mm/rev	t, mm	material of alloying electrode	h, µm	HV, kgf/mm^2	
U8 (after normalizing)	7.2	0.19	0.14	3.6	T15K6	19 – 84	1530 – 1100	1.33
12Kh18N10T	6.0	0.16	0.10	3.0	VK8	16 – 80	1500 – 1200	2.00
45 (work hardening*)	10.2	0.36	0.10	5.1	T15K6	10 – 50	1820 – 1070	2.33
45 (work hardening removed)	10.2	0.36	0.10	5.1	T15K6	10 – 50	1820 – 1070	3.00

* Retained after rolling.

Notations: *d*) drill diameter, *v*) speed, *S*) feed, *t*) cutting depth, *h*) coating thickness, *HV*) coating hardness, $K_{o.s}$) coefficient of growth in the operating stability.

Notes. 1. All of the drilled steels had $\sigma_r = 600$ MPa.
2. The drills coated by the method of electrospark alloying were produced from steel R6M5.

condary structure emerges on the surface of the electrode due to the inverse transfer of the material from the alloyed surface to the latter [5]. The secondary structure of the VK alloys that have a thermal conductivity 2.5 – 2.6 times lower than that of alloy T15K6 (Table 1) is more manifested than in T15K6. This structure is a true object of erosion until full consumption of the alloying electrode, which affects substantially the formation of the alloyed layer. For example, for the VR alloys, the erosion of which decreases substantially in the alloying process (curves *2* and *3* in Fig. 3), the total gain in the weight of the cathode is limited; when $\tau_{sp} = 10$ min/cm^2 the gain in the weight of the cathode is equal to zero. On the contrary, for hard alloy T15K6, the erosion of which decreases inconsiderably with growth in the duration of the alloying (curve *1* in Fig. 3), a brittle fracture threshold of the alloyed layer does not exist. For this alloy the total gain in the weight of the cathode increases continuously. Thus, the VK8 and VK6M alloys are much less effective than the hard alloy T15K6.

ESA with hard alloy T15K6 is also favorable from the standpoint of saving of the material because its density (Table 1) is 1.26 – 1.35 times lower than that of the VK8 and VK6M hard alloys.

After ESA with TK15K6 and VK alloys lasting for $\tau_{sp} = 1$ min/cm^2 the roughness parameter $R_a = 3.6$ and 6.5 – 7.7 μm, whereas at $\tau_{sp} = \tau_c$ $R_a = 12$ and 14.1 – 14.3 μm, respectively.

The results of testing of T15K6-hardened stud driver wedges are presented in Fig. 4. It can be seen that as the amount of the transferred material ($\Sigma\Delta_c$) increases, the operating stability of the stud driver wedges increases and exceeds that of uncoated wedges by a factor of 3 – 6.

Thus, the T15K6 hard alloy used as a material for the alloying electrode for depositing ESA coatings on high-speed steel R6M5 ensures better conditions for formation of coatings than the hard alloys VK8 and VK6M. These results present practical interest for actual formation of coatings with specified operating properties for various operating conditions of blade cutting tools and equipment parts and give data on the possibility of changing the properties of coatings by varying the electrode material.

In order to save high-speed steels the wedges were produced from a less scarce steel, in particular, from structural steel 45. Before reinforcing it with alloy T15K6 the wedges from steel 45 were heat treated (hardening from 830°C through water into oil and tempering at 350°C for 1 h). Tests of the hardened wedges gave positive results.

Uncoated wedges produced from steel 45 are suitable for driving two studs, whereas the wedges produced from high-speed steels ensure driving of three studs. Coating of wedges from high-speed steels with alloy T15K6 makes it possible to drive from 9 to 18 studs, i.e., the stability of the wedges increases by a factor of 3 – 6. Wedges from steel 45 coated with alloy T16K6 by the method of ESA are suitable for driving from 6 to 12 studs.

