Study of hardness and morphology of carbide coatings obtained on complex shaped steel items by electro-spark alloying

O Markelova¹, V Koshuro¹, A Fomin¹, A Aman²,³ and S Palis³

¹ Yuri Gagarin State Technical University of Saratov, Saratov 410054, Russia
² Otto Vollmann GmbH & Co. KG, Gevelsberg, Germany, 58285
³ Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, Magdeburg, Germany 39106
dimirion@mail.ru

Abstract. The work investigated the possibility of forming carbide coatings by electrospark alloying on steel products of complex shape. It has been established that electrospark alloying at an AC current of 1.0 to 4.5 A makes it possible to form coatings of hard carbide alloy VK6 and T15K6 characterized by microhardness up to 11.5 GPa and by hardness HRA 86.6 and 81.5 with the initial hardness of the steel product HRA 80.3.

1. Introduction

In most cases, protective coatings on steel products are formed from carbides, nitrides, borides, carbonitrides of a number of metals (Cr, W, Mo, V, Ti, Ta) and transition metal oxides (Zr, Ti, Al). At present, protective layers are formed on steels by CVD, PVD, ion-plasma spraying, etc. [1-2]. Nitride (TiN) coatings formed by CVD and PVD increase the corrosion resistance of the steel surface. In this case, the hardness of PVD coatings of the TiN system formed on steel substrates can reach 20 GPa, and the grain size can be 15-50 nm [3]. Layers of CrC/C, TiC and TiC/CrC/C systems increase the wear resistance of steel substrates [4]. At the same time, these layers are characterized by significant brittleness, small thickness and low values of adhesive strength, which sharply narrows the area of their rational use.

Despite the widespread use of CVD and PVD technologies, there remains a need for methods that allow the formation of wear-resistant layers characterized by high values of hardness, adhesive strength, low porosity, and a given surface morphology. The known method of electrospark alloying (ESA) allows surface alloying of metals and the formation of functional layers from conductive materials, including hard alloys [5]. Despite the knowledge of the ESA method, it remains necessary to study the features of the formation of high-strength coatings on products of complex shape.

2. Methodology

Steel products of complex shape with an initial hardness of HRA 80.3 were used as samples. Local spherical areas of the surface were hardened (figure 1a). For the formation of coatings from hard materials of grades VK6 (WC-94%, Co-6%) and T15K6 (WC-79%, TiC-15%, Co-6%) (ISO 513-75) at values of alternating current from 1.0 to 4.4 A, an "ARKOGRAF" electric spark marker was used.
The contact area of the electrodes and the surface of the samples was $1 \pm 0.25 \text{ mm}^2$. The contact area of the electrodes and the surface of the samples was $1 \pm 0.25 \text{ mm}^2$. Accordingly, the current density during ESA was: 2.8 and 4.0 A / mm$^2$ when using VK6 electrodes; 2.9 and 3.7 A / mm$^2$ for T15K6.

Images of the surface morphology of the coatings were obtained using an "MBS-10" microscope and an optical system of a "PMT-3" microhardness tester. The magnitude of open porosity, the distribution of the linear sizes of grains and coating defects were determined from the surface images using the "Metallograph" software, according to a well-known technique. The morphology of the formed coatings was investigated according to the well-known technique [6].

The microhardness was measured using a "PMT-3" microhardness tester with a load on the indenter of 100 gf in accordance with the requirements of known regulatory documents (GOST 9450 - 76, ISO 6507-1: 2005). The measurement of the hardness of the formed carbide layers was carried out using a portable Rockwell hardness tester "TX PHR-2". The qualitative assessment of the adhesion of the applied layers was carried out on the HF1-HF6 scale according to Verein Deutscher Ingenieure Normen VDI 3198.

3. Results
During ESA, a heterogeneous coating was formed on selected curved areas (figure 1b).

![Figure 1](image1.png)

**Figure 1.** General view (a) of a steel sample with areas of ESA coating from T15K6 and the morphology of the formed coating (b).

![Figure 2](image2.png)

**Figure 2.** Morphology of coatings formed by ESA electrodes from VK6 (a) and T15K6 (b) at currents of 2.9 and 2.8 A, respectively.
No significant differences in the morphology of coatings formed by ESA from VK6 and T15K6 were observed. Defects in the form of cracks, delamination and significant pores were not visualized (figure 2ab). The porosity of the coating was influenced by the current density at ECA. With an increase in the current density, the open porosity of the formed layers increased from 50-52% to 58%.

The study of the microstructure showed that coatings from VK6 and T15K6 are formed without significant defects, namely, pores and cracks. Coatings obtained on ESA VK6 steel are formed from particles with a size of 500 nm and more (figure 3a). With T15K6, coatings are formed from larger particles, as small as 1 µm (figure 3b). The difference in the microstructure is probably due to the different structure of the electrodes used. The thickness of the coatings was 15–45 µm.

The maximum microhardness of coatings obtained by ESA with the T15K6 electrode reached 11.5 GPa. When alloying VK6 steel, coatings with a maximum microhardness of 10.4 GPa were formed. Surface hardness increased from HRA 80.3 to 81.5 and 86.6 for T15K6 and VK6, respectively. The difference in hardness is justified by the different thicknesses of the layers being formed. After indentation, no cracks or delamination of the coating was found around the indentations, which corresponds to HF1 (VDI 3198) and is a high indicator of adhesive-cohesive strength.

4. Conclusions
As a result of the research, the possibility of forming carbide coatings on complex-profile steel surfaces has been established. The formed coatings are distinguished by the absence of significant defects in the form of cracks and pores. Carbide layers are formed from sub-micron-sized particles. Electrospark alloying makes it possible to obtain highly hard layers with high values of adhesive-cohesive strength.

Figure 3. Microstructure of coatings formed by ESA electrodes from VK6 (a) and T15K6 (b) at currents of 2.9 and 2.8 A, respectively.

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