INVESTIGATIONS ON SURFACE INTEGRITY PROCESSED BY EDM

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Abstract

Research conducted in many scientific centers on the operational properties of machine parts has shown that one of the critical components affecting the fatigue strength of parts is the condition of the surface integrity of their ingredients. In the case of elements produced by electrical discharge machining, the processes occurring during removal of the material: thermal and chemical, constitute the surface layer with different properties to the bulk material. In the paper presents results of experimental investigation of influence EDM process parameters on surface layers properties. The research was conducted using graphite electrode with varying discharge current, pulse duration, pulse interval. Furthermore, the mathematical model was established to estimate the influence of EDM parameters on surface roughness.

Keywords: Electrical discharge machining, surface roughness, micro-cracks

1. INTRODUCTION

The research conducted in many scientific centres on the exploitation properties of machine parts has shown that one of the essential components influencing the fatigue strength of devices is the condition of the surface layer of their components. Electrical discharge machining is precision methods of manufacturing hard, complex shape, conductive materials. Removal mechanism of the material in EDM is mainly the result of the electrical discharge which causes melting and evaporation in local surface layers of both the workpiece and the working electrode. In result of the impact of the thermal and chemical processes form electrcial discharges a surface layer of material changed properties [1-3]. The quality of surface after EDM process does not always meet the expectations [4,5]. Additional technological operations are used to change the surface integrity. One of the most applicable are electro discharge alloying [6], electrochemical machining [7] use of powders in dielectric [8], laser surface modification [9], applying coatings [10,11] or use hybrid machining [13-15] or nonconventional finishing [16,17]. However, the use of additional technological operations significantly increases production costs. Therefore, this work analyses the impact of the following parameters of EDM discharge current, pulse time pulse interval was conducted. Furthermore, the developed regression models of EDM will allow the selection of the most favourable processing conditions, allow to reduce the use of additive treatments to the minimum necessary.

2. MATERIALS AND METHODS

Experimental studies were carried out on the EDM machine of Charmilles Form 2LC ZNC. Samples of tool steel 1.2713 (55 HRC) after heat treated with dimensions of 12 x 12 x 4 mm was manufactured with a graphite electrode. EDM fluid 108 MP-SE 60 was used as the dielectric. Tool steel 1.2713 is characterized by high dimensional stability and cracks resistance with dynamically changing pressures and rapid heating and cooling during operation. The chemical composition of the steel is presented in **Table 1.** The research was carried out according to a design of experiment three level three parameters. The use of a three-level design it possible to obtain mathematical models of the studied process in the form of a second-degree polynomial.

Table 1 Chemical composition of tool steel 1.2713

Chemical composition (%)											
C	Mn	Si	P	S	Cr	Ni	Mo	W	V	Co	Cu
0.5-0.6	0.5-0.8	0.15-0.4	MAX 0.03	MAX 0.03	0.5-0.8	1.4- 1.8	0.15-0.25	MAX 0.3	MAX 0.1	MAX 0.3	MAX 0.3

The square model allows describing the extremity of the build regression function. **Table 2** shows the levels of machining parameters carried out in the experimental design. The ranges of variables were selected on the basis of conducted preliminary experiments. The primary assumption was to obtain a stability discharge in all range of conducted experiments.

Table 2 Design of experiment

Symbol	EDM parameters	Level 1	Level 2	Level 3
A	discharge current *I* (A)	3	8.5	14
B	pulse time t_{on} (μs)	10	205	400
C	time interval t_{off} (μs)	10	80	150

Measuring the surface topography after the EDM was carried out on a Taylor-Hobson FORM TALYSURF Series 2 scan profilometer. For each sample, the area 2 x 2 mm was measured. The following 3D parameter of surface topography was selected to characterise the surface after EDM:

$$Sa = \frac{1}{NM}\sum_{x=0}^{N=1}\sum_{y=0}^{M=1}|z_{x,y}| \quad (1)$$

Surface roughness *Sa* the arithmetic mean of the deviations from the mean - average value of the absolute heights over the entire surface.

Regression analysis was used to build empirical models of influence EDM parameters pulse current, pulse time and time interval on roughness *Sa.* In the study second-order polynomial regression model was chosen to fit the response function to experimental results equation:

$$Y = \beta_0 + \sum_{i=1}^{k}\beta_i X_i + \sum_{i=1}^{k}\beta_i X_i^2 + \sum_{i=1 i \neq j}^{k}\beta_{ij} X_i X_j \quad (2)$$

where:

β_0 is a constant

β_i, β_{ii}, β_{ij} represent the coefficients of linear, quadratic, and cross terms

X_i corresponds to the independent variable

For developed regression equation of surface roughness *Sa*, the correlation coefficient *R* was determined. Coefficient *R* is reflecting the variability of the investigated parameter. Adequacy of calculated *R* for the associated *p*-value (p = 0.05) was checked with the Fisher - Snedecor test. The significance of regression equation terms was also verified using the t-student test for the associated *p*-value (p = 0.05).

