RESEARCHES REGARDING THEORETICAL AND EXPERIMENTAL MODELING OF ELECTROEROSION PROCESSING OF THREADS IN SINTERISED METALLIC CARBIDES

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One of the main axes of contemporary technological development is the use of electrotechnologies on an increasing scale. Within these, the electroerosion carries a significant weight because of technological advantages it presents in the processing of hard and superhard materials.

In this paper, the authors present some of the results of theoretical and experimental research on the processing of inner threads with grooved copper electrode in sintered metallic carbides G20. These results are primarily concerned with the influence of electrotechnological parameters on thread pitch p and thread flank angle α. For these two geometrical parameters, in this paper are established the machinability functions that are useful for determining the processing parameters of threads by electroerosion.

Keywords: electroerosion, grooved electrode, metallic carbide, tapping, experimental programme

1. Introduction

The scientific and technical achievements of the last century conducted to the development of new branches of science, as: electronics, cybernetics, computing, cosmonautics, etc. The new scientific discoveries influenced also the traditional sciences and their technical fields. So, metallurgical and chemical industries produced new types of materials and alloys: metallic carbides, mineralo-ceramics, glass fibres, carbon fibres, etc.

The appearance of new materials and alloys, especially those hard and extra-hard, conducted to the necessity of use in industry of non-conventional machining processes called electrotechnologies. [1, 2, 3]

In some cases the non-convenventional technologies are not the most economical, but they are indispensable because they solve technological problems insurmountable by conventional processes.

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Romania is among the countries that produce competitive machines and equipment for machining by non-conventional technologies. New researches are carried out for designing and manufacturing of new machines and equipment with high performances.

The current trends in electroerosion machining are particularly concerned on machining of different inner surfaces in metallic carbides [4, 5, 6, 7], because these cannot be machined by conventional processes.

Tapping in sinterised metallic carbides requires special tapping devices [8, 9], that can that may exist in the endowment of the machine-tools produced by certain companies [10, 11] or can be designed and manufactured for specific demands [12, 13, 14].

The researches carried out by the authors focused on the determination of process function for geometrical parameters of thread in tapping metallic carbides type G20 with grooved electrode.

2. Means Employed in Experimental Research

The experimental researches were performed in the non-conventional machining laboratory of I.C.T.C.M. – Romania on the electro-erosion machine CHARMILLES D4, which is equipped with an ISOPULSE P3 generator.

The pulse time is set by the selector switch (Fig. 1) with 12 positions. The corresponding values of each position are presented in Table 1.

Table 1

Pulse duration at CHARMILLE D4 machine

Position of selector switch	1	2	3	4	5	6	7	8	9	10	11	12
Pulse duration [μs]	2	3	4	6	12	25	50	100	200	400	800	1600

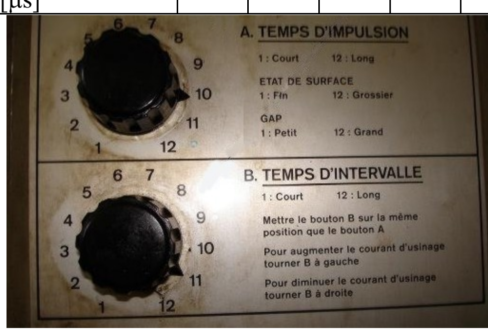

Fig. 1. Adjusting board for pulse time and pause time.

Fig. 2. Tapping device for electroerosion of machine CHARMILLES D4.

The pause time between pulses is set by a selector switch B (Fig. 1), which has 12 positions as selector A. The intensity levels of ISOPULSE P3 generator are: level 1 = 25 A; level 1/2 = 12.5 A; level 1/4 = 6.25 A; level 3/4 = 18.75 A.

The tapping device (Fig. 2) from machine’s endowment contains two fundamental sub-assemblies: electric board 1 and tool-holder body 2.

The tool-holder has an engine that activates the tap electrode. The engine has the following characteristics: tension – 24V; intensity – 0.45A; power – 4.5W.

