Electrochemical discharge machining of small diameter holes

M. Coteaţă, L. Slătineanu, O. Dodun, C. Ciofu

Technical University "Gh. Asachi" of Iaşi, D. Mangeron Blvd., 59A, 700050 Iaşi, Romania
URL: www.tuiasi.ro *e-mail: mcoteata@tcm.tuiasi.ro; slati@tuiasi.ro; oanad@tcm.tuiasi.ro; cdciofu@tcm.tuiasi.ro.*

ABSTRACT: Electrochemical discharge machining (ECDM) is considered to be a hybrid machining method where material removal is based on two phenomena: electrochemical dissolution of the material and thermal erosion by electrical discharges that occur between the electrodes. Obtaining holes of small diameter in hard materials is a challenge also for this machining method. The paper contains some results obtained by trying to achieve small diameters holes by electrochemical discharge machining using an aqueous solution of sodium silicate as working liquid. Identifying an optimized system for mechanical and electrical equipment was one of the targets of this research. By assuring a relative motion between the electrodes, holes (diameter <1 mm) in cutting steel workpieces were obtained.

Key words: Electrochemical dissolution, Electrical sparks, Holes, Tool wear

1 INTRODUCTION

The electrochemical discharge machining (ECDM) process is a complex physical–chemical system, where workpiece material is removed by an anodic dissolution of the material and also by electrical sparks that occur between the working surfaces of the electrode tool and of the electrode piece. The electrical discharges assure a chain of micro-explosions in the workpiece surface layer; thus, micro quantities of workpiece material are removed.

Amalnik [1] described a machining schema for obtaining profiled cavities by electrochemical discharge machining with electrical depasivating, by using an electrolyte based on sodium nitrate**.**

Kim [2] presented a drilling method by electrochemical discharge machining, used in the case of glass workpieces; a working liquid containing potassium hydroxide facilitated the machining process development.

The Japanese researcher F. Kobayashi proposed a practical solution to inject and to maintain the work liquid in the drilling zone, in the case of the electrochemical discharge machining [3].

Within the electrical discharge machining, some machining procedures supposing the rotation of the electrode tool are used [4, 5].

In the specialty literature, information concerning the electrochemical discharge drilling by using a semidielectric type liquid was not found. From the literature one can notice that most of the researches made by using an aqueous solution of sodium silicate refers to anodic-mechanical cutting processes.

2. PHENOMENA IN ECDM PROCESS

Generally, the ECDM process is developed in an electrolytic medium, when the electrode tool is connected to the cathode and the workpiece to the anode of a direct current generator.

Usually, the working current is of about 3-4 A, when the voltage is under 40 V. When the distance between the electrodes is small enough, the electrical sparks appear, at a certain moment when the gap size s is smaller than the ratio between the working voltage U and the dielectric resistance E ($s<U/E$). Due to the presence of the electrical field, the anodic dissolution of the workpiece material is developed. The anodic dissolution of the workpiece material increases the material removal rate and, at the same time, if the work voltage is higher, the increase of the surface roughness occurs. The working liquid, mainly by its chemical composition, plays an important role in establishing the electrochemical character of the machining process. Thus, when the electrolyte (aqueous solution of certain acids or salts) is used, the electrochemical dissolution is more intense (in comparison with the

use of semidielectric liquid) and sometimes difficult to be controlled.

In order to better control the electrochemical dissolution in an ECDM process, a working liquid based on sodium silicate was proposed. By using of the aqueous solution of sodium silicate, in the first stage, the presence of the electrical field makes possible the anodic dissolution of the material, followed by a passivating film generation on the workpiece surface. This passivating film decreases the electrochemical dissolution process intensity, thus insulating the surfaces nearby the machining area; in this way, the electrochemical dissolution is almost interrupted on the nonworking surfaces. The electrical sparks start when this passivating film is broken.

When a pressure between the electrodes is assured, the film may be removed and simultaneously the electrical sparks appear, removing material particles from both electrodes, but mostly from the anode.

Within the ECDM process, one of the most important technological parameters is the electrode tool wear. The reduction of the electrode tool wear at the increasing of the electrode tool diameter is expected; the increase of the tool electrode wear could be generated by the increasing of the voltage between the electrodes, by increasing the electrical capacity and by the increasing of the working liquid density.

3. EXPERIMENTAL RESEARCH

By trying to achieve ECDM of small holes on thin metal sheet (1.5 mm), a set of technical problems was identified. As working liquid, an aqueous solution of sodium silicate (the so called semidielectric liquid) was chosen. In this case, the chemical reactions, that immediately occur when the electrical field appears, have as result the generation of the passivating film, which assures a better control for the electrochemical dissolution of the working material. This film has a good adherence on the surfaces of the anode and decreases the intensity of the electrochemical dissolution process. In order to break and remove this film from the working surface of the workpiece, in a controlled way, a pressure and a relative motion between the electrodes are necessary.