The result of measured roughness dependent on investigated EDM parameters present in **Table 3.**

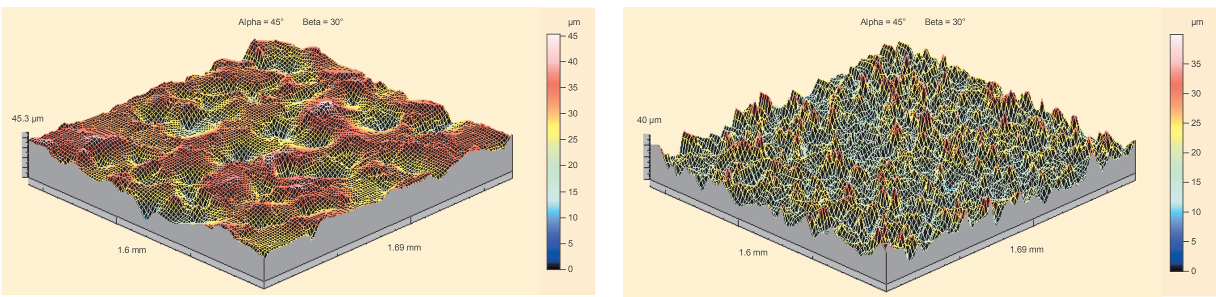
Table 3 Mesures surface topography roughness *Sa* with EDM parameters

Exp. no.	Parameters			Observed values
	Discharge current *I* (A)	Pulse time t_{on} (µs)	Time interval t_{off} (µs)	Roughness *Sa* (µm)
1	3.0	13	10	1.96
2	3.0	206	150	1.85
3	3.0	400	80	2.38
4	8.5	13	150	3.03
5	8.5	206	80	5.98
6	8.5	400	10	3.88
7	14.0	13	80	3.41
8	14.0	206	10	9.29
9	14.0	400	150	11.5
10	8.5	206	80	5.98
11	3.0	206	80	1.9
12	8.5	13	80	2.99
13	14.0	206	80	10.5
14	8.5	400	80	4.05
15	8.5	206	10	6.22
16	8.5	206	150	5.4

3. RESULTS AND DISCUSSION

3.1. Surface texture

The primary factor directly affecting the properties of machine parts is their surface texture. Conducted experimental investigations show that parameters such as surface roughness directly depend on the applied machining parameters. Surface topography after EDM is the result of the overlapping of craters from single discharges and has the isotropic structure **(Figure 1)**.



(a) (b)

Figure 1 Surface texture of tool steel 1.2713 after EDM (a) *U* = 25 V, *I* = 3,2 A, t_{on} = 400 µs, t_{off} = 100 µs, (b) *U* = 25 V, *I* = 8,6 A, t_{on} = 400 µs, t_{off} = 150 µs

Based on results from the conducted experiment an regression model of influence discharge current *I*, pulse time t_{on} and time interval t_{off} on the surface roughness *Sa* was build. After remove the non-significant terms, the final regression equations for the surface roughness *Sa* presented in equation (3). **Table 4** presents the regression summaries.

$$Sa = 2.18 + 0.01\ I^2 - 0.0000\,3\ t_{on}^2 + 0{,}002\ \ I\,t_{on} \tag{3}$$

Table 4 Regression summary

Investigated parameters	Calculate regression statistics			
	Ratio *R*	F/F_{kr}	*p-value*	Standard error of estimate
Sa	0.95	15.22	0.00001	1.1154

The correlation coefficients *R* have value 0.95 which indicates that that adopted model explain the variation of surface roughness *Sa* up to the 95 %. The high value of F/F_{kr} indicates that building model is adequate. **Figure 2** shows the estimated response surface for the roughness parameters *Sa* in relative to the discharge current *I* and pulse time t_{on}.

