ANALYSIS OF SURFACE TOPOGRAPHY AFTER MICRO-WIRE ELECTRICAL DISCHARGE MACHINING OF NICKEL-BASED SUPERALLOY

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Abstract

Micro-mechanisms are one of the main areas of development in manufacturing technology widely used in various production fields. Currently, new microelements are made of superalloys due to the high requirements of corrosion resistance and temperature resistance. Furthermore, effective methods of making micro elements are sought, which on the one hand will ensure the appropriate dimensional and shape accuracy and, on the other hand, the expected surface quality. Conducted research was focused on analyzing the influence of micro wire electrical discharge machining on the parameters of selected surface topography features, which directly impact the tribological properties of the surface of micro parts. The effect of the WEDM parameters on the functional parameters of the surface texture: *Sk* - the roughness of the core, *Spk* - the roughness of the peak, *Svk* - the roughness of the valleys are presented and discussed.

Keywords: EDM, electrical discharge machining, holes, geometry accuracy

1. INTRODUCTION

The application of new micro mechanisms from difficult-to-cut materials such as super nickel alloys requires the development of new machining technologies that will allow to obtain the appropriate dimensional accuracy of microelements and achieve the desired surface quality. One of the technologies that allow for the production of geometrically complex microelements made of nickel superalloys is wire electrical discharge machining. Using a working electrode with dimensions less than / equal to 0.1 mm allows for the production of microelements. In WEDM electric discharges occur between the wire electrode and the workpiece, causing the material to be locally removed by melting and evaporation, as a result of the impact of thermal processes from discharge [1-6]. On the surface of the workpiece and the working electrode, craters are formed (**Figure 1**).

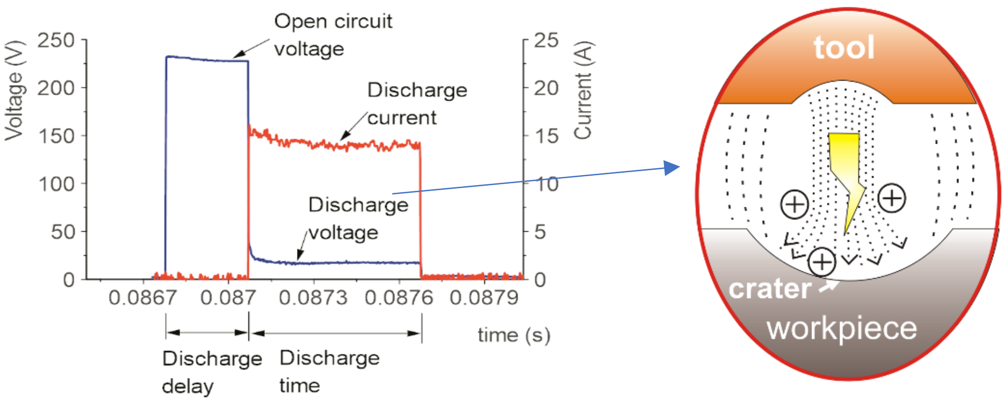


Figure 1 Scheme of material removal mechanism in electrical discharge machining

Surface topography is formed by the overlapping of individual craters and is specific to this treatment process [7-11]. The complexity of the physical phenomena occurring in the WEDM process, which are determined both by the parameters and the machining conditions, cause new solutions to be constantly sought. Main attention is focused on providing the appropriate dimensional and geometric accuracy of the cut elements and obtaining the appropriate efficiency of the process [12-16]. Increasing demand for wear-resistant of manufactured microelements causes surface texture properties in many cases to play a key role. The relatively small number of research concerned the analysis of the influence of micro WEDM parameters on the surface topography properties. Therefore in this study, the main attention was focused on analyzing the effect of the micro WEDM parameters on the functional parameters of the surface texture: *Sk* - the roughness of the core, *Spk* - the roughness of the peak, *Svk* - the roughness of the valleys. The main goal of this research is a better understanding of the relationship between the influence of WEDM process parameters and surface topography properties described with the material ratio curve.