During the electrical discharges, when the plasma channel is formed, an electrodes welding may appear. The electrodes welding can be avoided by modifying the characteristics of the electrical circuit or by mechanical solutions. The proposed working system, shown in figure 1, assures the rotation of the electrode tool and, at the same time, an alternative motion along the vertical direction, in order to avoid the welding process during the electrical discharges.

Each contact of the electrode tool *1* with the workpiece *6* contributes to the film breaking; at the same time the motions achieved by the electrode tool lead to the removal of the film rests and of the process results from the working gap. The workpiece is clamped in a transparent container *5,* fixed on the table 9.

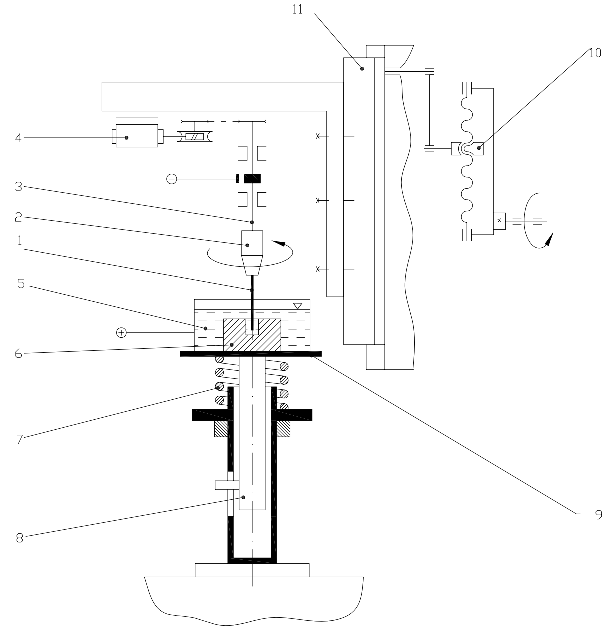


Fig. 1. Schematic representation of the working system

In order to assure a certain pressure between the electrodes but without breaking the electrode tool and to achieve a feed motion during the machining process, the spring 7 was used. The rotating motion of the electrode tool is transmitted from an electrical engine *4,* by a belt system. The alternative linear motion of the electrode tool is given by the mechanism included in the slotter ram of the milling machine.

The experiments were done with respect to the experimental plan presented in table 1. A set of 16 experiments was done with the following independent variables: electrode tool diameter *D* (with D_1= 0.5 mm and D_2=0.9 mm), the working voltage *U,* the capacity *C* (C_1= 33 μF, C_2= 840 μF), working liquid density *δ* (δ_1= 1.05 g/cm^3, δ_2= 1.20 g/cm^3).

After the preliminary experiments, two levels for the voltage were established, respectively U_1 =35 V and U_2= 45 V.

The used workpieces were made of high-speed steel sheet (of 1.5 mm thickness), the electrode tools being made of chisel steel.

Table 1. Experiments planning for ECDM drilling

Exp. no.	D	U	C	δ	W_l
1	-1	-1	-1	-1	0,10
2	+ 1	-1	-1	-1	0,03
3	-1	+1	-1	-1	1,34
4	+ 1	+1	-1	-1	0,28
5	-1	-1	+1	-1	0,50
6	+ 1	-1	+1	-1	0,19
7	-1	+1	+1	-1	2,89
8	+ 1	+1	+1	-1	0,69
9	-1	-1	-1	+1	0,88
10	+ 1	-1	-1	+1	0,19
11	-1	+1	-1	+1	1,63
12	+ 1	+1	-1	+1	1,03
13	-1	-1	+1	+1	1,27
14	+ 1	-1	+1	+1	1,91
15	-1	+1	+1	+1	2,08
16	+ 1	+1	+1	+1	4,54

For each experiment the working time was of 6 minutes. The frequency of the contacts between the electrode tool and the workpiece was about 80 contacts per minute.

All the workpieces and the electrode tools were weighted by using a digital balance. The length of each electrode tool was measured before and after the experiments, in order to obtain information on the electrode tool wear rate along the axial direction. All the electrode tools were polished in order to have a plane active surface.

4. RESULTS AND DISCUSSIONS

One of the output parameters for these ECDM drilling experiments was the electrode tool wear w_l. To evaluate w_l the length of the electrode tools was measured before and after the machining process. In the last column of the table 1, the sizes of electrode tool wear along the axial direction (the difference between the initial length and the length after machining of the electrodes) are presented.

By using of a GW Basic computer program, an empirical function establishing the influence of the independent variables on the electrode tool wear was obtained:

$$w_l = 1.329 \cdot 10^{-11} D^{-1.27} \cdot U^{5.739} \cdot C^{0.36} \cdot \delta^{9.655} \qquad (1)$$

One can observe that the working liquid density has a significant influence on the electrode tool wear evolution followed by the working voltage, the diameter, and the capacity; the statement is supported by the order of the absolute values of the exponents (9.655>5.73>1.27>0.36).

By analysing this mathematical model, one can notice that the electrode tool wear decreases at the increasing of the electrode tool diameter, as diagram from figure 2 shows, probably because the current density is smaller (the size of the exponent corresponding to the diameter *D* is negative). The possibility for heat dissipation in a greater mass of the electrode tool (evidently in the case of the electrode tools having greater diameters) could also generate a smaller wear for the electrode tool.

