Investigation of the machinability of composite materials electrode-tools while EDM

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Abstract. The aim of the work is to study the mechanical properties of composite material electrode-tools made of pseudo-alloy of the copper-colloidal graphite system for the Electrical Discharge Machining (EDM) processing of dissimilar materials. Electrode-tools made of copper, graphite and the specific composite material are compared. These electrodes were used for EDM of samples of alloyed steel and tungsten, aluminum and titanium based alloys. After processing, the surface roughness, wear and performance of the tool electrodes were evaluated. As a result of the experiment, it was established that the electrode made of a composite material, copper-colloidal graphite, in some cases, demonstrated significantly higher performance and wear resistance. Based on the data obtained, it was concluded that it is advisable to use an electrode made of a composite material to increase the efficiency of EDM processing of aluminum alloys and alloyed steels, as well as rough EDM processing of titanium alloys.

1. Introduction
Currently, there is an increasing trend of reducing the production time in industrial world. Manufacturing plants are quickly adapting to the release of new products, which is ensured, first of all, by a quick changeover of production. For machining of geometrically complex parts, expensive special equipments and tools are required. These manufacturing procedures require huge economic and technological investments. The use of physico-mechanical machining method is of utmost relevance, allowing the manufacture of parts with complex shapes using the three-dimensional reproduction technique [1] and EDM (Electric Discharge Machining) is the prominent choice.

The process of EDM involves the gradual melting and evaporation of conductive materials under the action of pulsating current. The molten debris, thus created is flushed off with the aid of hydrodynamic forces of the working fluid, called the ‘Dielectric’ [1, 2]. The ability of EDM process to machine hard-to-cut materials of any hardness is the main advantage of this technique as compared to other conventional mechanical routes, ensuring high accuracy of the resulting geometry and the surface properties of material being processed [3].

To perform EDM using the method of three-dimensional replication, die-sinker EDM machines are used, employing complex-profile electrodes as the tool. Electrolytic Copper (Grade M1 and M0) and Graphite are widely used as electrode material for EDM tool. The accuracy in the size and surface properties of processed parts using the die-sinker EDM machines depends on the geometrical accuracy
of the electrode. In order to produce complex and precise geometry, the process of manufacturing an electrode could include many other mechanical and physio-technical processing operations, which makes it a time-consuming and costlier process.

The EDM technology is widely used for the manufacture of working structural elements of critical parts, such as gearbox housings, copiers, parts of hydraulic cylinders and many others. These components work under conditions of variable temperatures and dynamic loads, and therefore, high-strength materials, such as alloyed thermally hardened steels, alloys based on titanium, aluminum, tungsten and others, are used. Many of these materials have high electrical resistance, which leads to intensive wear of the electrode tools and a decrease in the performance of the process of EDM.

Considering the above, the actual task was to improve the properties, such as performance and wear resistance of electrode-tool.

2. Literature review

One of the effective ways to increase the wear resistance of electrode tools is the use of pseudo-alloy as composite material for their fabrication, combining their different properties [2, 3, 4]. Pseudo-alloy refers to the system of immiscible components, that is, a system in which there is a tendency to stratification in the liquid state already and there is virtually no solubility in the solid state. The microstructure of pseudo-alloys is a thin uniform mixture of two or more phases, one of which has a high reinforcement and the second has high electrical conductivity. The low-melting phase melts the refractory phase and the physical properties of the phases are additively added.

Currently, a number of wear-resistant composite materials for electrical purposes have been developed, which can significantly improve the electro-erosion properties of electrode tools as compared to the traditionally used materials. One of the most promising materials for solving this problem is the composite material comprising of copper-colloidal graphite having a graphite content of less than 2% [5]. The results of the performance and wear resistance of the electrodes are shown in figures 1 and 2.

![Figure 1. Performance of tool with graphite](image1.png)

![Figure 2. Wear resistance with graphite content](image2.png)

The particular pseudo-alloy is a mechanical mixture of copper and dry colloidal graphite powders, pressed and sintered by powder metallurgy technique. The pseudo-alloy components practically do not fuse together with each other in the temperature range achieved during the EDM process [6].

