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Authors: Rafał Świercz, Dorota Oniszczyk-Świercz, Rafał Nowicki

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Wire electrical discharge machining nickel super alloy

Wycinanie elektroerozyjne nadstopów niklu

RAFAŁ ŚWIERCZ
DOROTA ONISZCZYK-ŚWIERCZ
RAFAŁ NOWICKI *

This article presents the influence of process parameters of wire electrical discharge machining using coated brass on the surface roughness and material removal rate of Inconel 718. Studies were conducted by design of the experiment. Based on the survey developed mathematical models which allow selecting the most favorable machining parameters depending on the desired process performance and quality features of the surface texture.

KEYWORDS: wire electrical discharge machining, surface roughness, Inconel,

Electric discharge machining is a modern technology that allows you to shape difficult-to-cut materials. The physics of phenomena that occur in the inter-electrode gap during WEDM (wire electrical discharge machining) has a complex character [1, 2]. In the WEDM process, the working electrode and the workpiece are connected to the current pulse generator. After applying voltage to the electrodes in the inter-electrode gap, the dielectric is ionized. The intensity of the electric field is inversely proportional to the distance between the workpiece and the working electrode. In the place where the distance between the electrodes is the smallest, the electrical strength of the medium decreases, which initiates electrical breakdown causing melting and evaporation of a small amount of material [3, 4]. The stochastic course of the initiation of electrical discharges determines the way of conducting experimental research. Due to the large number of process variables that determine the WEDM process, there are difficulties with unambiguous identification of the impact of processing parameters on its quality effects [5-7]. Therefore, statistical mathematical models of the process are built, based on the theory of research using the planned experiment [8].

Purpose of research

The aim of the study was to analyze (theoretically and experimentally) the electric discharge cutting process of super alloys with a galvanized electrode, including the analysis of the qualitative effects of the treatment, such as surface roughness parameters of the processed material and linear cutting speed.

Experimental research

Experimental studies were carried out on the basis of the planned Hartley experiment - rotatable, five-level, three-parameter. The purpose of the planned experiment was to investigate the simultaneous influence of several processing parameters on the selected parameters of the state of the surface layer (surface roughness) and the efficiency of the process.

The input parameters in the planned experiment were:

- pulse time = $0.3 \div 1 \mu\text{s}$,
- break time between pulses $t_{\text{off}} = 5 \div 25 \mu\text{s}$,
- scrolling speed of the working electrode $WS = 2 \div 8 \text{ m/min}$.

The application ranges of the parameter values in the planned experiment were selected based on the analysis of technological tables - for the adopted material, 10 mm cutting height and a single pass - and on the basis of preliminary tests that took into account the machining stability and no wire breaks.

WEDM was treated with samples of nickel superalloys - Inconel 718. This material was chosen due to its wide range of applications in the aerospace, automotive and energy industries. Inconel 718 retains its strength properties even at high temperatures. It is estimated that more than half of the elements used in the aviation industry are made of alloys on the basis of the nickel. These are, in particular, the components of the section of hot gas engines, e.g. turbine components, paddles, combustion chamber assembly.

The research on the impact of processing parameters on the condition of the surface layer of Inconel 718 was carried out on the Robofil 440 electric discharge cutter. The experiment employed a working electrode in the form of a brass, galvanized wire with a diameter of $\varnothing 0.25 \text{ mm}$. The processing consisting in cutting cubes from the semi-

* Dr inż. Dorota Oniszczyk - Świercz (doo@meil.pw.edu.pl), dr inż. Rafał Świercz (rsw@meil.pw.edu.pl), inż. Rafał Nowicki (rano@meil.pw.edu.pl) – Instytut Techniki Wytwarzania, Politechnika Warszawska

finished product - Inconel 718 - took place in its full immersion in the dielectric (in demineralized water, deionized water).

Test results

The measurement of the geometric structure of the surface of the cut samples was carried out using the high (first) class of the Form Talysurf Series 2 scanning profilometer by Taylor Hobson. Based on the measurements, it was found that the geometric structure of the surface after WEDM treatment is random and characterized by high surface density of local elevations. The randomness of the structure is related to the physics of the material removal phenomenon in the process of erosion and the unevenness of occurrence of electrical discharges on the length of the working electrode. In the place of discharge, a crater forms, part of the molten metal is ejected into the inter-electrode gap and removed along with the passing dielectric. The molten metal, which has not been removed from the surface of the crater, solidifies it again, forming a thin layer (on the order of several micrometers) with properties changed in relation to the core material. During the treatment, hundreds of electric discharges occur that shape the geometric structure of the surface, characteristic for the WEDM process, which is the effect of overlapping craters from individual discharges (fig. 1).

