

MATERIAL REMOVAL RATE IN ELECTROCHEMICAL DISCHARGE MACHINING OF SMALL DIAMETER HOLES

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ABSTRACT: Electrochemical discharge machining method is based on the material removal from workpiece as a consequence of simultaneous development of electrical discharges between the electrodes and of the electrochemical reactions between the work liquid and workpiece material. One application of the electrochemical discharge machining is drilling of small diameter holes in workpieces made of electroconductive materials. Distinct workpiece materials have different behaviour, if the machining speed is considered. A full factorial experiment was designed and applied in order to highlight the influence exerted by tool electrode diameter, voltage applied to electrodes, total capacitance of the electrical circuit and density of work liquid on the penetration speed. Power type mathematical empirical relations were determined. Analysing the empirical mathematical models, one concluded that the order of influence of input process factors is the following: sodium silicate electrolyte density, applied voltage, tool diameter and circuit capacitance.

KEYWORDS: electrochemical discharge machining, small diameter, penetration speed.

1. INTRODUCTION

The electrochemical discharge machining (ECDM) could be defined as a machining method based on material removal due to the simultaneously development of electrical discharges process and of chemical reactions between the work liquid and workpiece material under the action of the electrical current. Initially, the electrochemical discharge machining was preferentially applied to the workpieces made of metallic material, but the last decades highlighted extended solutions for machining of workpieces made of insulating materials, such as glass, silicon [1, 2]etc.

Over the years, distinct machining processes were proposed on considering the principles valid in the case of electrochemical discharge machining method.

Holes with distinct diameters could be obtained by classical drilling, but for small diameter holes often are applied so called nontraditional methods, inclusively electrochemical discharge drilling. Huang et al [3] developed their research on electrochemical discharge drilling of micro-holes in stainless steel, using pure water as electrolyte.

The aim of this paper is to emphasize some considerations and experimental results concerning the electrochemical discharge drilling of test pieces made of two distinct metallic materials, namely

spring steel and carbon steel C45, the second being considered as an etalon material.

2. ELECTROCHEMICAL DISCHARGE DRILLING PROCESS

Some aspects concerning the obtaining of small diameter holes in electroconductive materials could be discussed by taking into consideration the graphical representations of machining scheme presented in figures 1 and 2. One can see that a cylindrical tool electrode achieves a rotation motion with a rotation speed n_{TE} and it is pressed on the workpiece surface with a pressure p . Both the tool electrode and workpiece are connected in the electric circuit of a source including an electric transformer and a rectifier.

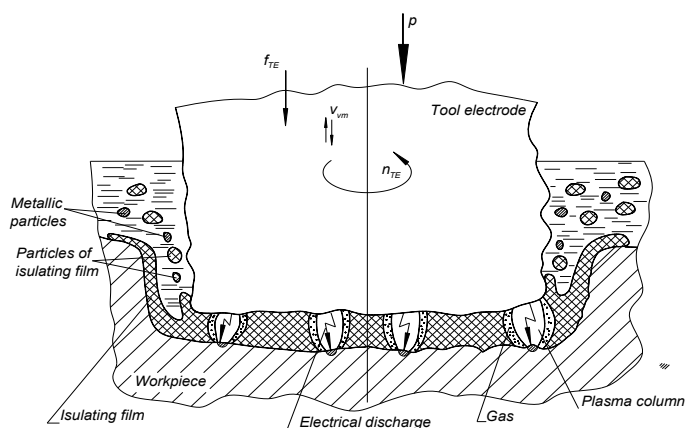


Figure 1. Detail from machining zone in case of electrochemical discharge drilling process

In case of the tool electrode, a subsystem brush-collector ring must be used, in order to connect the tool electrode holder shaft in the machining electrical circuit. The machining process develops in a tank where a work liquid is present; in order to ensure conditions for developing chemical reactions between work liquid and workpiece material, electrolytes type work liquid are used. The experience accumulated in the previous experimental researches highlighted the good results obtained by using an aqueous solution of soluble sodium silicate as work liquid.

As a consequence of electrochemical reactions developed between the workpiece material and work liquid, an insulating layer forms on the accessible surface of the test piece; if this film is not removed,

gradually the intensity of the chemical processes and electric current diminishes and the anodic dissolution stops.

In order to ensure the process continuation, the tool electrode is rotated and pressed on the workpiece surface; it is expected that as a consequence, the thickness of the insulating films diminishes, up to the moment when the size s of the work gap could correspond to the relation:

$$s \leq \frac{U}{E} \quad (1)$$

where U is the voltage applied to the tool electrode and workpiece and E is the electric rigidity of the work gap liquid.