2. MATERIALS AND METHODS

Experimental investigation of influence discharge energy during micro WEDM of Inconel 718 was conducted on the GF Charmiles machine Robofil 440. Samples with the dimension of 5 mm x 5 mm were cut by a brass wire electrode with a diameter of 0.1 mm. During machining dielectric deionized water was flushing the gap. Experiments were conducted with the following machining conditions: pulse current in the range I_c = 22 - 44 A, pulse duration in the range t_{on} = 0.2-0.6 μs, with hold constants (open voltage U_0 = 225 V, discharge voltage U_c = 30 V), and time interval t_{off} = 8 μs.

Discharge current *I*c, pulse duration time t_{on}, along with discharge voltage U_c defines the energy of the electrical discharge which was calculated according to equation (1):

$$E = \int_0^{ton} U_c(t) \cdot I_c(t)\, dt \quad (mJ) \tag{1}$$

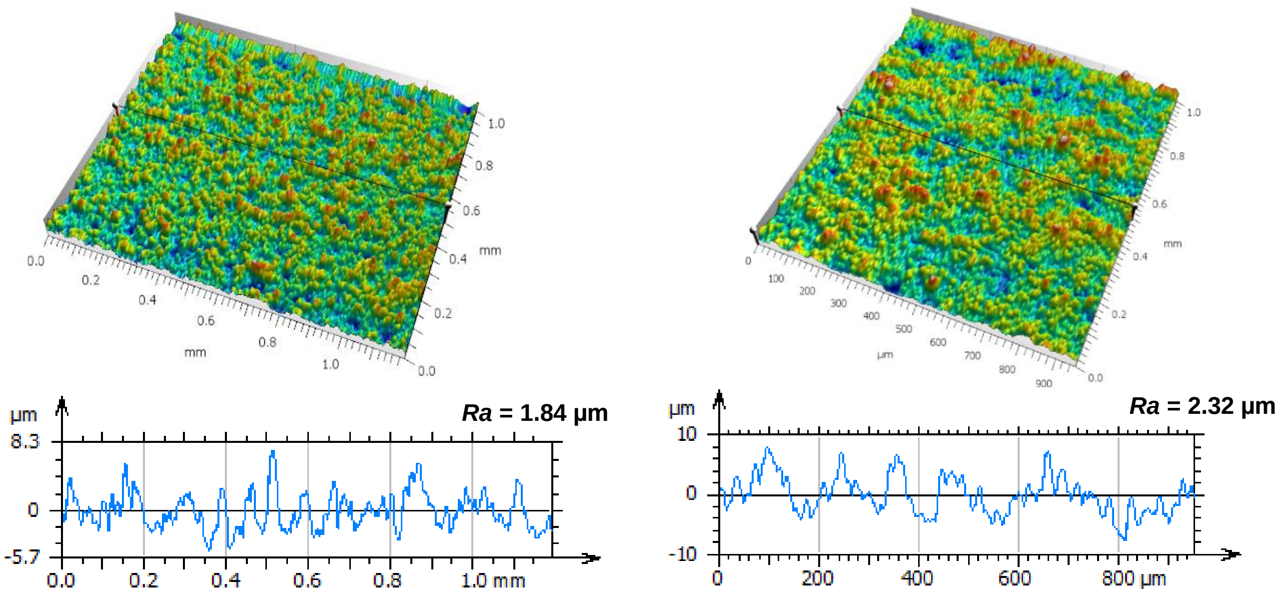
Investigation of the surface topography properties of Inconel 718 after the mikro WEDM was carried out on a Taylor-Hobson FORM TALYSURF Series 2 scan profilometer. To investigate the surface roughness, an area of 1 x 3 mm was measured with a discretization step (10 μm) and Y-axis and X-axis. To characterize the surface topography after the WEDM, the following functional parameters were chosen: *Sk* - the roughness of the core, *Spk* - the roughness of the peak, *Svk* - the roughness of the valleys. **Table 1** shows the levels of machining parameters carried out in the experiment.