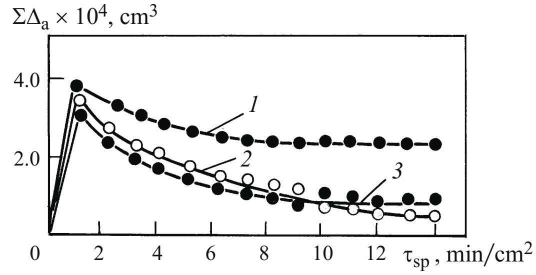

Fig. 3. Effect of the specific time of deposition of coating on the erosion of the anode Δ_a in alloying of high-speed steel R6M5 with hard alloys: *1*) T15K6; *2*) VK6M; *3*) VK8.

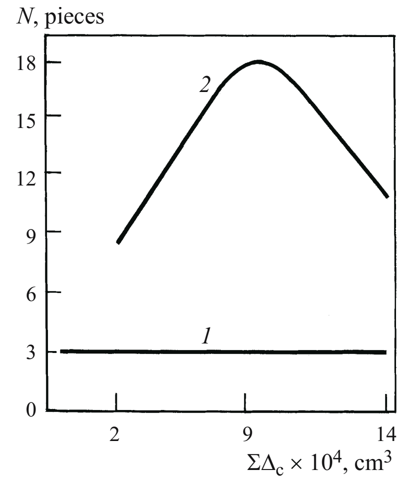

Fig. 4. Operating stability of stud driver wedges: *1*) after heat treatment; *2*) with electrospark coating deposited from hard alloy T15K6 (Δ_c is the erosion of the cathode).

The use of electrospark alloying for hardening stud driver wedges not only increases their stability but also improves the operating efficiency due to shortening of the time required for replacing and mounting of the wedges. Another advantage of ESA is the fact that after the layer deposited on the wedges is worn, it can be formed again and again from alloy T15K6 without changing the substrate. Repeated and numerous ESA not only restore the initial endurance but can also substantially improve it according to the data of [6].

The thickness of a coating is determined by its purpose and the kind of the tool. Thick coatings on stud driver wedges ensure considerable growth in the operating time of the tools. For blade cutting tools that include twist drills the efficiency of the coatings is lower. The results of production tests presented in Table 2 confirm this inference.

According to the data of [3] thin-layer (film) coatings are effective for twist drills. Analysis of the results obtained for steel specimens after ESA [2, 4, 7] has shown that the thickness and the roughness of the coating is directly dependent on the power regime of operation of the device. In accordance with [3, 8] a more favorable regime for ESA of twist drills is the first mode of operation of "Élitron-10."

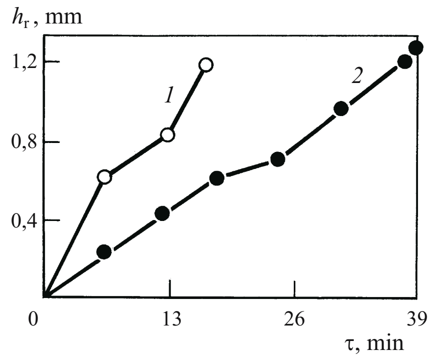

Fig. 5. Wear of twist drills from high-speed steel R6M5 over the rear surface h_r as a function of the cutting time in drilling holes in steel 45: *1*) without coating; *2*) with electrospark coating from hard alloy T15K6.

The wear resistance of twist drills with electrospark coatings and without them used for drilling holes in steel 45 is presented in Fig. 5 as a function of the cutting time. It can be seen that the wear curves of the drills studied have regions of running-in, of normal wear, and of enhanced wear. In these regions the intensity of the wear differs. The running-in period for uncoated drills worn to 0.6 mm ends after 6 min of cutting. For coated drills this period is longer and ends after cutting for 19.5 min. In the running-in period the operating stability of twist drills with electrospark coatings is 3.5 times higher than that of uncoated twist drills. At $h_r = 1.2$ mm the operating stability of twist drills without coatings is 2.33 times lower than that of coated drills. It can also be seen from Fig. 5 that the drilling with the uncoated drill was stopped after 17.2 min of operation because of its complete dulling. In the case of the use of a drill with a coating from alloy T15K6 the drilling was stopped after 40 min of operation due to the high wear and characteristic creak.