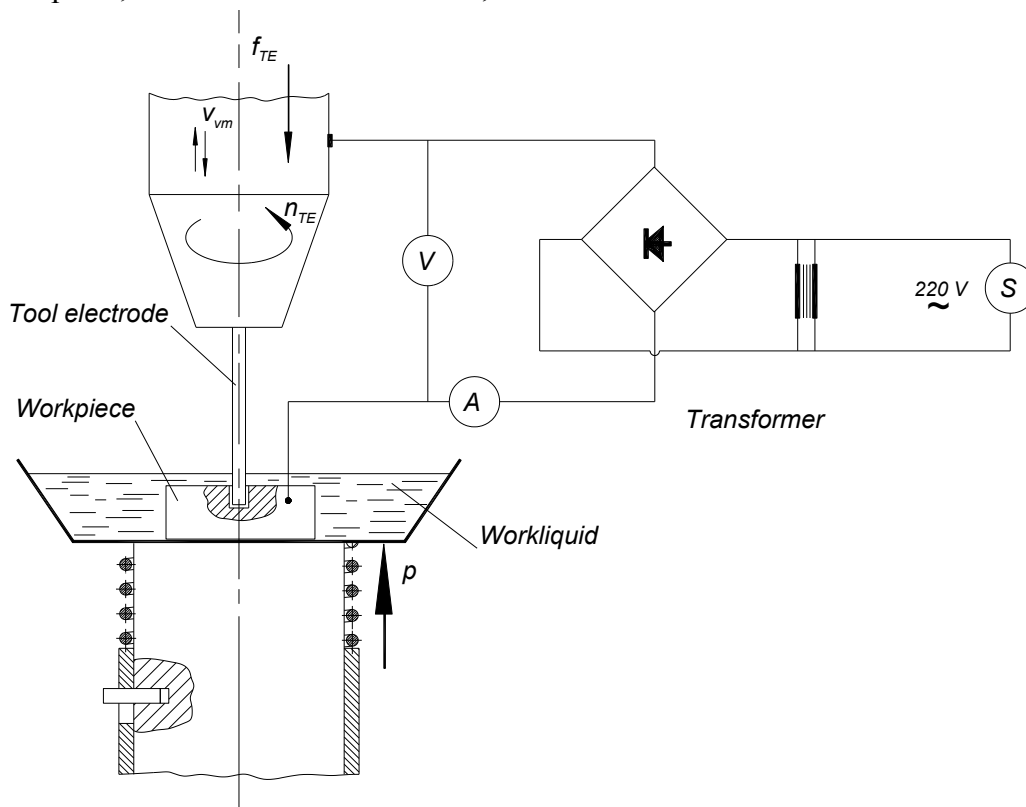


Figure 2. Machining scheme applicable for studying the electrochemical discharge drilling process

When the condition expressed by the equation (1) is fulfilled, an electrical discharge develops between the closest asperities existing on the frontal surface of tool electrode and workpiece surface.

If the intensity of electrical discharge is high enough, the material removal from electrodes develops, due to the thermal phenomena as heating, melting and vaporizing mainly on the workpiece surface.

A supplementary consequence of the electrical discharge is the breaking of the insulating layer, thus, facilitating the access of the electrolyte on new zones from the test piece surface [4]. In order to ensure periodical interruption of electrical discharge

process and the penetration of the work fluid in the work gap, the tool electrode is periodically removed from the test piece along a short distance and immediately it moves to the workpiece surface. The periodical movement of tool electrode and its withdrawal to and from workpiece exerts effects of pressure - repression, determining a removal process of the metallic particles detached from tool electrode and workpiece as a consequence of the electrical discharges; this tool electrode alternative motion contributes also to the removal of particles detached from the insulating film. In this way, the tool electrode succeeds to penetrate gradually in workpiece material and the drilling process being materialized.

The *systemic analysis of the electrochemical discharge machining of small diameter holes* shows the following main group of process input factors:

- a) Drilling scheme, essentially characterized by using a rotating tool electrode and a periodical contact between tool electrode and workpiece;
- b) Chemical composition of workpiece material;
- c) Chemical composition and properties of work liquid (concentration, density, viscosity etc.);

d) Operating electrical parameters as applied voltage and capacitance, current intensity;

e) Mechanical operating parameters (rotation speed, size of tool electrode cross section, pressure exerted by tool electrode on the workpiece surface etc.);

f) Chemical properties and physical properties of tool electrode material etc.