Table 1 WEDM process parameters and observed values

Element	Mikro WEDM parameters					Measured parameters				
	t_{on} (μs)	t_{off} (μs)	I (A)	Uc (V)	E (mJ)	Sk (μm)	Spk (μm)	Svk (μm)	Smrk1 (%)	Smrk2 (%)
1.	0.2	8	68	30	0.066	6.935	3.138	2.021	12.02	91.89
2.	0.6	8	68	30	0.396	8.633	4.125	2.678	11.94	91.27

3. RESULTS AND DISCUSSION

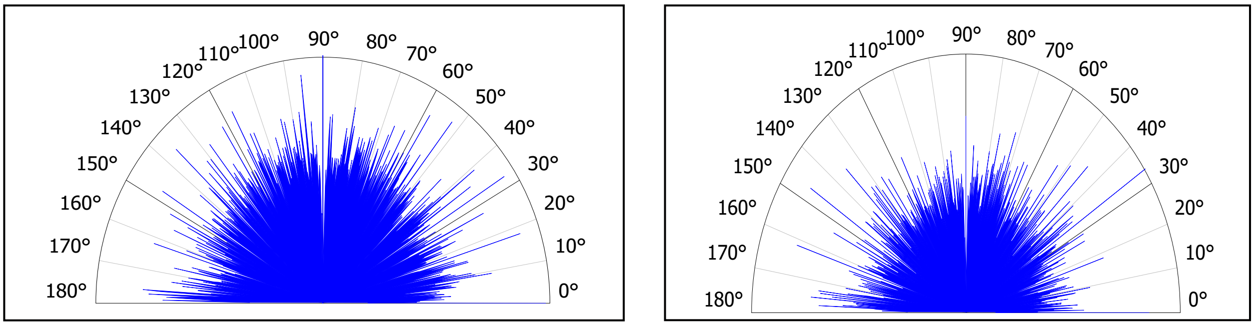
Analyzed samples of surface properties after micro WEDM Inconel 718 for two different levels of discharge energy sample 1: E= 0.066 mJ and sample 2: E= 0.396 mJ have been carried out. **Figure 2** presents the surface topography with profile section and polar graph with texture direction.



(a) (a)

Figure 2 Surface topography of Inconel 718 with profile section and polar graph with texture direction after WEDM: (a) discharge energy E = 0.066 mJ; (b) discharge energy E= 0.396 mJ

The surface topography after WEDM is a result of overlapping craters of single electric discharges. The surface roughness for the sample is *Sa* =2.182 µm, *Ra* = 1.84 µm, and for the second sample, *Sa* =2.747 µm, *Ra* =2.32 µm. The surface structure is isotropic (**Figure 3**).



a) b)

Figure 3 Polar graph with texture direction after WEDM for: (a) discharge energy E=0.066 mJ; (b) discharge energy E=0.396 mJ

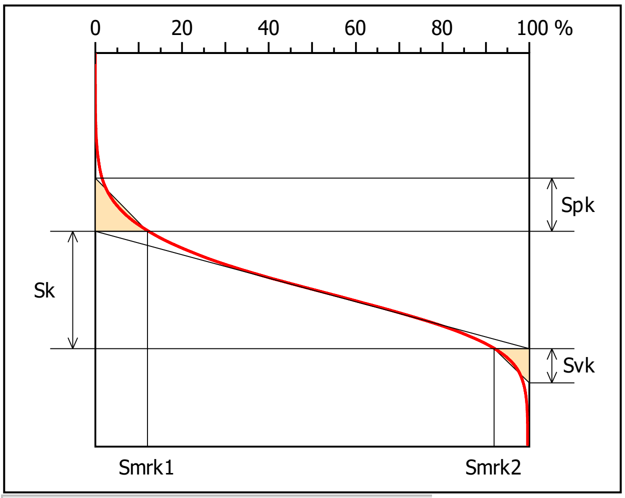
The tribological properties of the surface directly depend on the used processing technology. The material ratio curve (**Figure 4**) gives information about the tribological properties of functional elements such as the load-carrying capacity or wears resistance. The shapes of the material ratio curve can take various profile types and depends on the type of machining used. In the case of wire electrical discharge machining in which the electrical discharges have a stochastic character, the material ratio curve exhibits an S-letter shape. The material ratio curve is characterized by parameters:

- *Spk* - the value of the roughness of peaks gives information about the assessing of the surface resistance to abrasion,
- *Sk* - the roughness of the core is a measure of the effective depth of inequality,
- *Svk* - the roughness of valleys, which presents the reduced depth of the cavities, describes the ability to maintain fluid through the sliding surfaces,

- *Sr1* - which describes the percentage contribution of vertices,
- *Sr2* - which describes the percentage contribution of the recesses is described by the parameter.