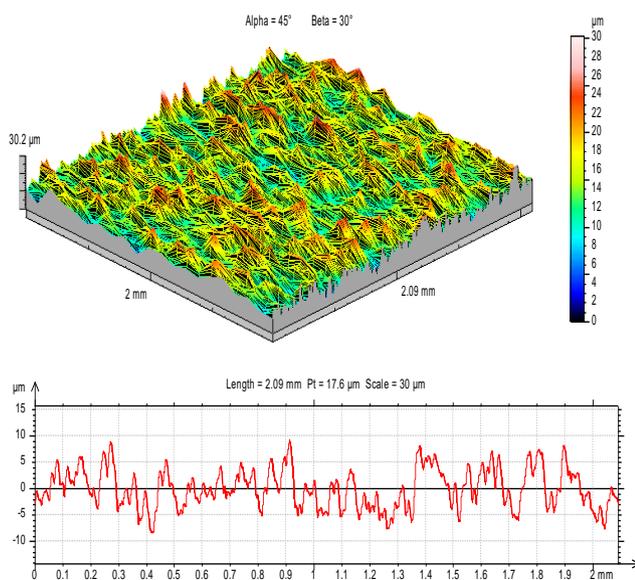


Fig. 1. Surface topography after WEDM machining with a surface profilograph

On the basis of the results of the research, statistical mathematical models were created, describing the influence of input factors on the selected parameter of the geometric structure of the surface. The results were approximated by the polynomial regression function. At the significance level of $\alpha = 0.05$, a high value of the multiple correlation coefficient R was obtained, which determines the quality of the fit of the function to the results of the measurements. The significance of individual coefficients was checked by the F -Snedecor test (if $F/F_{kr} \geq 1$, the R coefficient is significant). The significance of the influence of individual regression equation coefficients was also taken into account, which was verified by the Student's t test (at the level of significance $\alpha = 0.05$).

TABLE I. Regression equation describing the influence of processing parameters on surface roughness S_a

Equotation	R	F/F_{kr}
$S_a = 2,44 - 1,16 t_{on}^2 + 0,1 t_{on} t_{off} + 0,95 t_{on} - 0,05 t_{off}$	0,96	1,88

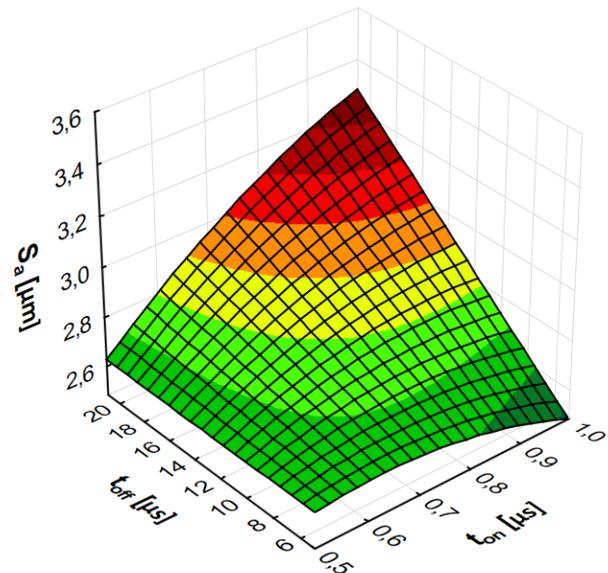


Fig. 2. Relationships of the surface roughness parameters S_a from the time of the tone pulse and the break time t_{off}

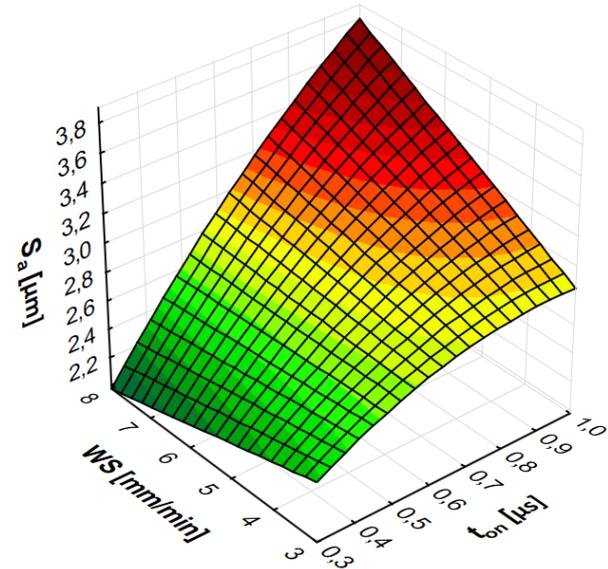


Fig. 3. Relationships of surface roughness parameters S_a from the time of the tone pulse and speed of the WS electrode scrolling

The selected regression dependence of surface roughness is shown in the table And, and its graphical interpretation - in fig. 2 and fig. 3.