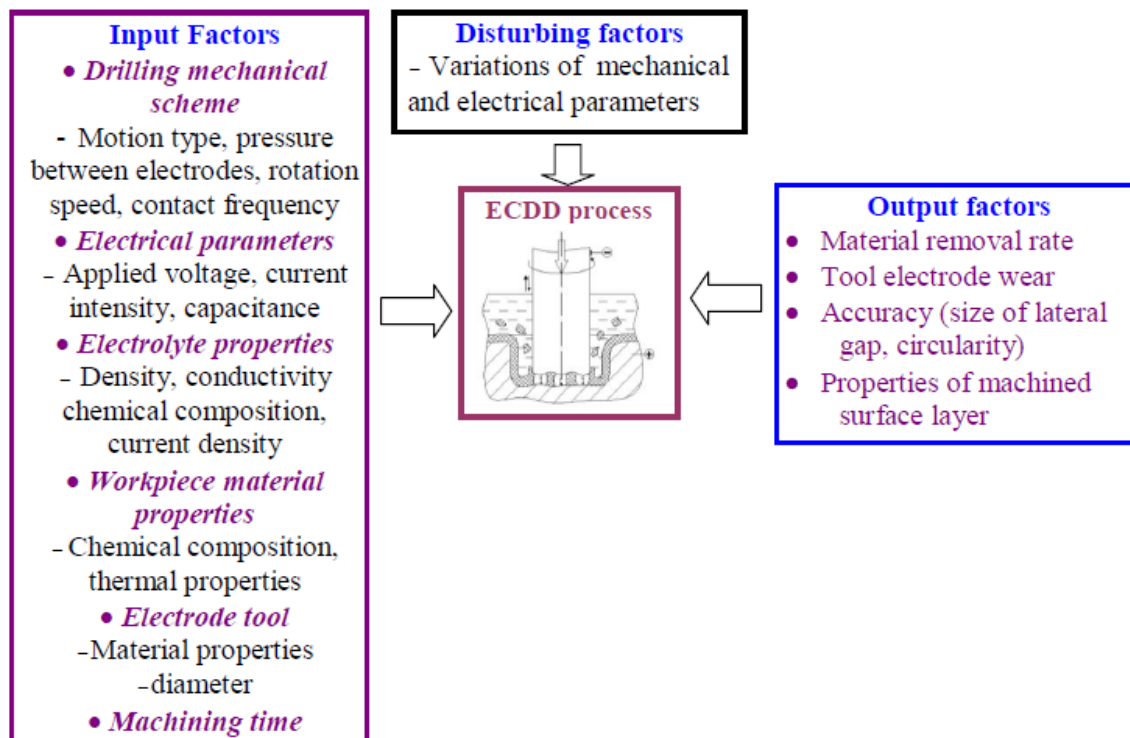


Figure 3. Systemic approach of electrochemical discharge drilling process (ECDD)

As main group of output factors, one can take into consideration:

- a) Material removal rate, evaluated by means of hole thickness obtain in a certain duration of machining process, penetration speed, quantity of material detached from workpiece for a certain process duration etc;
- b) Tool electrode wear, determined as the diminishing of tool electrode length, quantity of material removed from tool electrode for a certain process duration, changing of the tool electrode active zone shape etc.;
- c) Size of lateral work gap;
- d) Properties of machined surface layer etc.

The uncontrolled variation of some input factors could constitute the disturbing factors.

3. EXPERIMENTAL CONDITIONS

In order to develop an experimental research concerning the influence of some input factors on the material removal rate, an experimental device was designed and materialized, adaptable on the slotting head of a classical milling machine. The slotting head ensured the periodical removal of the tool electrode from workpiece surface.

The recipient containing the workpiece, the fixture and the work liquid were placed at the end of a rod which could move into a sleeve.

A spring facilitates the motion of the table when the tool electrode is pressed on the workpiece surface. The spring was selected so that it can ensure a pressure able to determine the breaking of the insulating film appeared on the workpiece surface ($0.2 - 2 \text{ daN/cm}^2$).

As independent variables (process input parameters), one selected the tool electrode diameter, the voltage

applied to electrodes, the capacitance of the capacitors included in the machining electrical circuit, the density of the work liquid.

The material for the tool electrode was the high speed steel of 65 HRC. Two materials were taken into consideration for the test samples: spring steel and as material for comparison (etalon material) the medium carbon steel C45. The working liquid was the aqueous solution of soluble sodium silicate (Na_2SiO_2) with two distinct densities.

A full factorial experiment with four independent variables at two levels was designed; in such

conditions, $2^4=16$ experiments were necessary for each test sample material.