Production of electrode tools made of composite material by powder metallurgy method is technologically advanced technique. It can be carried out on commercially available equipments when the constituent materials are available in the form of powder with an average particle size of less than 40 microns [7]. It becomes possible to vary the chemical composition, dispersion and technological parameters of the powders used for developing the composite materials for a tool electrode by this technique, which makes it possible to significantly enhance its properties [8].
Despite the advantages of a composite material such as a pseudo-alloy system of copper-colloidal graphite, this material does not find wide application for the manufacture of complex-profile tool electrodes. This is due to the fact that the operational properties of this material during the EDM processing of various steels and alloys are not fully understood, and there are no practical recommendations. Thus, the analysis of the literature has shown that there is a need to study the machining properties of electrodes made of composite materials for the EDM processing of dissimilar alloys.

Hence, the objective of this study was to investigate the wear resistance and performance of electrode tools made of a composite material such as a pseudo-alloy system of copper-colloid while EDM of titanium, aluminum, tungsten alloys and alloyed steel.

3. Materials and methods

For the experiment, electrodes were made of copper, graphite, and a composite material such as a pseudo-alloy of the copper–colloidal graphite system with a graphite content of less than 2%.

Copper powders PMS-1 GOST 49-60-75 and dry colloidal graphite C-1 grade TU 113-08-48-63-90 were used for the fabrication of an electrode tools. The powders were mixed in the required proportion in a mixer with a displaced axis of rotation for 4 hours, after which samples of 6x6x50 mm were formed from the mixture at a pressure of 600 MPa. Then, the samples were annealed in a vacuum oven at 700 °C and pressed again. After re-pressing, the samples were finally sintered in a vacuum oven at a temperature of 1000 °C for 2 hours.

For the manufacturing of an electrode tool made of composite material, copper powders PMS-1 GOST 49-60-75 and dry colloidal graphite C-1 grade TU 113-08-48-63-90 were used. After mixing the powders in the required proportion, the samples of 6x6x50 mm were developed at a pressure of 600 MPa. Afterwards, the samples were annealed in a vacuum oven at 700 °C and were re-pressed. The samples were finally sintered in a vacuum oven at a temperature of 1000 °C for duration of 2 hours.

The specimen of titanium alloy OT-4, aluminum alloy AK6, tungsten-based alloy VK8 and low alloy steel 35GS were prepared as samples of dissimilar materials.

The study of functional properties of the electrodes was carried out on a die-sinker EDM machine (Electronica Smart CNC) on rough processing modes. IPOL SEO 450 was employed as the EDM working fluid.

The performance of the electrode was estimated by the depth of the hole machined in the sample, and wear was measured by recording the difference in weight of electrode before and after machining. The surface roughness of the machined samples and electrodes was measured on a Mahr Perthometer S2 profilometer.

4. Results

The results of the EDM of the AK6 alloy are presented in Table 1. An analysis of the results of EDM processing of the AK6 aluminum alloy showed that the efficiency of the electrode-tool made of composite material is 1.1 times lower than that of the electrodes made of copper and graphite. When assessing the wear resistance, it was observed that the electrode-tool made of composite material possesses 3.5 times higher wear resistance than the electrode made of copper. During the experiment, the weight of the graphite electrode increased after treatment. There was adhesion of the workpiece material on the working surface of the electrode tool. Evaluation of the obtained roughness of the treated surface showed that the highest quality was provided by the electrode made of graphite.

| Part roughness (Ra) | Electrode roughness (Ra) | Electrode wear (gr.) | Depth of processing (mm.) |
|---------------------|--------------------------|----------------------|--------------------------|

Table 1. The experimental results of EDM of AK6 alloy
Cu  8.3131  0.9872  0.0014  1.2121  
Gr  6.9828  0.9310  --   1.24    
Cu-Gr 8.3687  0.8480  0.0004  1.08    

The experimental results of the EDM of steel 35GS are presented in Table 2. Analysis of the results while EDM of low-alloy steel 35GS showed that the electrode-tool made of composite material shows 2.4 times higher performance than the copper electrode and graphite, as well as 3.8 times higher wear resistance than the electrode from copper. Evaluation of the surface roughness showed that the electrode made of a composite material provided a lower surface quality.

