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BEHAVIOUR OF CONICAL SURFACES DURING THE ELECTROCHEMICAL MACHINING PROCESS

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ABSTRACT: The electrochemical machining process is based on the material removal from workpiece as a consequence of electrochemical reactions developed between the workpiece material and electrolyte, when both tool electrode and workpiece are found in an electrolyte and they are connected in the electric circuit of a direct current supply. Distinct factors could exert influence on the sizes of parameters of technological interest in case of electrochemical machining process. The paper presents the results of some theoretical considerations and experimental researches concerning the evolution of the work gap size and diminishing the test piece mass in case of using a conical active surface of the test piece and an aqueous solution of sodium chloride as electrolyte. The experimental results were mathematically processed and empirical mathematical models were determined. The empirical models and the graphical representations based on these empirical models illustrated the diminishing of the final gap size when the angle of conical surface increases and when the initial gap size is higher; the increase of voltage determines an increase of the final gap size. A similar influence is exerted when the test piece mass is considered as output factor.

KEY WORDS: electrochemical machining, conical surface, influence factors, gap size, material removal rate, power type empirical models.

1. INTRODUCTION

The nonconventional machining technologies could be defined as a group of technologies based essentially on the use of such a type of energy in the work zone that the material is removed from the workpiece as a consequence of processes different in comparison with the processes specific to the so-called classical machining technologies. If in case of classical machining technologies the plastic deformation process is especially applied in order to remove the material from workpiece as chips, in the case of the non-conventional technologies thermal or chemical processes are essentially developed in the work zone and they contribute to the material removal from workpiece. It is accepted that the nonconventional technologies are applied when the classical machining technologies could not be used, due to high hardness of the workpiece material or when the surfaces to be obtained cannot be addressed by the classical machining technologies [5, 6, 7].

If the criterion of the main processes developed in the work zone is considered, one can highlight machining processes based on thermal phenomena (electrical discharge machining, plasma beam machining, laser beam machining, electron beam machining) and chemical phenomena (chemical machining, electrochemical machining), respectively. There are also hybrid nonconventional machining process which combines either nonconventional machining processes (electrochemical discharge machining, laser assisted electrical discharge machining, laser assisted plasma beam machining etc.) or just nonconventional machining processes with classical machining process (laser assisted cutting machining, plasma assisted cutting machining etc.).

As above mentioned, the electrochemical machining is included in the larger group of nonconventional machining processes based on chemical phenomena; essentially, one can consider that the electrochemical machining is based on the material removal process developed as a consequence of the change of material and electrical charges between the tool electrode, electrolyte and workpiece material. The electrochemical machining could be applied to electro conductive materials, when the workpiece material is too hard or the surface could not be obtained efficiently by other machining processes.

As a consequence of the electrochemical reactions developed between the workpiece material and electrolyte when the tool electrode and workpiece are connected in the circuit of direct current supply, there is a phenomenon of passivation, materialized in diminishing the concentration of the electrolyte near the machined workpiece surface. The new formed passivating layer could be sometimes strongly adhered to the workpiece surface and adequate action could be materialized in order to remove the passivating layer. There are distinct ways in which the passivating layer could be removed from workpiece surface and from work zone: one could highlight the natural depassivation, the hydrodynamic depassivation, the mechanical – abrasive depassivation etc. If in the case of natural deppasivation the passivating layer is removed under the action of hydrogen bubbles which stir the electrolyte, in the case of hydrodynamic depassivation, the electrolyte is circulated in the work gap with high speed and under high pressure; in this way, the passivation layer is broken and removed from work zone.

