Hardening of VK10KS hard alloy surface for solving tribological problems in machine-building

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Abstract. Hard alloy with a gradient structure consisting of a viscous core made of VK10KS alloy and a more wear-resistant surface made of VK6-OM alloy is obtained by electrodischarge hardening alloying. In this case, the base of the alloy is able to absorb shock loads, and the surface can play the role of wear-resistant cutting elements.

1. Introduction

For stamped and boring tools, which are required to have an increased fracture energy, as well as a high wear resistance, there are other ways to increase their wear resistance in addition to coating hard alloy tools. These include the method of manufacturing a “multilayer” hard-alloy tool [1].

The scientists of All-Russian Research and Development Institute of Hard Alloys and Refractory Metals have developed a method for producing hard-alloy inserts for equipping a metal-cutting tool with a variable cobalt binder content, when the composition changes when pressing a blank for a plate: VK3–VK6–VK10–VK15–VK10–VK6–VK3 [2]. The obtained plate had a viscous core and a hard surface layer, which ensures its resistance to the processing of various materials.

However, this method for obtaining a multilayer hard alloy with a gradient structure is quite complex, energy-intensive and time-consuming, requires sophisticated equipment. Obtaining a multilayer hard alloy by this method is possible only on a flat surface. It is of interest to obtain hard alloys with a gradient structure – from a viscous core to a wear-resistant surface by the method of electrodischarge hardening by alloying (EDHA).

The advantages of the EDHA process are the ability to produce complex micrometallurgical processes in limited areas of the treated surface; extremely high adhesion strength of the applied coating layer to the treated surface; simplicity of the process; lack of distortion of the workpiece; small dimensions and low power consumption of equipment.

The essence of the EDHA process is that during a spark discharge, of the anode (electrode) erosion and transfer of erosion products to the cathode (part) occur. In this case, a layer is formed on the part having a changed composition and structure, which depend on the electrode material and the electrical mode of the installation. High discharge temperature (5000 ÷ 10000 °C), short duration of action (10⁻⁶…10⁻³ seconds), instantaneous cooling of heated sections with a mass of cold metal makes it possible to conclude that ultra-high-speed quenching occurs after EDHA. Along with this process, there is a contact or drop transfer of alloying elements from the hardening electrode to the treated surface when it comes in contact with it and subsequent diffusion resorption of these elements in the layer.

2. Results and discussion

In the framework of this work, a low-cobalt VK6-OM coating on the surface of VK10KS hard-alloy was obtained by the EDHA method [3 - 6]. The alloy VK6-OM in accordance with GOST 3884 - 74
was used as the alloying electrode. The alloys of the OM group (VK6-OM, VK10-OM, VK15-OM) were developed for cutting especially hard and abrasive materials. VK6-OM alloy of composition 91.9 WC + 6 % Co + 2 % TaC + 0.1% VC does not reduce strength, VC and TaC additives contribute to obtaining a fine-grained structure – they prevent the growth of WC phase grains, while VK6-OM alloy with its wear-resistant properties is not inferior to the most wear-resistant alloy of the WC – Co group (B 253), but significantly exceeds it in strength [1].

Thus, a gradient hard-alloy plate may consist of a viscous core that serves as a damper, well absorbs shock loads, is able to withstand significant bending stresses, and the surface layer has increased wear resistance compared to a viscous core. The creation of hard-alloys with a gradient structure should be considered as a new stage in the improvement of hard-alloys.

The surface treatment of VK10KS hard-alloy by the EDHA method was carried out using the portable installation UR – 121 manufactured by the Instrumental Plant “Koncern Podolsk” OJSC. The surface treatment of VK10KS hard-alloy was carried out using a double technological mode at the rate of 0.55 min/1 cm² in Norma mode, 3 + 1.0 min/1 cm² in Turbo mode.

The investigation of the structural features after processing and determining the depth of the surface hardening zone was carried out using OLIMBUS – GX 50 optical microscope and Philips SEM 515 scanning electron microscope.

Figure 1 shows the microstructure of VK10KS alloy with a hardened layer of VK6-OM after EDHA. A poorly etched layer was detected, the thickness of which reaches 20 μm.

![Figure 1. The microstructure of VK10KS alloy after EDHA coated with VK6-OM.](image)

The results of scanning electron microscopy confirm the presence of a gradient structure on the VK10KS alloy: an increased content of tungsten in the surface layer and a lower content of cobalt (figure 2).

![Figure 2. Microstructure of VK10KS alloy after EDHA in characteristic x-rays: a – cobalt, b – tungsten.](image)
X-ray phase analysis showed that the surface treatment of the hard alloy by EDHA leads to a change in its phase composition (figure 3).