This device can be adjusted for machining the following threads:

a) metric thread’s pitch: 0.5 mm; 1 mm; 1.5 mm; 2 mm.

b) imperial thread’s pitch: 1/4’’; 5/16’’; 1/2’’; 1’’.

During the experiments performed by authors, there were machined M12 x 1.5 threads in OLC45 steel (considered as reference material – Fig. 3) and sinterised metallic carbide G20 (Fig. 4).

The tapping was performed with grooved electrodes made from cathode copper (Fig. 5). The probes were sectioned by laser in order to measure the geometrical parameters of the thread. The measurement of geometrical parameters was performed using the universal microscope 19JA (Figure 6). This microscope has the following features:

- longitudinal measuring range: 0 - 200 mm;
- transversal measuring range: 0 -100 mm;
- angles (from 0° to 360°) are measured by an ocular protractor with a precision of 1’;
- graduation: 0.001 mm.

Fig. 3. Thread M12,5x1,5 machined in steel OLC45

Fig. 4. Thread M12,5x1,5 machined in sinterised metallic carbide G20

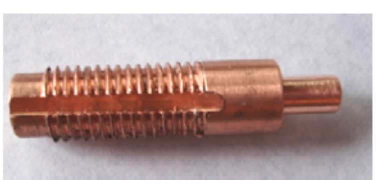

Fig. 5. Grooved electrode

Fig. 6. Universal Microscope 19JA

The POLYVAC installation was used to determine the chemical composition of electrodes. The resulted composition is displayed in Table 2.

Table 2

Chemical composition of electrodes

Chemical element	Cu	Al	Sn	Fe
Concentration [%]	99.5	0.0032	0.288	0.1576

S.C. CARMESIN S.A., the producer of metallic carbides, offered the mechanical, physical and metallographic characteristics of G20 metallic carbides samples (Table 3) and the sinterisation and cooling conditions of the metallic carbides mixture.

Table 3

Characteristics of samples made of G20

Characteristics	Unit of measurement	Company standard	Sample's values
Horizontal contraction after sinterisation	%	-	19.40
Diametric contraction after sinterisation	%	-	19.79
Density	g/cm^3	14.2 – 14.5	14.32
Hardness	HV50	1120 - 1240	1240
Fracture strength	N/mm^2	min. 1800	2038
Magnetic saturation	Tcm^3/g	min. 177×10^{-4}	176×10^{-4}
Cobalt magnetic	%	min. 8.82	8.75

The sinterisation conditions were: sinterisation temperature - 1400°C; retardation time - 40 min; cooling in vacuum to 1150°C; cooling in CH_2 atmosphere.

3. Establishment of Independent and Dependent Variables and Process Functions

After the study of the specialised literature [15, 16], the authors selected as independent variables the following: mean intensity of the discharge current, i_e; pulse duration, t_i, and pause duration, t_0. As dependent variables, there were considered: thread's pitch, p and flank angle, α.

Table 4

Natural levels of independent variables

Independent variables	Natural levels x_j		
	Min.	Mean	Max.
i_e [A]	12.5	18.75	25
t_i [μs]	12	25	50
t_0 [μs]	12	25	50

Table 5

Structure of experimental programme

x_j / No. exp. j	Variable level		
	x_1	x_2	x_3
1	12.5	12	12
2	12.5	12	50
3	12.5	50	12
4	25	12	12
5	25	50	50
6	25	50	12
7	25	12	50
8	12.5	50	50
9	18.75	25	25
10	18.75	25	25
11	18.75	25	25
12	18.75	25	25

Considering the general framework of research, there were determined the process functions for dependent variables. The process functions were mathematically described as:

$$y = A_0 \cdot i_e^{A_1} \cdot t_i^{A_2} \cdot t_0^{A_3},$$

Where A_i are constants and the parameters are indicated at the beginning of chapter 3.