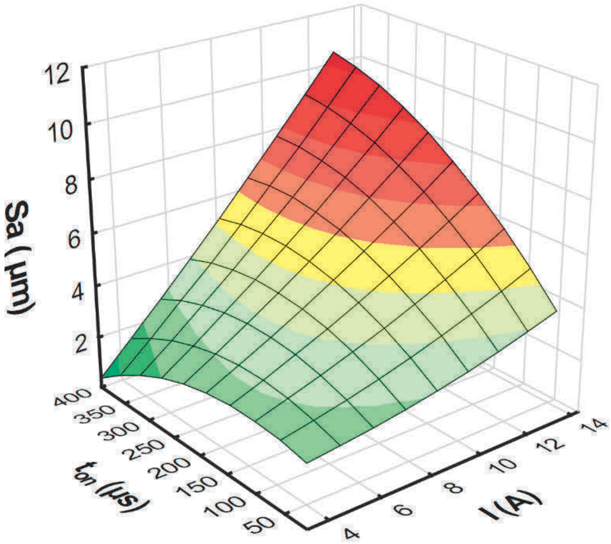
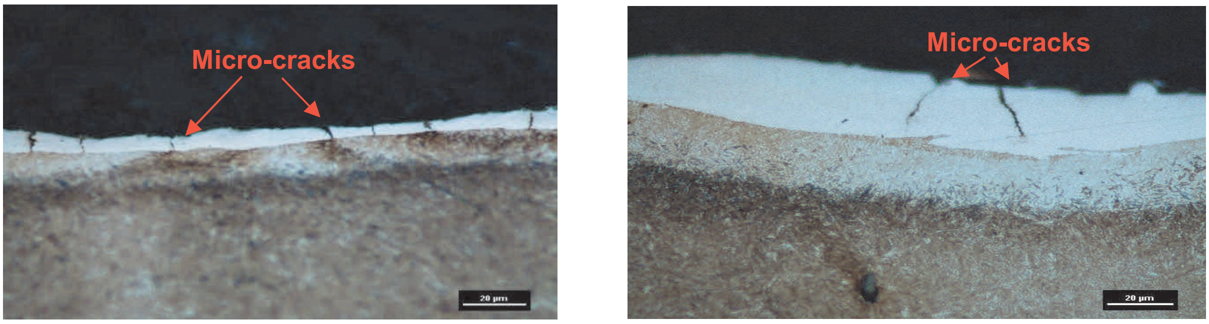


Figure 2 Estimated response surface for the arithmetic mean of the deviations from the mean *Sa*

Surface roughness *Sa* (**Figure 2**) is mainly dependent on the discharge current *I*. The increased current and pulse time cause an increase in the amount of eroded material in a single discharge. However, these relations are not directly proportional. At low currents (about 3 A) increasing the pulse time (and therefore energy) does not lead to a significant increase in the *Sa* parameter. With the same current and increasing the pulse time, change only the diameter of craters which causing that the value of *Sa* not changed. With the increasing pulse time and current, the diameter and the depth of the craters increase. Heats generated in the discharge are delivered to the workpiece and cause melting and evaporation more volume of material.

3.2. Metallographic structure

As a result of rapid local thermal processes during electrical discharge machining, phase changes occur in the surface layer of the workpiece. The analysis of images of the metallographic structure of tool steel 1.2713 showed the occurrence of three characteristic sublayers for the whole range of machining parameters investigated (**Figure 3**).



(a) (b)

Figure 3 Metallographic structure of the surface after EMD corresponding to: (a) U = 25 V, I = 3.2 A, t_{on} = 200 μs, t_{off} = 80 μs, (b) U = 25 V, I = 14.3 A, t_{on} = 400 μs, t_{off} = 80 μs

An external molten layer (commonly referred to as a white layer), is formed by melting and rapidly solidifying a thin layer of metal not removed from the surface of the crater during an electric discharge. Haet effet zone, which is located directly under the melted layer (visible as a light structure) is characterised by an increased hardness about the core material. The last observed layer is a tempered layer which is visible as a dark streak immediately below the heat affected zone layer.

Electrical discharges lead to local melting, material evaporation, removal of erosion products and rapid re-solidification of the molten metal. The described processes caused to the generation of typical microstructure defects of material such as micro-cracks. Microcracks are an undesirable effect, resulting in reduced fatigue resistance and corrosion resistance. In many cases, micro-cracks propagate to the end of the white layer (**Figure 3**). In rare cases, a propagation crack has been observed penetrating into the core of the material. Micro-cracks can be observed directly on the machining surface.

4. CONCLUSIONS

Experimental studies and their analysis show that the main factors influencing the surface roughness *Sa* after EDM is the discharge energy. The increase in current and pulse time increases the diameter and power of the discharge channel. It is leading to the generation of the roughness of much greater height and the distance between the individual vertices. The developed model of surface roughness *Sa* is considered reliable representatives of the experimental results with prediction errors less than ± 5 %. It can be used in the technology of manufacturing parts of tool steel 1.2173 for achieved desired surface roughness.

As a result of rapid local thermal processes during electrical discharge machining, in surface layers of tool steel 1.2173 phase changes occur. In the surface layer of the manufacturing, workpiece micro-cracks have been observed. Micro-cracks an undesirable effect, resulting in reduced fatigue resistance and corrosion resistance.

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