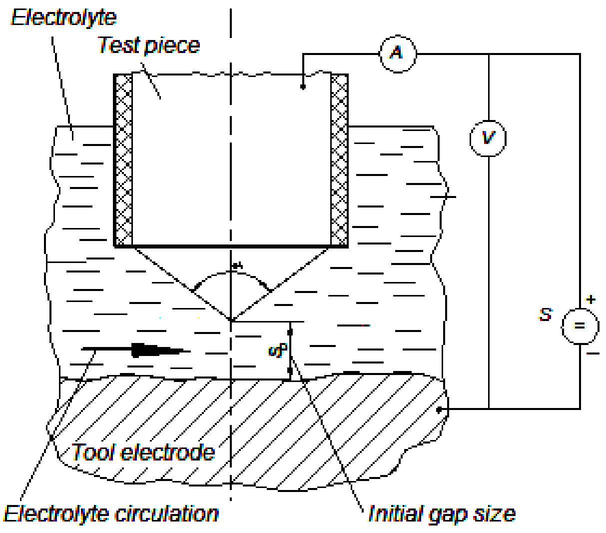

Figure 1. Experimental scheme for the study of electrochemical machining process

In the case of the machining processes based on the natural or hydrodynamic depassivation, the main parameters of technological interest are the evolution of the machining gap, the machining accuracy, the material removal rate, the roughness of the machined surface etc. One could remark that in case of the electrochemical machining process, there is not a tool electrode wear and the superficial layer resulted by machining is not significantly thermally or mechanically affected. On the sizes of technological interest, many groups of factors could exert influence: values of electrical parameters, chemical properties of workpiece material, chemical and hydrodynamic properties of electrolyte, pressure and speed of electrolyte circulation in work gap etc.

Over the years, the researchers were interested in investigation of the influence exerted by distinct factors on the sizes of parameters of technological interest. Thus, Klocke et al. [3] proposed a multi-physical model for the material removal in case of electrochemical machining process, by taking into consideration a large set of machining conditions. A research objective was also to determine the shape of the cathode active surface by a strategy in which the blade – test piece was used in order to establish the cathode profile by inverting the electric field.

As other machining methods, the electrochemical machining was studied in order to establish conditions for obtaining parts or surfaces of small dimensions.

Thus, Kurita et al. [4] developed an electrochemical micromachining system for which the optimal

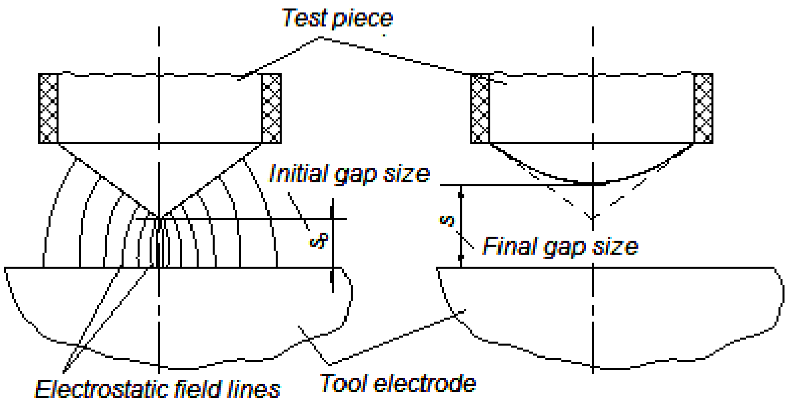

Figure 2. Initial and final gap size

machining conditions were investigated. They considered that factors able to affect the evolution of electrochemical micromachining process are the machining voltage, pulse-on time, pulse-off time, amplitude of flushing out and electrolyte concentration.

Hinduja and Kunieda analysed a set of models applied in order to simulate the phenomena specific to the electrochemical machining process and highlighted the significance of current density distribution for anodic dissolution in the material removal process [2].

In the present paper, some results obtained in the study of the electrochemical process based on hydrodynamic depassivation and taking into consideration conical surfaces of the test piece are discussed.

2. PREMISES FOR EXPERIMENTAL STUDY

The graphical representation from figure 1 was taken into consideration in order to illustrate some aspects corresponding to the electrochemical machining process.

The test piece has a cylindrical shape, but it presents a conical active surface. This shape of the test piece was selected in order to faster and clearly observe the evolution of the machined surface during the machining process.

In order to avoid the participation of the cylindrical surface of the test piece to the electrochemical machining process, the cylindrical surface was covered with a plastic tube.

The tool electrode has a plane active surface. Both tool electrode and test piece are connected in the electric circuit of direct current supply *S* and they find in a salt (sodium chloride) aqueous solution having the role of electrolyte. In order to notice the evolution of some electrical parameters, an ammeter and a voltmeter were also included in the electric circuit of direct current supply *S*.

The hydrodynamic depassivation scheme was adopted in order to remove the electrolyte from machining gap; this means that a pump was used in order to ensure the electrolyte circulation in the machining zone.

When the tool electrode and test piece are connected to the direct current supply, lines of static field are generated and these lines have a direction perpendicular on the electrodes surfaces; the density of the lines of electric field is higher in the zones were the gap size is lower and this could determine a more intense process of test piece material dissolution (fig. 2).

If the gap initial size is s_0 (fig. 2, *a*), it is expected that after a duration *t* of the electrochemical machining process, the gap size becomes *s*; one supposes also that a certain rounding of the initial conical shape of the active zone of the test piece could be observed (fig. 2, *b*).