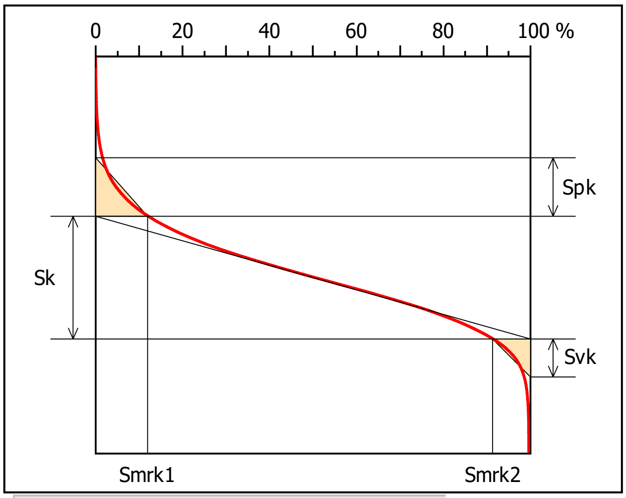
The comparative analysis of the parameters describing the material ratio curve shows a significant influence of the discharge energy on the properties of the treated surfaces. For the first sample, where the discharge energy was E = 0.066 mJ; the value of the parameters *Sk* - the roughness of the core, *Spk* - the roughness of the peak, *Svk* - the roughness of the valleys was as follows: *Sk* = 6.935 µm, *Svk* = 2.021 µm, *Spk* = 3.138 µm. Increasing the discharge energy to E= 0.396 mJ (for sample 2) leads to grow the value of each investigated parameters: *Sk* = 8.633 µm, *Svk* = 2.678 µm, *Spk* = 4.125. The percentage contribution of vertices is described by the parameter *Sr1* (upper bearing of the surface) and is about 12 % and *Sr2* (lower bearing of the surface) is 92 % for both samples. The higher value of the roughness of the peak *Spk* indicates that there are more peaks investigated. From a tribological point of view, it can lead to a decrease in the area of contact between the two working together surfaces. In this case, the peaks will be damaged and will affect the lapping process. Nevertheless, the increase in electric discharge energy is not directly proportional to the growth of parameters describing the material ratio curve.

WEDM is characterized by its complexity, resulting in both the material removal physics and the machining conditions affecting its stability. Discharges in the gap could be divided into individual cases. In the first stage, discharges occur in the place where the gap is the smallest. Next, discharges can occur on the single erosion produced. Finally, discharges will appear in the place of concentration of debris. Overlapping craters of single electrical discharges from the surface topography Tribological properties of manufactured surfaces represented by material ratio curve will depend on the geometry of the crater, which directly depends on the discharge energy. Conducted studies indicate that a significant increase in discharge energy does not cause a substantial increase in the amount of eroded material during a single electric discharge. In this case, discharge voltage was constant. The discharge energy E was set up by changing discharge current and pulse time (equation 1). The distance gap was constant, which reduced the effect of the discharge energy value on the amount of eroded material in a single discharge.



Parameters	Value	Unit
Sk	6.935	µm
Spk	3.138	µm
Svk	2.021	µm
Smrk1	12.02	%
Smrk2	91.89	%

a)



Parameters	Value	Unit
Sk	8.633	µm
Spk	4.125	µm
Svk	2.678	µm
Smrk1	11.94	%
Smrk2	91.27	%

b)

Figure 4 Material ratio curves after micro WEDM of Inconel 718 for: (a) discharge energy E=0.066 mJ; (b) discharge energy E=0.396 mJ

4. CONCLUSION

The experimental studies were focused on the analyses of surface texture properties represented by the material ratio curve. The influence of discharge energy during the micro wire electrical discharge machining of Inconel 718 on tribological properties was established. Summarizing the results of the experimental investigation can be concluded:

- The material ratio curve after micro WEDM exhibits an S-letter shape which proves that the surface is random. This is a direct result of the stochastic nature of electrical discharges occurring between the thin wire electrode and workpiece.
- The increase in electric discharge energy leads to an increase in the value of parameters describing the material ratio curve.
- For the low value of the discharge energy the tribological properties of the cut surface are improved. The lover value of the roughness of the peak Spk indicates that there are less peaks in investigated are compared to the treated surface with higher discharge energy. From a tribological point of view, it can lead to an increase the area of contact between the two working together surfaces and have a good influence on the lapping process.

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