Carbide coatings obtained by electro-spark alloying and finishing

V Koshuro

1 Yuri Gagarin State Technical University of Saratov, Saratov 410054, Russia

Abstract. In this study it is proposed to increase the mechanical properties of HSS 1.3343 tool steel by electro-spark alloying with a hard carbide alloy. As a result, the hardness of coatings obtained by electro-spark alloying reached at least 18–22 GPa, the substrate hardness reached 3.7 GPa. After induction quenching in the air, the hardness of the coating equaled 12.0±0.1 GPa. The hardness of the steel substrate increased to 9.1±0.6 GPa. The subsequent sizing (finish grinding) ensured a reduction in roughness Ra to 0.16–0.32 and in open porosity. After grinding, the hardness of the coating and the substrate was 10.3±0.5 GPa and 8.0±0.6 GPa, respectively. The proposed solution can improve the functional qualities of various frictional surfaces used in tool-making facilities.

1. Introduction
Carbide tool materials, e.g. WC-Co, WC-TiC-Co and WC-TiC-TaC-Co hard alloys, are applied in engineering due to their high hardness and wear resistance. These materials are mainly used for the production of tool and frictional elements operating at high temperatures and pressure [1,2]. In order to increase the strength and wear resistance of various products fabricated from steel tools, metal-ceramic coatings are deposited on their surface, e.g. oxide [3-6], carbide or carbonitride [7,8] ones.

Various methods are used to deposit coatings, e.g. plasma spraying, PVD and CVD, however, they are rather complicated. It is known that the method of electro-spark alloying (ESA) is quite efficient [9,10]. Hence, the present study describes the possibility of using ESA for the production of hard WC-TiC-Co coatings on the surface of HSS 1.3343 tool steel, and the subsequent sizing that ensures the reduction in the parameters of roughness and open porosity.

2. Methodology
Samples of HSS 1.3343 tool steel were subjected to ESA with hard carbide alloy WC-TiC-Co (composition: WC – 85 wt.% , TiC – wt.6 %, Co – wt.10 %; hardness HRA 88.5, equivalent of HRC 72–73). The samples had a disc shape with a diameter of 14 mm and thickness of 2 mm. ESA was performed in a pulse mode with the following parameters: pulse duration t within 10–20 ms, operating current I from 0.8 to 2.5 A. In this work the effect of 3 steps of current ranging was studied: 0.8–1.2, 1.5–2 and 2–2.5 A. The duration of ESA was 2, 5 and 10 min.

The coated samples were subjected to induction quenching [11]. The samples were heated to 1000–1100 °C and then cooled in the air. The exposure time for quenching was 10–20 s. The coating surface after ESA and ESA followed by quenching was subjected to semifinishing and finishing in order to obtain the required roughness parameter Ra 0.16–0.32.

The surface morphology of the samples was studied using optical microscopy (MBS-10). The hardness of the resulting coatings was evaluated by microindentation using "PMT-3M" (at the load of 100 gf).
3. Results
The surface structure of the WC-TiC-Co coatings on HSS treated at the minimum value of the current strength \( I = 1.0 \) A and with the minimum treatment duration \( t = 2 \) min was characterized by a noticeable heterogeneity (Figure 1a). Numerous areas containing open pores were observed on the surface (Figure 1b).

![Figure 1(a, b). WC-TiC-Co coatings after ESA (a); open pores after semifinishing (black and white image, the pores are shown by dark areas) (b).](image)

When the current strength of electrical discharges grew to \( I = 2–2.5 \) A, the uniformity of the coating improved. The average size of pores on the coatings produced at the minimum treatment duration was \( D = 31\pm10 \) μm, and the open porosity of the coatings reached a high value \( P = 65 \) %. With an increase in the treatment duration to \( t = 5 \) min, the uniformity of the coating grew as well. However, to improve the quality of the coating, the treatment time should be increased to \( t = 10 \) min. As the discharge current increased to \( I = 2–2.5 \) A, the uniformity grew accordingly. The average size of pores increased to \( D = 45\pm15 \) μm, and porosity of the coatings increased as well reaching a very high value \( P = 72 \) %. The coating produced at the maximum treatment duration \( t = 10 \) min was considered the most suitable for subsequent finishing, e.g. grinding.

Induction quenching did not practically affect the parameters of the surface morphology of the carbide coatings. Visually, the coating surface, which was formed at \( I = 1.0 \) A and duration \( t = 2 \) min, became more homogeneous (Figure 2a). After heat treatment, the porosity of the coatings slightly decreased compared to the untreated coating by an average of 5% (Figure 2b). The average pore size was \( 53.7\pm10 \) μm. The increase in current during the formation of the initial coating to \( I = 2–2.5 \) A led to a decrease in porosity to \( 50\pm5 \) %. The maximum pore size also reduced to \( 42.3\pm10 \) μm. At the same time, the minimum porosity characterized the ESA coatings at different current values and a duration of 5 min. So the surface of samples doped at the current of \( I = 1.0 \) A and duration of 5 min after heat treatment was characterized by a porosity of 54%. Increasing the current to \( I = 1.75 \) A made it possible to reduce the porosity to 45%.

