Studying the process of electric discharge machining of products obtained by powder laser welding

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Abstract. In modern mechanical engineering, machine parts and mechanisms are made of new materials. These materials are characterized by enhanced mechanical properties. Expensive are products made from them. Deterioration of working surfaces leads to the need to replace the entire part. About 80% of the part is not subject to wear. The method of laser surfacing allows you to restore the part. The operability of the mechanism is returned. Cost-effectiveness is increasing. The processing of deposited surfaces is difficult. The properties of mechanical surfacing increases and cutting with a blade tool is not possible. Electroerosive technologies are beginning to be actively used in the processing of deposited parts. The study of the electro discharge machining (EDM) process of such details is now relevant. After EDM, the formation of the roughness of deposited surfaces has not been fully studied. The aim of the work is an experimental study of the EDM process of such surfaces. It is important to study the effect of EDM modes on the formation of roughness is important. A full factorial experiment was conducted during the study. EcoCut wire-cutting EDM machine selected as experimental equipment. Brass wire \(d = 0.25\) mm is used as an electrode tool. The deposited material titanium VT-01 is selected for the experiment. An empirical model was obtained during the experiment. To establish the relationship between the EDM modes and the quality of the processed surface allows the model. An increase in the stress \((U, \text{mm})\) and the height of the workpiece \((N, \text{mm})\) leads to an increase in the roughness of the treated surface \((Ra, \mu \text{m})\) when processing titanium was found. The maximum roughness value for \(Ra = 3.3\ \mu \text{m}\) is achieved at a voltage of \(U = 25\) V, duty cycle \(q = 3.5\), and a workpiece height of \(10\) mm.

1. Introduction
Continuous improvement of the products of the aviation industry, rocket science and special engineering is required to improve operational characteristics.

Materials with high physical and mechanical properties are actively used in modern industry for the manufacture of products. Deterioration of working surfaces leads to the need to replace the entire part. About 80% of the part is not subject to wear. The method of laser surfacing allows you to restore the part. The operability of the mechanism is returned. Cost-effectiveness is increased. Processing of deposited surfaces is difficult. The properties of mechanical surfacing increases and cutting with a blade tool is not possible. Often, small restored areas of products are not processed.
Methods of electrophysical, electrochemical and physico-chemical effects in production are relevant. Technologies for wire-cutting electro discharge machining (WCEDM), waterjet processing, laser cutting are used in the processing of complex products. These technologies make blanks and products of any shape and profile. Products are independent of the strength of the material and do not require complicated equipment [1].

Laser and waterjet cutting technologies provide maximum productivity. These technologies do not fulfill the requirements of accuracy and quality of the processed surface.

Electroerosive technologies are beginning to be actively used in the processing of deposited parts. The study of the EDM process of such details is now relevant.

Technology (WCEDM) produces complex geometric products with high accuracy and low roughness [1]. WCEDM of deposited reconditioned products is widely used at the best engineering enterprises.

The process of EDM is a complex electrophysical process [1-4]. The roughness of the treated surface after WCEDM depends on various factors. The roughness depends on the properties of the working fluid, the properties of the material being processed, the properties of the electrode wire, the parameters of the pulse (pulse on and off times, voltage, current), the height of the workpiece [5-7].

The working surface of the product after PVEEO gets roughness. This roughness consists of intersecting and randomly located craters (holes). The location of these holes has a very chaotic order. This phenomenon makes it difficult to predict surface quality (Figure 1).

![Figure 1. The surface of the titanium billet after WCEDM.](image)

The experimental design technique is used to analyze the relationship between roughness factors in WCEDM [5-8].

The aim of the work is an experimental study of the EDM process of deposited reconditioned products

2. Materials and research methods

A full factorial experiment was conducted in the study. Regression analysis is used to process the results and obtain a model.

The experiment was conducted on Ecocut EDM machine. The brass wire d=0.25 mm was selected as a tool material and the titan VT-01 was used as workpiece. Liquid was distilled water. The roughness of the treated surface was measured on a profilometer Mahr Perthometer S2. Measurements were taken at a base length of 0.8 cm. Surface shots were studied by using an OLYMPUS GX 51 light microscope, increase is x100.

Assumptions made:
1. All pulses from the electrode-wire are perpendicular to the electrode-parts;
2. The electrical conductivity of the dielectric is constant.

In this study, the variable factors were:
1. Duty cycle, q;
2. Voltage, U (V);
3. Workpiece height, H (mm).

The study was based on the central composite design (CCD) of the experiment. In this design strategy, the factors are tested at minimum two levels i.e., minimum, and maximum and are represented with the coded units as -1, -1 respectively. Table 1 presents the value of factors and their levels:

Table 1. Levels and intervals of variation of factors

| Factors  | Code designation | Max value | Min value | Range of variation |
|----------|------------------|-----------|-----------|-------------------|
| q        | X<sub>1</sub>     | +1        | -1        | 1.5               |
| U, V     | X<sub>2</sub>     | 70        | 25        | 25                |
| H, mm    | X<sub>3</sub>     | 12        | 4         | 4                 |

8 experiments were carried out in the experiment. Experiments require a processing mode. The experiments are consistent with the planning matrix (table 2).