All experiments were carried out with the voltage U = 80 V. The steel OLC45 was considered the reference material. The natural levels of variables i_e, t_i, t_0 and the structure of experimental programme are presented in Tables 4 and 5.

The mathematical processing of experimental data was performed using MATLAB 7.0 software. Using the regression analysis indicators calculated with MATLAB 7.0 software allowed the establishment of the weight and the influence of machining parameters (i_e, t_i and t_0) on process functions (p and α).

4. Theoretical and Experimental Modeling of Process Functions

In order to model statistically the thread's pitch p, there are presented in Tables 6, 7 and 8 the following: experimental programme and the results of the thread's pitch model; verification of model's adequacy and verification of coefficients' significance. After statistical calculations, the mathematical model proved to be adequate (Table 7).

It can be observed that the responses predicted by the model (Table 6) present very small errors under 1%. The highest error is 0.19% at 6th experience.

From the verification of coefficients' significance (Table 8), it results that the most influent factor upon the machining process is the pulse duration t_i followed by mean intensity of the discharge current i_e and pause duration t_0. The three associated coefficients are highly strong significant, both for 95% and 99% probability.

Table 6

Experimental programme and the results of the thread's pitch model *p*

No. exp.	Variables			Responses		Confidence interval 95%	Error Δ (%)
	i_e [A]	t_i [μs]	t_0 [μs]	Measured p [mm]	Calculated $\tilde{p}$ [mm]		
1	12.5	12	12	1.507	1.5064	1.5029 ÷ 1.51	0.037402
2	12.5	12	50	1.505	1.5051	1.5016 ÷ 1.5086	-0.0081392
3	12.5	50	12	1.502	1.5026	1.4991 ÷ 1.5061	-0.041453
4	25	12	12	1.506	1.5048	1.5014 ÷ 1.5082	0.078182
5	25	50	50	1.498	1.4997	1.4963 ÷ 1.5031	-0.11366
6	25	50	12	1.504	1.501	1.4976 ÷ 1.5044	0.19894
7	25	12	50	1.506	1.5035	1.5001 ÷ 1.5069	0.16556
8	12.5	50	50	1.505	1.5013	1.4978 ÷ 1.5048	0.24564

No. exp.	Variables			Responses		Confidence interval 95%	Error Δ (%)
				Measured	Calculated		
	i_e [A]	t_i [µs]	t_0 [µs]	p [mm]	$\tilde{p}$ [mm]		
9	18.75	25	25	1.505	1.5029	1.5014 ÷ 1.5043	0.14261
10	18.75	25	25	1.5	1.5029	1.5014 ÷ 1.5043	-0.19009
11	18.75	25	25	1.498	1.5029	1.5014 ÷ 1.5043	-0.32317
12	18.75	25	25	1.5	1.5029	1.5014 ÷ 1.5043	-0.19009

Table 7

Verification of model's adequacy

Dispersion	Values
$SP_{rz} = Y'Y - B'(X'X)$	6.0378e-005
$f_{rz} = n - m - 1$	8
$PM_{rz} = SP_{rz} / f_{rz}$	7.5472e-006
$SP_{er} = (Y - \overline{Y})'(Y - \overline{Y})$	1.1861e-005
$f_{er} = n_0 - 1$	3
$PM_{er} = SP_{er} / f_{er}$	3.9536e-006
$SP_{in} = SP_{rz} - SP_{er}$	4.8517e-005
$f_{in} = f_{rz} - f_{er} = n - m - n_0$	5
$PM_{in} = SP_{in} / f_{in}$	9.7034e-006
$F_{ci} = PM_{in} / PM_{er}$	2.4543
$F_T (f_{in}, f_{er}, 95\%)$	9.01
$F_{ci} < F_T$	adequate

Table 8

Verification of coefficients' significance

Coefficient		PM_{bi}	F_{cs}	$F_{T\,[1;\,12;\,(1-\alpha)x100]}$	
				α	
Symbol	Value			0.05	0.01
				4.84	9.33
b_0	0.41958	2.0516	271830	√	√
b_1	-0.0015456	-0.021853	-2895.5	√	√
b_2	-0.0017762	-0.027824	-3686.6	√	√
b_3	-0.00061149	-0.009582	-1269.6	√	√