3. EXPERIMENTAL CONDITIONS AND RESULTS

In order to experimentally study the evolution of machining gap size during the electrochemical machining process, an experimental test was designed and applied. Essentially, the tool electrode and the test piece were placed in a recipient where the electrolyte circulation was ensured. Since a wall of the machining recipient was made of transparent material, the measure of the gap size was possible. One measured also the test piece mass after 1, 2 and 3 minutes of machining, in order to evaluate inclusively the evolution of the material removal rate.

An aqueous solution of sodium chloride was used as electrolyte.

The test pieces were made of carbon steel S 235,

Table 1. Experimental conditions and results (process duration: t=3 min)

Exp. No.	Input factors			Output factors	
	Angle α, degrees	Initial gap size, s_0, mm	Voltage *U*, V	Final gap size, *s*, mm	Quantity Δm of material removed from test piece, mg
Column no. 1	2	3	4	5	6
1	120	0.3	20	0.79	110
2	120	0.3	12	0.26	60
3	120	0.1	20	0.64	120
4	120	0.1	12	0.35	70
5	60	0.3	20	0.95	140
6	60	0.3	12	0.33	50
7	60	0.1	20	1.07	120
8	60	0.1	12	0.40	70

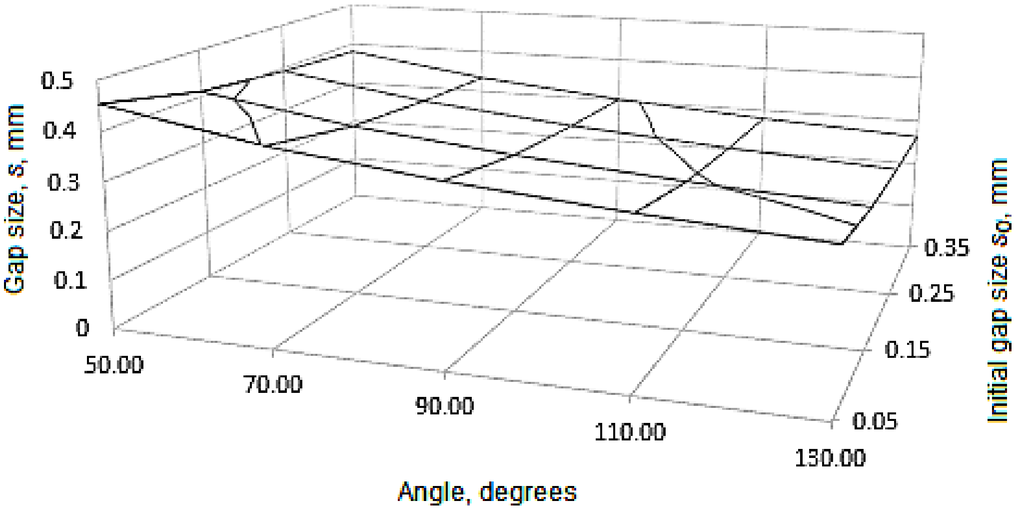

Figure 3. Influence exerted by the size *α* of the angle and initial gap size s_0 on the evolution of the gap size *s* (test piece material: steel S 235, electrolyte: aqueous solution of sodium chloride, process duration *t*=3 min, machining voltage *U*=12 V)

while electrotechnical copper was used for the tool electrode material.

The input factors were the initial angle *α* of the conical zone of test piece, the initial gap size s_0 and the voltage *U* applied to electrodes.

In order to diminish the number of the experimental tests necessary to establish an empirical mathematical model, the rules specific to a full factorial experiment with three independent variables at two levels were applied. Thus, a maximum and a minimum size were established for the angle *α* (60 and 120 degrees), initial gap size s_0 (0.1 and 0.3 mm) and machining voltage *U* (12 and 20 V).

The initial test piece mass and the test piece mass after a machining duration of 3 minutes were measured by means of analytical balance.

In accordance with the rules corresponding to a full factorial experiment with 3 independent variables at two levels, 8 experiments were necessary. The experimental conditions and the values of the output factors for each of the eight experiments were inscribed in table 1.

The column nos. 2, 3 and 4 include the values of the input factors (angle *α* of the test piece conical active surface, initial gap size s_0, machining voltage *U*), while in the column nos. 5 and 6, the values of the output parameters (final gap size *s*, quantity *Δm* of material removed from test piece, for a process duration *t*=3 min) were inscribed.