Table 2. Experiment planning matrix

| №    | X<sub>0</sub> | X<sub>1</sub> | X<sub>2</sub> | X<sub>3</sub> | X<sub>1</sub>X<sub>2</sub> | X<sub>1</sub>X<sub>3</sub> | X<sub>2</sub>X<sub>3</sub> | X<sub>1</sub>X<sub>2</sub>X<sub>3</sub> | y     |
|------|---------------|-------------|-------------|-------------|-----------------|-----------------|---------------|-----------------|-------|
| 1    | +1            | -1          | -1          | -1          | +1              | +1              | +1            | -1              | Y<sub>1</sub> |
| 2    | +1            | +1          | -1          | -1          | +1              | +1              | +1            | +1              | Y<sub>5</sub> |
| 3    | +1            | -1          | +1          | -1          | +1              | -1              | +1            | -1              | Y<sub>3</sub> |
| 4    | +1            | +1          | +1          | -1          | +1              | +1              | +1            | +1              | Y<sub>4</sub> |
| 5    | +1            | -1          | -1          | +1          | -1              | -1              | +1            | -1              | Y<sub>5</sub> |
| 6    | +1            | +1          | -1          | +1          | +1              | -1              | -1            | +1              | Y<sub>6</sub> |
| 7    | +1            | -1          | +1          | +1          | -1              | -1              | +1            | +1              | Y<sub>7</sub> |
| 8    | +1            | +1          | +1          | +1          | +1              | +1              | +1            | +1              | Y<sub>8</sub> |

Checks of the homogeneity and adequacy of the model are presented in work [8]. The significance of the coefficients was estimated using Student's criterion. The adequacy of the model was checked by Fisher's criterion [8].

3. Research results and discussion

The empirical equation is obtained using regression analysis. This equation characterizes the relationship between roughness and input factors.

\[ Ra = 10^{-6} \cdot (4,53 - 0,79q + 0,02U + 5,5H) \]

Graphs of the dependence of roughness on factors are constructed to analyze the regression model. The surface and contour plots of the significant parameters (q, U and H) contributing change in Roughness (Ra) are shown in Figure 2.
The surface roughness is inversely proportional to the duty cycle of the pulses. From the analysis of the graph it follows that the surface roughness is inversely proportional to the duty cycle of the pulses. An increase in the duration of the ton pulses and a decrease in the toff pulse off time reduces the duty cycle and increases the roughness parameter values. The roughness of the deposited surface decreases by 0.7 times with an increase in the duty cycle of pulses by 1.5 times, from a value of 1.2 to 3.

The roughness of the deposited surface increases with increasing voltage. This fact is explained by the physical nature of the EDM process. The minimum roughness value $Ra = 2.5 \, \mu m$ is achieved with a voltage value of $U = 25 \, V$ and a duty cycle of $q = 4$.

The graph shows that the surface roughness increases with increasing height of the workpiece. When the height of the workpiece increases from 4 mm to 12 mm, the roughness increases 1.1 times and is $Ra = 3.2$. The height of the microlevels increases because the interelectrode gap is distributed unevenly. Also, EDM is formed in the breakdown channel in the process of WCEDM. The probability of accumulation of erosion products in the channel increases with the processing area. Additional spark discharges occur between the electrode-tool and the metal particles of the removed material. Additional spark discharges contribute to the uneven formation of the surface roughness (Figure 3).
Figure 3. The roughness of the machined surface of the deposited titanium VT-01:

a is the minimum value of the parameter $Ra = 2.3 \mu m$ at a voltage of $U = 25 V$, duty cycle $q = 2$, workpiece height $4 mm$, x100;

b - the maximum value of the parameter $Ra = 3.3 \mu m$ at a voltage of $U = 25 V$, duty cycle $q = 3.5$, workpiece height $10 mm$, x100

The surface of the deposited titanium VT-01 has a large number of microroughnesses after processing at maximum speed. Microroughnesses form the general structure of the fracture surface in the form of cobwebs and combined large holes. These wells overlap each other. The VT-01 billet has fewer melted zones after processing. This fact positively affects the quality of the processed weld surface.

4. Conclusions

The empirical model allows us to evaluate the influence of cutting conditions and the height of the deposited titanium billet after on the quality of its surface after WCEDM.

It is shown that when the stress in the gap and the height of the workpiece increase, when processing deposited titanium of the VT-01 grade, the surface roughness $Ra, \mu m$ increases.

The maximum value of the roughness parameter in $Ra = 3.3 \mu m$ is achieved at a voltage of $U = 25 V$, duty cycle $q = 3.5$, and a workpiece height of $10 mm$.

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