Due to the low hardness of the surface of uncoated drills the texture of the transverse edge exhibits features of repeated plastic deformation (Fig. 6*a*). Plastic deformation occurs in the ribbons of twist drills [3]. The softened rear surface of the uncoated drills (Fig. 5*c*) is covered by large deep and shallow scratches, the direction of which coincides with that of the vector of the cutting speed. The cutting edge transforms and loses its rectilinear shape and sharpness. Stuck pieces of the treated material are absent on the rear surfaces, on ribbons, and on the transverse edge. The cutting parts of the drills (transverse edges, rear surfaces, ribbons) bear well-manifested temper colors. Drills with electrospark coatings have no feature of plastic deformation of the transverse edge (Fig. 6*b*). The latter preserves its sharpness. On the side of the front edge the metal is torn off at some places that go

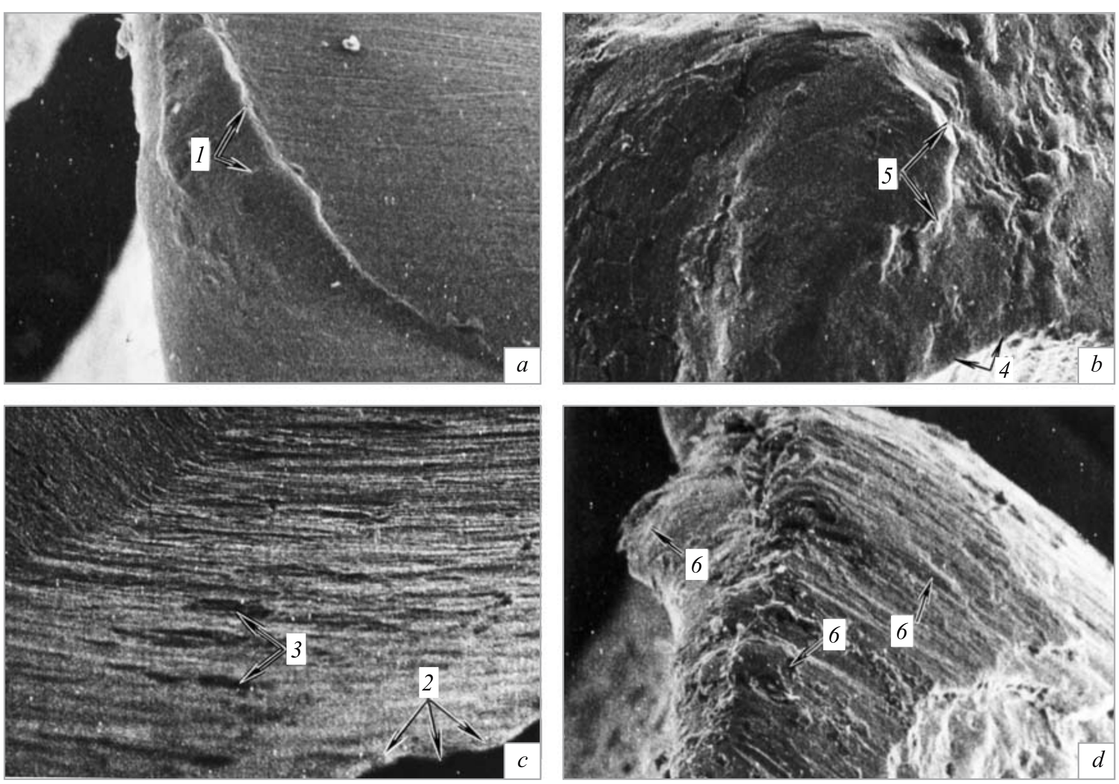

Fig. 6. Topography of wear of the surfaces of a twist drill from steel R6M5 10.2 mm in diameter after drilling holes in steel 45: *a*, *b*) transverse edge of uncoated and coated drills, respectively; *c*, *d*) rear surface of uncoated and coated drills, respectively; *a*, *c*, *d*) × 75; *b*) × 60; *1*) plastic deformation; *2*) transformation of the cutting edge; *3*) scratches; *4*) undeformed transverse edge; *5*) protective film on the transverse edge; *6*) pickups on the rear surface and furrows on them produced by hard particles.