The experimental results were processed by means of a specialized software based on the method of least square [1]. The software uses as criterion for

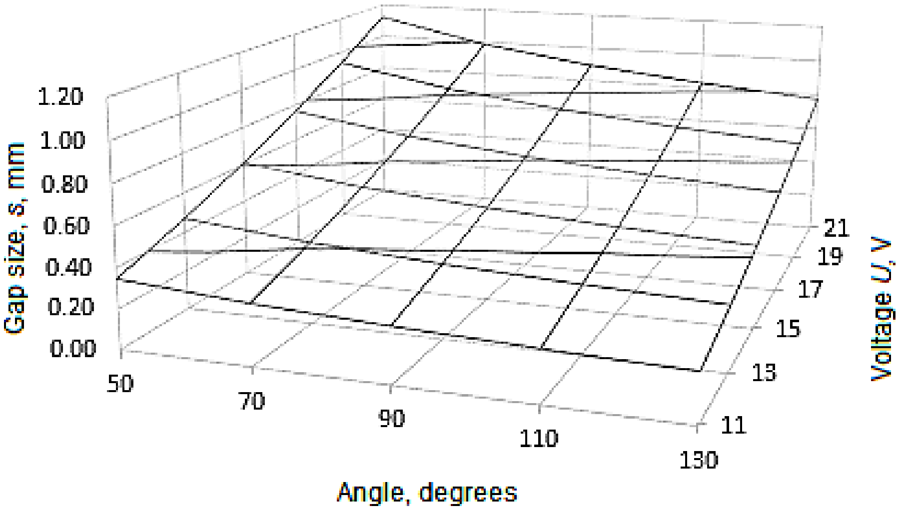

Figure 4. Influence exerted by the angle *α* and machining voltage *U* on the evolution of the gap size *s* (test piece material: steel S 235, electrolyte: aqueous solution of sodium chloride, process duration *t*=3 min, initial gap size s_0=0.1 mm)

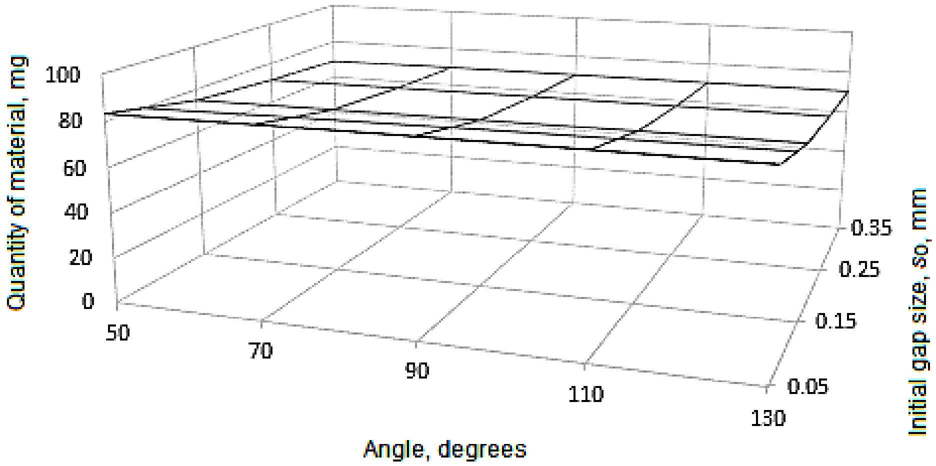

Figure 5. Influence exerted by the size of the angle α and initial gap size s_0 on the quantity Δm of material removed from test piece (test piece material: steel S 235, electrolyte: aqueous solution of sodium chloride, process duration t=3 min, machining voltage U=12 V)

evaluation of the model adequacy to the experimental result the value of the so-called Gauss criterion. This value of the Gauss criterion is determined as a sum of the least squares corresponding to the differences between the measured values and the values allocated on the base of the applied function, for the same experimental points.

As a consequence of the mathematical processing of the experimental results, in an initial stage the following empirical mathematical models were determined:

$$s = 0.133 \cdot 0.995^{\alpha} \cdot 0.608^{s_0} \cdot 1.124^{U}, \qquad (1)$$

for which the Gauss criterion has the value S_G=0.00554982 and

$$\Delta m = 200.0007 + \frac{600.0025}{\alpha} + \frac{0.749}{s_0} - \frac{1800.01}{U}, \qquad (2)$$

in this case the Gauss criterion having the value S_G=109.3323.