The coded values and the real values of the input variables were inscribed in the columns 1-8 from table 1. In the column 9 and 10, the experimental values for the penetration speed, v , obtained in the case of test samples made of steel C45 and spring steel.

Table 1. Experimental conditions and results

Exp. No.	Independent variables (process input factors)								Penetration speed v , mm/min	
	Tool electrode diameter, d		Voltage applied to electrodes, U		Total capacity of electric capacitors, C		Work liquid density, δ		Carbon Steel, C45	Spring steel
	Coded values	Real values, mm	Coded values	Real values, V	Coded values	Real values, μF	Coded values	Real values, g/mm^3		
0	1	2	3	4	5	6	7	8	9	10
1	+1	0.86	+1	45	+1	840	+1	1.20	0.29	0.19
2	+1	0.87	+1	45	-1	33	+1	1.20	0.12	0.07
3	+1	0.88	-1	35	+1	840	+1	1.20	0.14	0.17
4	+1	0.85	-1	35	-1	33	+1	1.20	0.06	0.09
5	+1	0.86	+1	45	+1	840	-1	1.05	0.12	0.11
6	+1	0.88	+1	45	-1	33	-1	1.05	0.04	0.07
7	+1	0.86	-1	35	+1	840	-1	1.05	0.06	0.08
8	+1	0.86	-1	35	-1	33	-1	1.05	0.02	0.03
9	-1	0.49	+1	45	+1	840	+1	1.20	0.15	0.25
10	-1	0.50	+1	45	-1	33	+1	1.20	0.17	0.17
11	-1	0.49	-1	35	+1	840	+1	1.20	0.27	0.25
12	-1	0.48	-1	35	-1	33	+1	1.20	0.05	0.12
13	-1	0.50	+1	45	+1	840	-1	1.05	0.24	0.18
14	-1	0.49	+1	45	-1	33	-1	1.05	0.09	0.12
15	-1	0.51	-1	35	+1	840	-1	1.05	0.11	0.13
16	-1	0.49	-1	35	-1	33	-1	1.05	0.06	0.08

4. ANALYSIS OF EXPERIMENTAL RESULTS

The experimental results corresponding to the penetration speed v included in the last columns from table 1 were mathematically processed by means of specialized software based on the method of last squares. Thus, the following power type functions were determined for the penetration speed v :

- in the case of medium carbon steel C45:

$$v_{C45} = 1.152 \cdot 10^{-6} D^{-0.778} U^{2.503} C^{0.26} \delta^{4.256} \quad (2)$$

- in the case of spring steel, 60CrMnSi 17A:

$$v_{spring} = 2.863 \cdot 10^{-4} D^{-1.029} U^{1.139} C^{0.193} \delta^{3.495} \quad (3)$$

where D is the tool electrode diameter, U is the applied voltage, C is the capacitance and δ is the electrolyte density.

Using experimental results and power type function corresponding to the relation (2) and (3), the graphical representation from figures 3, 4, 5 and 6 were elaborated. The analysis of the power type empirical mathematical relations (3) and (4) and of the graphical representations from figures 4-7 facilitates the elaboration of some general observations. Thus, the most significant influence is exerted by the electrolyte density δ whose exponents in the empirical mathematical relations is maximum in both cases of test samples made of medium carbon steel C45 and spring steel 60CrMnSi 17A, followed by voltage U applied between the tool electrode and test pieces, the tool electrode diameter

D (this giving an image over the current density during the process, actually) and the less significant, in the given setup, seems to be the circuit capacitance.

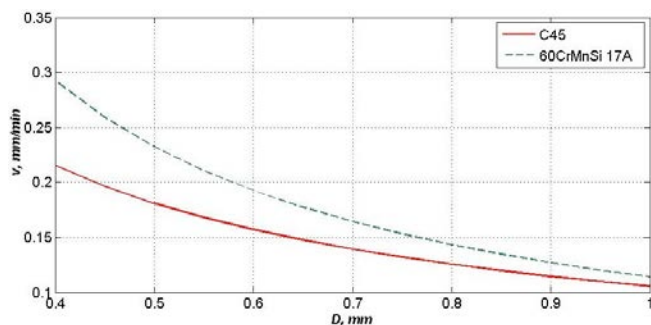


Figure 4. Influence of the tool electrode diameter D on the penetration speed v for test pieces made of carbon steel C45 and spring steel 60CrMnSi 17A ($U=35V$, $C=840 \mu F$, $\delta=1.2 \text{ g/mm}^3$)

One can notice that both materials, due to their quite similar chemical composition (for C45 being 0.51% C, 0.15% Ni, 0.28% Si, 0.21% Cu, 0.15% Cr, and for 60CrMnSi 17A is: 0.48 % C, 0.15 % Ni, 1.37 % Si, 0.13 % Cu, 0.57 % Cr, 0.67 Mn) the behaviour is not very different, the results and the graphical representation showing that the spring steel has the machinability by electrochemical discharge machining comparable with the one of C45 steel.