The analysis of the regression equation and its graphical interpretation indicate that the value of the S_a roughness parameter depends mainly on the time of the tone pulse, i.e. on the energy value of the electric discharge, because the pulse time is a parameter that simultaneously determines the discharge current. As the pulse time increases, the current increases and the amount of eroded material increases in a single pulse, which leads to increased surface roughness.

The influence of the pause time between impulses is negligible in the case of a small value of the pulse time. As

the pulse time increases and the pause interval between pulses increases, the S_a parameter increases. This is related to the physics of phenomena occurring in the inter-electrode gap.

The time interval between impulses is responsible for deionizing the inter-electrode channel and for removing the erosion products from the work gap. After the electric discharge, the molten material evaporates to form craters on the treated surface. With a short break time, the discharge channel will not be fully deionized and the melted material will not evaporate. This may lead to the situation that the electric discharge will be initiated again in the same place and will be replicated on the surface of the melt, which has not been removed during the interval between pulses. Extending the break time with a short pulse time results in a slight increase in the S_a parameter. This may be related to the amount of heat energy generated and supplied to the workpiece during the electric discharge which is responsible for melting and evaporation of the material. The amount of this energy depends on the time of the pulse and hence on the current. Extending the break time at high values of tons increases the surface roughness (S_a parameter), because then full de-ionization takes place in the gap and a better purification of the treatment products takes place. The increase in the current causes an increase in the diameter and power of the plasma channel during the electric re-discharge, which leads to the formation of craters of ever larger sizes and depths and, consequently, to an increase in the S_a parameter roughness.

According to the regression equation, the scroll speed of the WS wire does not significantly affect the value of the S_a parameter. There is a slight decrease in roughness with short pulse time and high wire rewinding speed, which can be the result of a decrease in the number of discharges per unit of wire length. Extending the pulse duration and increasing the wire rewinding speed leads to an increase in the S_a parameter, because the discharge energy is higher which generates a greater surface roughness. This is due to better cleaning of the inter-electrode gap with erosion products.

The used working electrode was covered with zinc, which evaporated during processing and thus intensified the cleaning of the working gap.

The longer break between pulses provides for greater stabilization and better deionization of the inter-electrode channel, which reduces the probability of non-uniform electrical discharges on the surface of the wire electrode, generating a higher surface roughness.

One of the factors determining the economics of using spark erosion is the cutting line speed. The determined regression dependence of the rope cutting speed is shown in the tab. II, and its graphical interpretation - on fig. 4.

TABLE II. Regression equation describing the effect of treatment parameters on the linear speed of V_c cutting (in mm/min)

Equotation	R	F/F _{kr}
$V_c = -2,85 + 24,05 t_{on} - 16,3 t_{on}^2 - 0,005 t_{off}^2 + 0,22 t_{on} t_{off}$	0,97	1,87

The main factor affecting the cutting performance is the time of the tone pulse. In this case, the influence of the pause time between the toff pulses is low, and the scroll speed of the WS working electrode is zero. Extending the pulse time promotes an increase in the energy of discharges, which leads to the eroding of a larger volume of material in a single pulse. This is manifested by an increase in the speed of cutting and surface roughness.

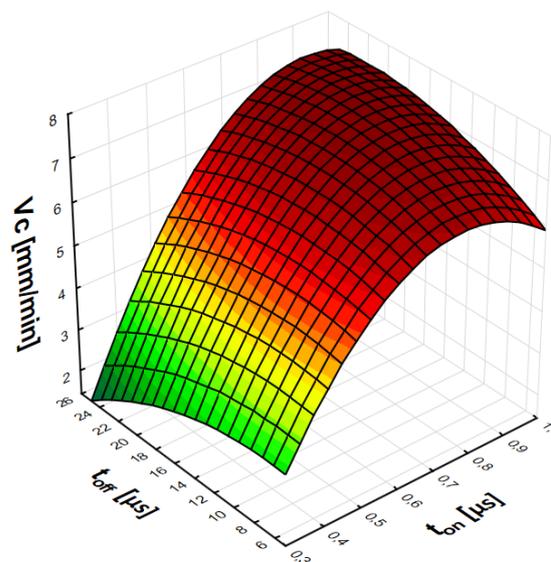


Fig. 4. Dependence of the cutting speed V_c on the time of the tone pulse and the break time t_{off}

Conclusions

The experimental investigations carried out indicate that in the case of spark erosion of Inconel 718 with galvanized brass wire, the greatest impact on the process efficiency and parameters of the geometry of the surface had pulse time and (to a lesser extent) the interval between impulses. The speed of wire rewinding only slightly affects the surface roughness generation, and the cutting speed does not affect at all.

The results can be the basis for the technology of processing nickel super alloys on industrial electric discharge cutters. In turn, the mathematical models of the WEDM process enable the selection of process parameters that will ensure the achievement of the assumed effects of the treatment (ie the specified process efficiency and surface stereometry features). At the same time, intelligent machining strategies can be built on the basis of these models.

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