On the basis of measured responses, the coefficients of proposed model were determined using the least squares method. It resulted the equation:

$$p = 1.523 \cdot i_e^{-0.0015456} \cdot t_i^{-0.0017762} \cdot t_0^{-0.00061149} \qquad (2)$$

In order to model statistically the thread flank angle α, there are presented in Tables 9, 10 and 11 the following: experimental programme and the results of the flank angle model; verification of model's adequacy and verification of coefficients' significance. After statistical calculations, the mathematical model proved to be adequate (Table 9).

From the verification of coefficients' significance (Table 11), it results that the most influent factor on the machining process is the pause duration t_0 followed by mean intensity of the discharge current i_e and pulse duration t_i. The three associated coefficients are very significant, both for 95% and 99% probability.

On the basis of measured responses, the coefficients of proposed model were determined using the least squares method. It resulted the equation:

$$\alpha = 27.766 \cdot i_e^{0.0093138} \cdot t_i^{0.0046215} \cdot t_0^{0.033274} \tag{3}$$

Table 9

Experimental programme and the results of the flank angle α

No. exp.	Variables			Responses		Confidence interval 95%	Error Δ (%)
				Measured	Calculated		
	i_e [A]	t_i [μs]	t_0 [μs]	α [mm]	$\tilde{\alpha}$ [mm]		
1	12.5	12	12	31.383	31.234	31.195 ÷ 31.272	0.479
2	12.5	12	50	34.067	32.753	32.714 ÷ 32.791	4.0119
3	12.5	50	12	31.1	31.44	31.402 ÷ 31.479	-1.0827
4	25	12	12	31.85	31.436	31.399 ÷ 31.473	1.3169
5	25	50	50	34.167	33.183	33.146 ÷ 33.22	2.9646
6	25	50	12	32.3	31.644	31.607 ÷ 31.681	2.073
7	25	12	50	32	32.965	32.928 ÷ 33.002	-2.9267
8	12.5	50	50	32.65	32.969	32.931 ÷ 33.008	-0.96873
9	18.75	25	25	31.083	32.236	32.22 ÷ 32.252	-3.5762
10	18.75	25	25	32.917	32.236	32.22 ÷ 32.252	2.111
11	18.75	25	25	31.183	32.236	32.22 ÷ 32.252	-3.266
12	18.75	25	25	31.983	32.236	32.22 ÷ 32.252	-0.78429

Table 10

Verification of model's adequacy

Dispersion	Values
$SP_{rz} = Y'Y - B'(X'X)$	0.0072125
$f_{rz} = n - m - 1$	8
$PM_{rz} = SP_{rz} / f_{rz}$	0.00090157
$SP_{er} = (Y - \overline{Y})'(Y - \overline{Y})$	0.0021261
$f_{er} = n_0 - 1$	3
$PM_{er} = SP_{er} / f_{er}$	0.00070871
$SP_{in} = SP_{rz} - SP_{er}$	0.0050864
$f_{in} = f_{rz} - f_{er} = n - m - n_0$	5
$PM_{in} = SP_{in} / f_{in}$	0.0010173
$F_{ci} = PM_{in} / PM_{er}$	1.4354
$F_T (f_{in}, f_{er}, 95\%)$	9.01
$F_{ci} < F_T$	adequate

Table 11

Verification of coefficients' significance

Coefficient		PM_{bi}	F_{cs}	$F_{T[1;\,12;\,(1-\alpha)x100]}$	
Symbol	Value			α	
				0.05	0.01
				4.84	9.33
b_0	3.3238	138.49	153610	√	√
b_1	0.0093138	1.1224	1244.9	√	√
b_2	0.0046215	0.6173	684.69	√	√
b_3	0.033274	4.4483	4934	√	√

On the basis of the models presented in equation (2) and (3), the response surfaces for thread's pitch and for thread's angle were made. For each response surface, two parameters were varied and the third was maintained constant at the middle of it's variation interval (Figures 7, 8 and 9 – for thread's pitch and Figures 10, 11 and 12 – for thread's angle).