![Diffraction Pattern](image)

**Figure 3.** A fragment of the diffraction pattern of VK10KS hard-alloy after EDHA.

In addition to the existing tungsten monocarbide alloy WC and cobalt binder, which were present in the initial state in the hard alloy, a finely dispersed carbide of ditungsten $\text{W}_2\text{C}$ and carbide $\text{WC}_{1-x}$ are formed in the surface layer. The authors of [7] describe the positive role of divofram carbide in the surface layer of a hard-alloy WC + 20% Co after a high-energy impact on the surface, noting a higher $\text{W}_2\text{C}$ hardness compared to WC hardness.

A change in the phase composition of the surface layer in the hard alloy was reflected in the indices of nanosolidness. The result of nanoindentation of the hard-alloy after EDHA is an increase in surface hardness to 22000 MPa (table 1).

**Table 1.** Properties of VK10KS alloy after hardening treatment.

| Coating material | Nanohardness of the surface layer, MPa | Depth of the worn track, $\mu$m | Wear track area, $\mu$m$^2$ | Coefficient of friction, $\mu$ | Roughness, $R_a$, $\mu$m |
|------------------|----------------------------------------|-------------------------------|--------------------------|--------------------------|------------------------|
| Electrodischarge hardening by alloying | 21649 ÷ 22000 | 10.8 | 941 | 0.23 | 1.83 ÷ 2.15 |
| VK10KS alloy in the initial state | 58 | 12921 | 0.41 | 0.41 |

Durability tests were carried out on a PC-Operated High Temperature Tribometer at room temperature. The wear of the samples was determined by measuring the depth and area of the track after testing, formed as a result of the action of a stationary diamond indenter on a rotating sample at a load of 3 N, the number of revolutions 4000, linear velocity of 2.5 cm/s. For comparison, similar tests were performed on the initial samples with the same parameters (figure 4). The depth and area of the wear track after testing, as well as the coefficient of friction after running-in, were measured using the Micro Measure 3D station high-precision measuring system with software. The analysis of the obtained profiles was carried out using the Mountains Map Universal sofware, version 2.0.13. The results of tribological tests (figure 5, table 1) are presented as arithmetic mean values obtained from 10 tests in one processing mode on three samples.
Figure 4. Appearance of tracks during tribological tests: a – VK10KS alloy coated with VK6-OM; b – initial alloy.

The wear of samples coated with VK6-OM after EDHA showed that the track depth is 10.8 μm, and that of the original sample, the track depth is 58 μm (figure 5). The cross-sectional area of the track of worn samples with and without coating is 941 μm² and 12921 μm², respectively (table 1). The friction coefficient (μ) for VK10KS alloy coated with VK6-OM is defined at 0.23, and for the initial alloy μ = 0.41 (table 1).

Figure 5. Profile tracks of samples wear: a – after EDHA; b – initial sample.

Since EDHA always leads to an increase in surface roughness [8, 9], an important factor is the study of microgeometry after hardening of VK10KS using this method, the results of which are presented in table 2. Hardening of the surface of VK10KS hard-alloy by EDHA slightly worsens the surface microgeometry, but keeps it within the technical requirements with recommended surface finish \( R_a = 2.5 \) μm [8].
Table 2. Treatment modes and microgeometry of the coating with a thickness of 20 μm.

| Treatment   | Treatment time, min | Roughness $R_a$, μm |
|-------------|---------------------|---------------------|
| Turbo 80 %  | 1.10(0.2 Norma 3 + 0.9 Turbo) | 2.15 |
| Norma 3 20 %|                     |                     |
| Turbo 60 %  | 1.20(0.2 Norma 3 + 1.0 Turbo) | 1.90 |
| Norma 3 40 %|                     |                     |
| Turbo 50 %  | 1.40(0.4 Norma 3 + 1.0 Turbo) | 1.87 |
| Norma 3 50 %|                     |                     |
| Turbo 40 %  | 1.55(0.55 Norma 3 + 1.0 Turbo) | 1.83 |
| Norma 3 60 %|                     |                     |

3. Conclusion
Using the proposed EDHA method for coating the surface of a hard-alloy in comparison with existing methods makes it possible to obtain a hard-alloy plate with a gradient structure, for example, VK3–VK6–VK8–VK10–VK15–VK20. In addition, using the EDHA method, it is possible to restore the surfaces of various hard alloys after using the corresponding electrodes, this will extend the life of products equipped with these alloys, as well as save scarce materials (tungsten and cobalt).

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