Since in the machine building the power type functions are preferred frequently in order to more direct observe the evolution and the intensity of the evolution of the output parameter when the input factors are variable, in a second stage, power type functions were also determined for the same experimental results. Thus, the following empirical models were established:

$$s = 0{,}01627\alpha^{-0{,}386} s_0^{-0{,}0905} U^{1.838}, \qquad (3)$$

for which the Gauss criterion has the value S_G=0.005550094 and:

$$\Delta m = 2.119\alpha^{0.0212} s_0^{-0{,}963} U^{1.328}, \qquad (4)$$

the Gauss criterion having the value S_G=142.5836.

On the base of the last two empirical functions, the graphical representations from figures 3, 4 and 5 were elaborated. One can notice that the highest influence on the output parameters is exerted by the machining voltage U, since the values of the exponents attached to this factor in the equations (3) and (4) have the maximum absolute values, in comparison with the values of the other exponents corresponding to the other process input variables, s_0 and U.

If the equation (3) is analysed, one can notice that, as expected, the increase of the angle α and initial gap size s_0 generates the decrease of the gap size s (the values of the exponents being negative), while the increase of the machining voltage U determines an increase of the final gap size s. Practically, the influence exerted by the initial gap size s_0 on the evolution of the final gap size s is very reduced, the exponent attached to the size s in equation (3) being close to zero.

The empirical mathematical model constituted by the equation (4) shows that the angle α practically does not influence the evolution of the quantity Δm of material removed from test piece for a process duration of 3 minutes, since the size of the exponent attached to the angle α in the equation (3) is very close to zero.

As expected, the increase of the initial gap size s_0 determines a decrease of the quantity Δm, while the increase of the machining voltage U has as a result the increase of the quantity Δm.

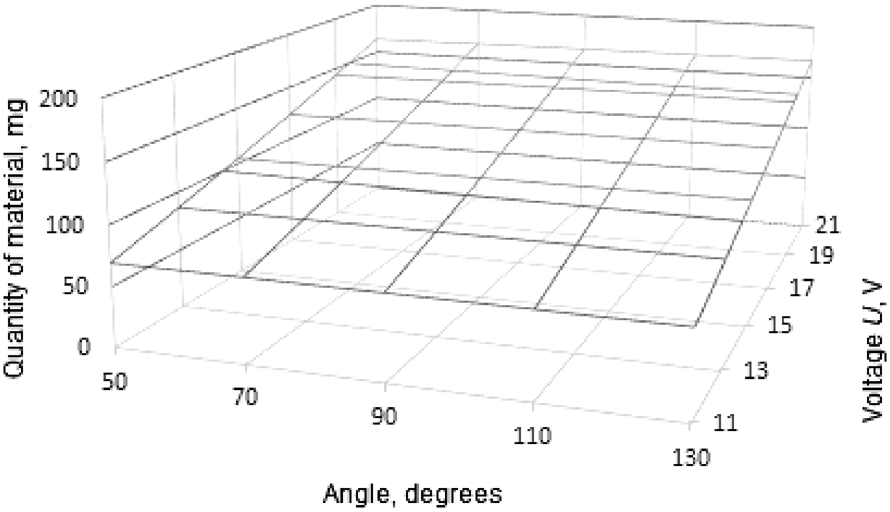

Figure 6. Influence exerted by the size of the angle α and voltage U on the quantity Δm of material removed from test piece (test piece material: steel S 235, electrolyte: aqueous solution of sodium chloride, process duration t=3 min, initial gap size s_0=0.1 mm)

4. CONCLUSIONS

The electrochemical machining process is based on the material removal from workpiece as a consequence of chemical reactions developed between the workpiece material and the electrolyte, when the tool electrode and workpiece are connected in the electric circuit of a direct current supply. There are many process factors able to exert influence on the evolution of the sizes of technological interest specific in the electrochemical machining process. Theoretical considerations showed that the increase of the initial gap size could diminish the final gap size, while the increase of the machining voltage could determine an increase of the final gap size, for a certain duration of the electrochemical machining process. The quantity of material removed from workpiece could decrease when the initial gap size increase and when the machining voltages diminishes. A full factorial experiment with three independent variables at two variation levels was designed and achieved, in order to determine the influence exerted by the angle of the test piece conical active surface, initial gap size and machining voltage on the final gap size and on the quantity of material removed from test piece for a certain duration of the electrochemical machining process and test pieces made of carbon steel S 235. The experimental results were processed by means of a specialized software based on the method of least squares and power type empirical mathematical models were determined. The experimental results confirmed the initially formulated hypotheses concerning the influence exerted by some input process factors on sizes of technological interest.

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