Considering the variation intervals presented in Table 4, there are possible the following cases for thread's pitch and also for thread's angle:

a) The mean intensity of the discharge current i_e is constant at 18.75 A and the pulse duration t_i and the pause duration t_0 vary between 12 and 50 μs. The associated graphic is displayed in Fig. 7 – for thread's pitch and Figure 10 – for thread's angle.

b) The pulse duration t_i is constant at 25 μs, the pause duration t_0 varies between 12 and 50 μs and the mean intensity of the discharge current i_e varies between 12.5 and 25 A. The associated graphic is displayed in Figure 8 – for thread's pitch and Figure 11 – for thread's angle.

c) The pause duration t_0 is constant at 25 μs, the pulse duration t_i varies between 12 and 50 μs and the mean intensity of the discharge current i_e varies between 12.5 and 25 A. The associated graphic is displayed in Figure 9 – for thread's pitch and Figure 12 – for thread's angle.

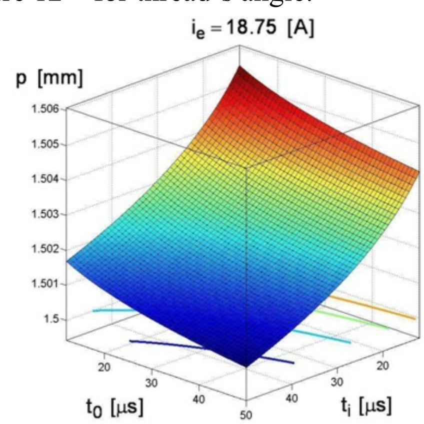

Fig. 7. Response surface for thread's pitch p [mm] at constant i_e = 18.75 A

From the analysis of the response surfaces, there resulted the following conclusions. The Figure 7 indicates that the value of thread's pitch *p* significantly increases when pulse duration t_i decreases. It should be observed that the value of thread's pitch increases at a lower rate when t_0 decreases. The value of thread's pitch has an almost linear increase.

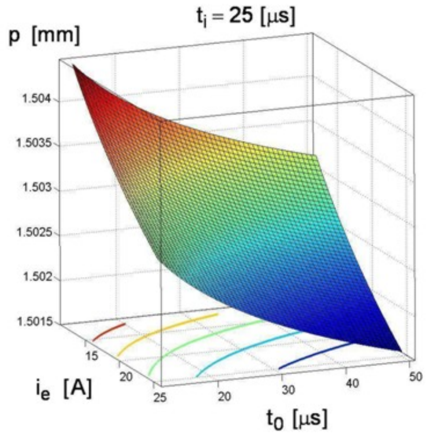

Fig. 8. Response surface for thread's pitch *p* [mm] at constant t_i = 25 μs

The Figure 8 shows that the value of thread's pitch *p* increases almost to its maximum, when the value of mean intensity of the discharge current i_e is decreasing. It can be observed that the value of thread's pitch *p* decreases almost to its minimum when pause duration t_0 increases to its maximum.

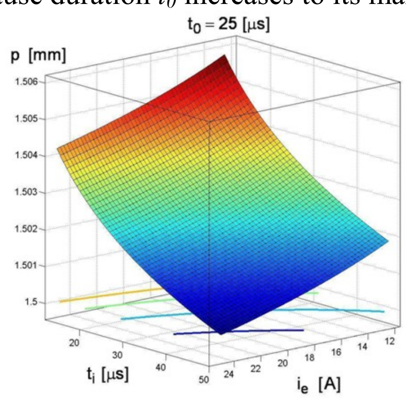

Fig. 9. Response surface for thread's pitch *p* [mm] at constant t_0 = 25 μs

The Figure 9 indicates that the value of thread's pitch *p* significantly increases with the decrease of pulse duration t_i. Also, it can be observed that the value of thread's pitch *p* linearly and slowly increases when mean intensity of discharge current i_e decreases.