After finishing the coating surface acquired a metallic luster. Defects in the form of pores became clearly visualized (Figure 3a). Apparently, this was due to the opening of the volume of closed pores. On average, the porosity of the coatings after grinding increased by 5–10%. The surface of samples subjected to ESA at \( I = 1.0 \) A and duration \( t = 2 \) min was characterized by the porosity of 56%.
The average pore size after machining decreased by 5±2% and it did not depend on ESA modes.

Figure 2(a, b). WC-TiC-Co coatings after ESA and IHT (a); open pores (black and white image, the pores are shown by dark areas) (b).

The hardness of WC-TiC-Co coatings on HSS 1.3343 tool steel depended strongly on the discharge current $I$ and duration $t$ of ESA treatment. A minimum hardness of about 68–70 HRC (about 8–11 GPa) was observed at the maximum treatment duration $t = 10$ min. High hardness 72–73 HRC (12–13 GPa) corresponded to the minimum and medium treatment duration $t = 2$ min and $t = 5$ min. The hardness of the substrate after ESA increased from 33–34 HRC (3.2–3.3 GPa) to 37–38 HRC (about 3.6–3.7 GPa).

Figure 3(a, b). WC-TiC-Co coatings after ESA, IHT and finishing (a); open pores after semifinishing (black and white image, the pores are shown by dark areas) (b).
After induction quenching, the hardness of the carbide coatings remained unchanged whereas the hardness of steel increased significantly. The hardness of 67–68 HRC (9.1–9.3 GPa) was observed in the substrates subjected to ESA at the current $I = 1.0–1.75$ A in the entire range of the treatment duration. After machining (grinding) of the surface, the hardness of the coatings decreased. The maximum hardness of 68–70 HRC (9.3–10.6 GPa) was observed in the coatings formed at low current values ($I = 1.0–1.5$ A) and short treatment. The hardness of steel substrates after quenching and subsequent finishing decreased to 64–66 HRC (7.8–8.5 GPa).

4. Conclusion
The surface morphology of HSS 1.3343 after ESA had high morphological heterogeneity and mechanical properties, e.g. hardness. WC-TiC-Co coatings were characterized by the pore size $D = 30–45$ μm. Thus, the obtained results can find application in the manufacture of metalworking tools and elements of friction pairs. The optimal combination of morphology parameters, hardness of carbide coatings (68–73 HRC) and steel (64–66 HRC) was ensured due to the ESA duration $t = 5$ min and operating current $I = 1.0–2.5$ A, as well as subsequent induction quenching and machining (finish grinding).

Acknowledgments
The research was supported by the Ministry of Education and Science of the Russian Federation and German Academic Exchange Service (DAAD) in the framework of the program "Mikhail Lomonosov" (project No. 11.12784.2018/12.2).

References
[1] Xiong J, Guo Z, Yang M, Wan W and Dong G. 2013 Ceram. Int. 39 337
[2] Fomin A, Dorozhkin S, Fomina M, Koshuro V, Rodionov I, Zakharevich A, Petrova N and Skaptsov A 2016 Ceram. Int. 42 10838
[3] Fomin A A, Steinhauser A B, Rodionov I V, Petrova N V, Zakharevich A M, Skaptsov A A and Gribov A N 2013 Biomed. Eng. 47(3) 138
[4] Fomin A, Fomina M, Koshuro V, Rodionov I, Zakharevich A and Skaptsov A 2017 Ceram. Int. 43 11197
[5] Fomin A A, Steinhauser A B, Rodionov I V, Fomina M A, Zakharevich A M, Skaptsov A A, Gribov A N and Karsakova Ya D 2014 J. Fritct. Wear. 35(1) 32
[6] Fomin A A, Fomina M A, Rodionov I V, Koshuro V A, Poshivalova E Yu, Shchelkunov A Yu, Skaptsov A A, Zakharevich A M and Atkin V S 2015 Tech. Phys. Lett. 41(9) 909
[7] Wang B and Liu Z 2016 Int. J. Refract. Met. Hard. Mater. 55 24
[8] Yang W, Xiong J, Guo Z, Du H, Yang T, Tang J and Wen B 2017 Ceram. Int. 43 1911
[9] Fomin A A, Fomina M A, Rodionov I V, Koshuro V A, Poshivalova E Yu, Shchelkunov A Yu, Skaptsov A A, Zakharevich A M and Atkin V S 2016 Tech. Phys. Lett. 42(9) 932
[10] Koshuro V, Fomin A, Fomina M, Rodionov I, Brzhozovskii B, Martynov V, Zakharevich A, Aman A, Oseev A, Majcherek S and Hirsch S 2016 J. Phys. Conf. Ser. 741(1) 012197
[11] Fomin A A and Fomina M A 2016 Proc. 57th Int. Sci. Conf. on Power and Electrical Engineering of Riga Technical University (Riga, Latvia) (Riga: IEEE), p 1