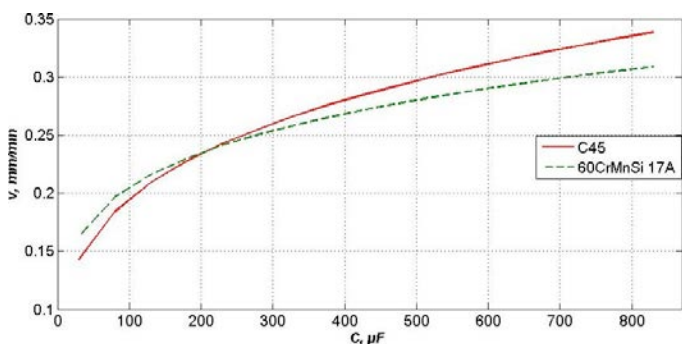


Figure 5. Influence of the total capacitance C of capacitors include in the electrical circuit on the penetration speed v ($D=0.5 \text{ mm}$, $U=45 \text{ V}$, $\delta=1.05 \text{ g/mm}^3$)

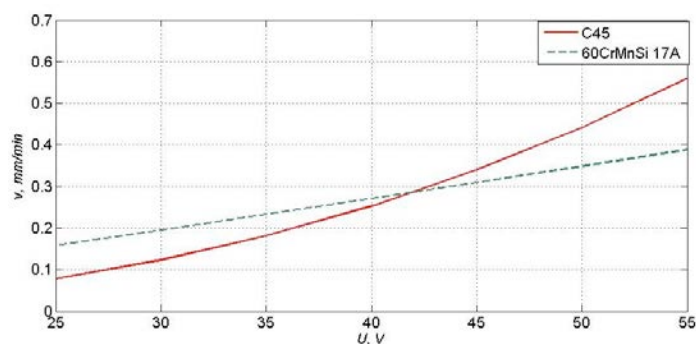


Figure 6. Influence of the voltage U applied to the two electrodes on the penetration speed v for test pieces made of carbon steel C45 and spring steel 60CrMnSi 17A ($D=0.5 \text{ mm}$, $C=500 \mu F$, $\delta=1.05 \text{ g/mm}^3$)

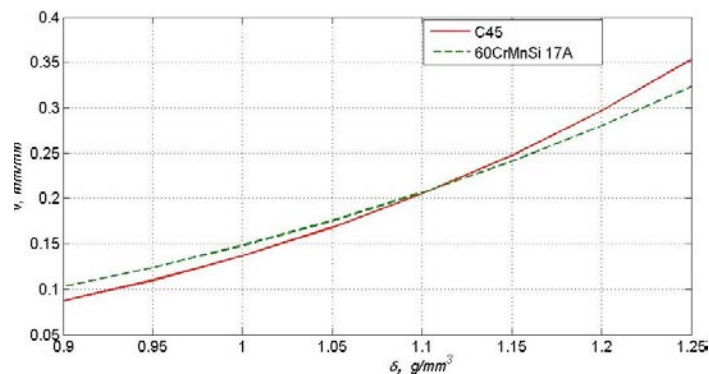


Figure 7. Influence of the work liquid density δ on the penetration speed v for test pieces made of carbon steel C45 and spring steel 60CrMnSi 17A ($D=0.5 \text{ mm}$, $U=45V$, $C=500F$)

5. CONCLUSIONS

Small diameter holes in metallic parts can be obtained by electrochemical discharge drilling method. Using a passivating electrolyte ensures a better control of the electrochemical dissolution of the anode material by forming an insulating layer, this layer can be removed by relative pressure and motion between the electrodes.

An experimental setup was established for studying the electrochemical discharge drilling. The experiments were running according to 2^4 factorial experiment planning for two types of steel, medium carbon steel and spring steel, the main output parameter being considered here the penetrating speed.

By analysing the empirical data and the graphical representation one could notice that the two material have very similar behaviour and the density of the aqueous solution of sodium silicate, used as electrolyte, is the most significant influencing factor for penetration speed. The tool diameter is also influencing the process since it gives the current density.

As further research one may consider the validation of the results by changing the levels of the varying input parameters.

6. REFERENCES

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