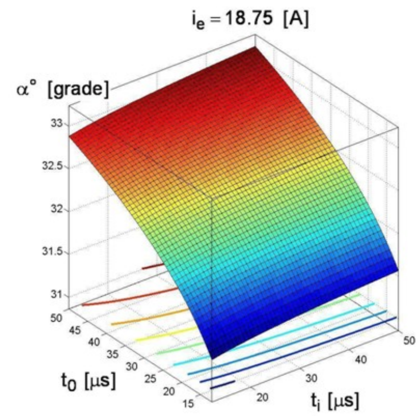

Fig. 10. Response surface for flank angle α [∘] at constant i_e = 18.75 A

The Figure 10 indicates that the value of flank angle α increases almost to its maximum when pauses duration t_0 increases. It should be observed that the value of flank angle increases at a lower rate when t_i increases.

The Figure 11 indicates that the value of flank angle α increases almost to its maximum, when the value of t_0 is increasing. It can be observed that the value of flank angle α increases linear with a low rate, when the value of i_e is increasing.

The Figure 12 indicates that the value of flank angle α increases with the increase of pulse duration t_i. Also, it can be observed that for the increase of i_e the value of flank angle α increases at a lower rate. The increase of flank angle α is linear.

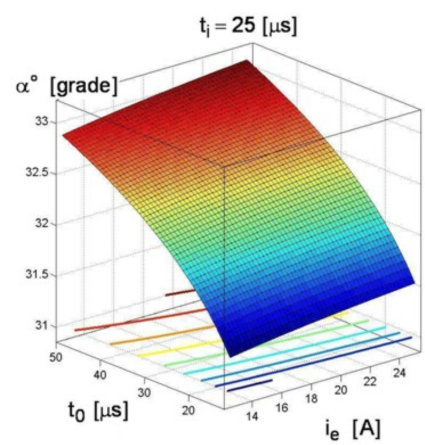

Fig. 11. Response surface for flank angle α [∘] at constant t_i = 25 μs

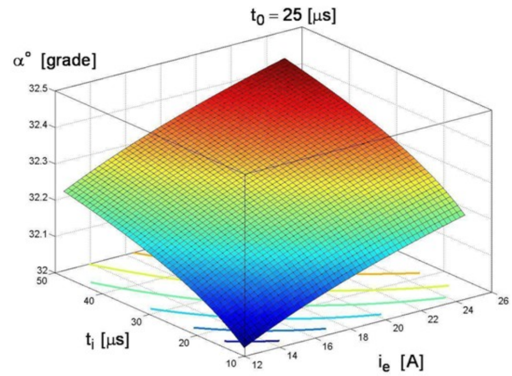

Fig. 12. Response surface for flank angle α [◦] at constant t_0 = 25 µs

5. Conclusions

On the basis of researches presented in this paper, there were determined the process functions for electroerosion of inner threads in sinterised metallic carbides type G20. These functions allow the correct determination of process parameters for electroerosion of threads in sinterised metallic carbides.

Because the electroerosion processing (EDM) of threads is characterised by a certain deficiency regarding the shape and dimensional precision [6], the authors' researches were especially focused on the analysis of geometrical parameters of metric threads machined in metallic carbides from group G.

In these circumstances, there were established the defining relationships of process functions for two geometrical parameters specific to threads, i.e. thread's pitch p and flank angle α. All the experiments were carried out in the context of adequate variation and interpretation of influence of independent variables (considered also in the scientific literature): mean intensity of the discharge current i_e, pulse duration t_i and pause duration t_0. Consequently, the analytically defined process functions (as a result of experiments) are useful to technological engineers for determination of process parameters adequate in complying to shape and dimensional precision requirements imposed by specific processing cases.

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