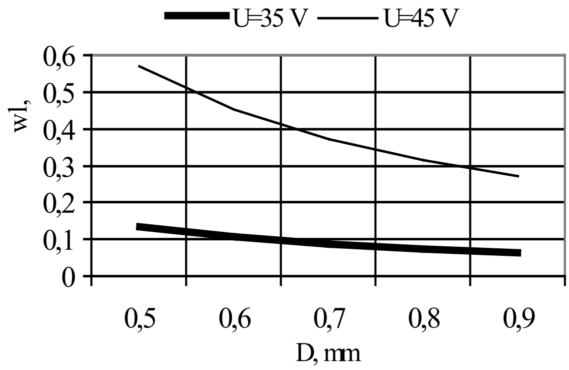


Fig. 2. Influence of electrode tool diameter on electrode tool axial wear

The experimental results confirmed the increase of the electrode tool wear confirmed the increase of the electrode tool wear as the electrode tool diameter decreases, and electric capacity, electric voltage between electrodes and work liquid density increase. The mathematical model represented by the relation (1) was used for elaborating the graphical representations included in figures 2, 3 and 6.

When the voltage and the capacity, respectively the

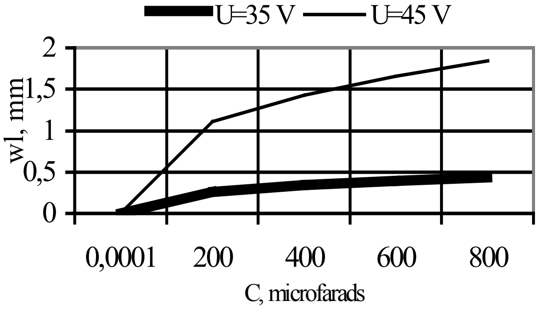
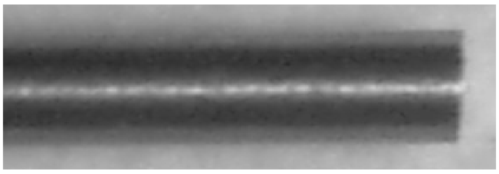
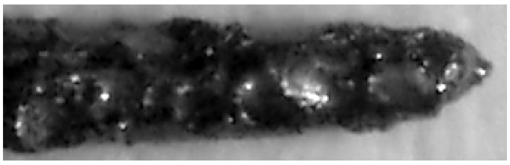


Fig. 3. Influence of electric capacity on electrode tool axial wear

liquid density, were at the upper values, the electrode tool registered the maximum wear on the length, but also on the diameter. Many microcavities could be observed on the lateral side of the electrode tool examined with a digital microscope, as figure 4 shows (the initial diameter was 0.5 mm).



a



b

Fig. 4. - Electrode tool: a) ET before machining; b) electrode tool wear after machining process at upper values of voltage, capacity and liquid density

In this working setup (by using of upper values for the other three independent variables) with an electrode tool 0.5 mm in diameter, during the same working time of 6 minutes, the workpiece was completely drilled on its thickness.

An image of the obtained hole is presented in figure 5.

The hole edge has small burrs, probably formed by the melted material during the electrical sparks.

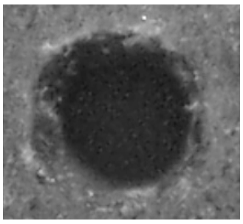


Fig. 5. Hole obtained by ECDM in a cutting steel workpiece

The working liquid density has an important influence on the process development and also on the electrode tool wear (as diagram from figure 6 shows).

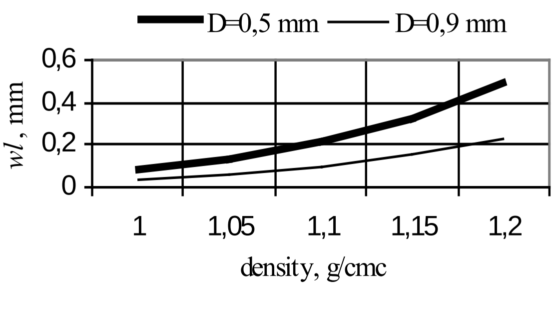


Fig. 6. Influence of the work liquid density on the electrode tool wear

5. CONCLUSIONS

The paper proposes a new solution for drilling by ECDM, in the case of metallic workpieces. Some experimental researches emphasized the increase of the electrode tool wear as the electrode tool diameter decreases, and, as the electric capacity, the electric voltage between electrodes and work liquid density increase.

The experimental results permitted to establish an empirical mathematical model, showing the influence of the voltage *U,* the capacity *C,* the electrode tool diameter *D,* and the work liquid density on the electrode tool wear, evaluated by the reduction of the tool length.

Further researches will be focused on ECDM drilling of different metallic materials.

As performance criteria, the material removal rate and the shape accuracy of the machined hole could be considered. Different machining procedures, based on the use of tubular electrode tool for ECDM process or electrical discharge machining process could be studied.

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