| Part roughness (Ra) | Electrode roughness (Ra) | Electrode wear (gr.) | Depth of processing (mm.) |
|---------------------|--------------------------|----------------------|---------------------------|
| Cu                  | 5.5095                   | 1.0256               | 0.0023                    | 0.1120                   |
| Gr                  | 5.4083                   | 1.4088               | --                        | 0.1124                   |
| Cu-Gr               | 6.7746                   | 2.8705               | 0.0006                    | 0.276                    |

The experimentation results of EDM of titanium alloy OT-4 presented in Table 3. Analysis of the results showed that while processing of titanium alloy OT-4, the productivity of a composite electrode tool was 21.2 times higher than that of a copper electrode and 3.9 times higher than that of a graphite electrode, but the surface roughness was enhanced significantly than other electrodes.

| Part roughness (Ra) | Electrode roughness (Ra) | Electrode wear (gr.) | Depth of processing (mm.) |
|---------------------|--------------------------|----------------------|---------------------------|
| Cu                  | 2.8615                   | 2.4104               | 0.0048                    | 0.0127                   |
| Gr                  | 3.9301                   | 2.5033               | --                        | 0.069                    |
| Cu-Gr               | 5.1555                   | 2.9380               | 0.0035                    | 0.2691                   |

The results obtained after EDM of VK8 alloy based on tungsten are presented in Table 4. Analysis of the results of EDM processing of the VK8 alloy showed that the electrode-tool made of composite material has a significantly lower performance indicator than the copper electrode and the graphite electrode, as well as lower wear resistance compared to the copper electrode. Since the weight of electrode made of graphite was higher, it was not possible to estimate its wear. The quality of the machined surface also turned out to be significantly lower when treated with a composite electrode.

| Part roughness (Ra) | Electrode roughness (Ra) | Electrode wear (gr.) | Depth of processing (mm.) |
|---------------------|--------------------------|----------------------|---------------------------|
| Cu                  | 0.4517                   | 2.6592               | 0.0099                    | 0.0095                   |
| Gr                  | 2.7619                   | 2.9384               | --                        | 0.0112                   |
| Cu-Gr               | 8.6498                   | 6.1635               | 0.0326                    | 0.0024                   |

5. Conclusions
Based on the results of the experiment and analysis of the data obtained, it can be concluded that the use of a composite material such as a pseudo-alloy system of copper-colloidal graphite with graphite content of less than 2%, in some cases, can be an effective solution to improve the wear resistance of
electrode tools and the performance of the EDM process. In particular, it is advisable to use this material for the EDM processing of aluminum alloys and alloyed steels, as well as for the rough EDM operations of titanium alloys. For the Electrical Discharge Machining of tungsten based alloys, the use of electrodes made of composite material such as a pseudo-alloy system of copper-colloidal graphite is not advisable.

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References

[1] Bains P S, Sidhu S S, Payal H S 2016 Fabrication and machining of metal matrix composites (Kapurthala: IKG Punjab Technical University) p 533
[2] Smolentsev V 1983 EDM and electrochemical methods of processing materials vol 2 (Moscow: Higher School) p 247
[3] Yeliseyev Y, Savushkin B 2010 EDM of aerospace products (Moscow: MSTU him NE. Bauman) p 437
[4] Potapov V High-speed milling and erosion processing: allies or rivals (Electronic resource) URL: http://www.instr-stan.com/text/text_08.html
[5] Grisharin A, Abyaz T and Ogleznev N 2017 Improving the efficiency of electroerosive machining of parts of hydraulic cylinders and special-purpose products through the use of electrode tools with enhanced electroerosion properties (Perm: Perm national research polytechnic university, University Press) p 151
[6] Avraamov Y and Shlyapin A 1999 New composite materials based on immiscible components: production, structure, properties (Moscow: MGIU) p 208
[7] Livshits A and Rosh A 1980 EDM and electrochemical machining. Calculation, design, manufacture and use of electrode (Moscow: Institute of Information on Mechanical Engineering) p 223
[8] Bains P, Payal H and Sidhu S 2017 Analysis of Coefficient of Thermal Expansion and Thermal Conductivity of Bi-Modal SiC/A356 Composites Fabricated via Powder Metallurgy Route doi:10.1115/ht2017-5122