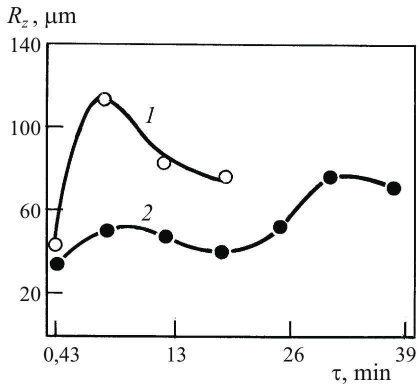

Fig. 7. Dependence of the roughness of the treated surface on the cutting time in drilling of holes 10.2 mm in diameter in steel 45 by twist drills from high-speed steel R6M5: *1*) without coating; *2*) with coating from hard alloy T15K6.

into the front surface. The transverse edge is covered with a film that performs a protective function. The rear surface of the drills with electrospark coatings (Fig. 6*d*) is closed by pieces of stuck treated material. On the rear surface the coating is deteriorated. The microscopic texture has deep furrows. The cutting parts of the drills have well-manifested temper colors, but in the drills with electrospark coatings these colors propagate to a much shorter distance than in the uncoated drills. Consequently, the fracture of the surfaces of uncoated twist drills on the region of enhanced wear is a result of lowering of the microhardness and of the ductility of the matrix due to the scratching and cutting action of the abrasive and due to repeated deformation of the surface layers accompanied by oxidation processes. In the drills with electrospark coatings the surface is fractured due to the scratching and cutting action of the abrasive and due to the occurrence of adhesive and oxidizing processes on the surface. This difference in the wear behavior of the cutting parts of the twist drills studied determines their operating capacity and shows that the length of the cutting path passed by coated and uncoated drills amounts to 2833 and 1240 mm, respectively.

The wear of the tools is connected with the roughness of the treated surface because the texture of the cutting edge is directly copied on the treated surface forming its profile, which is confirmed by the data of Fig. 7 and of [3].

In accordance with the data of [3] drilling is performed under conditions of continuous built-up, especially in the initial stage, as a result of which the quality of the treated surface determined by the roughness parameter R_z worsens. On drills with electrospark coatings the built-up occurs too but its intensity is lower. In our experiments this was confirmed by the 2 – 3 times lower values of the roughness parameter R_z .

CONCLUSIONS

1. The use of hard alloys T15K6, VK8, and VK6M as alloying electrodes for depositing electrospark coatings on blade cutting tools and in equipment parts produced from high-speed steel has shown that hard alloy T15K6 ensures better conditions for formation of such coatings.

2. Deposition of electrospark coatings increases the operating capacity of blade cutting tools by a factor of 1.33 – 3 and of equipment parts by a factor of 3 – 6.

3. In the case of the use of twist drills with electrospark coatings the quality of the treated surfaces determined by the roughness parameter R_z is improved by a factor of 2 – 3.

REFERENCES

1. E. V. Shemegon and V. I. Shemegon, “Electrospark hardening of pipe-bending mandrels,” *Metalloved. Term. Obrab. Met.*, No. 7, 37 – 38 (2003).
2. V. I. Shemegon and M. V. Zhuk, “Experience in the commercial use of electrospark alloying for raising the wear resistance of blade and die tools,” in: *Protective Coatings on Metals* [in Russian], Issue 23, Naukova Dumka, Kiev (1999), pp. 96 – 99.
3. V. I. Shemegon, “Surface hardening of twist drills,” *Metalloved. Term. Obrab. Met.*, No. 6, 23 – 30 (1998).
4. A. E. Gitlevich, A. V. Mikhailov, et al., *Electrospark Alloying of Metallic Surfaces* [in Russian], Shtinitsa, Kishinev (1985).
5. A. D. Verkhoturov, I. A. Podchernyaeva, and L. N. Kurilenko, “Formation of secondary structure on the anode in the process of electrospark alloying,” *Élektron. Obrab. Mater.*, No. 1, 26 – 32 (1987).
6. V. I. Andreev, V. I. Derevyanko, et al., “Increasing the life of parts by repeated electrospark alloying,” *Élektron. Obrab. Mater.*, No. 1, 84 – 85 (1975).
7. V. I. Shemegon, “Increasing the life of punches by electrospark alloying,” *Tekhnol. Sudostr.*, No. 1, 42 – 46 (1989).
8. V. I. Shemegon, “Effect of electrospark coatings on the cutting properties of twist drills,” *Élektron. Obrab. Mater.*, No. 5, 85 – 87 (1990).