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Topological Characterization of Surfaces in Electro-Discharge Machining Using Motif Combination

In the present study the method of surface motif combination is applied to Electro-Discharge Machining surfaces. By statistical mean, as analysis of variance and response surface methodology, predictive models for the motif parameters are developed in terms of the machining conditions. Using these models the appropriate conditions for successful finish can be selected, as well as functional surface characteristics are quantified.

1. Introduction

Every machining process imparts geometric defects on the surface of engineering components and as a consequence, characteristic textures are generated, which play an important role in the quality and function of the surface.

The surface motif combination is a method of analyzing surface texture alternatively to the central line system 'M' and gives a graphical evaluation of surface profile using parameters without filtering waviness from roughness. Its origin is in Maxwell's ideas a hundred years ago of dividing a landscape into regions consisting of hills or dales. A motif consists of the portion of a profile between two peaks and the final combination of these motifs eliminates ''insignificant'' peaks and retains ''significant'' ones. As a consequence, this method determines the upper points of the profile, which have functional importance by an envelope based algorithm [1-3].

The French NF05-015 standard incorporates the following ten parameters (Table 1); eight of them are proposed in the international ISO 12085: 1996 standard [4].

Table 1: The motif (R & W) parameters

Parameters	Description
R	Mean depth of roughness motifs
Rx	Maximum depth of roughness motifs
Ar	Mean spacing of roughness motifs
W	Mean depth of waviness motifs
Wx	Maximum depth of waviness motifs
Wte	Maximum depth of the waviness profile
Aw	Mean spacing of waviness motifs
Kr	Mean slope of roughness motifs
Kw	Mean slope of waviness motifs
Pt	Maximum depth of the raw profile

Electro-Discharge Machining (EDM) is an unconventional machining process that manufactures with high precision and versatility conductive materials regardless of their mechanical and physical properties (hardness, melting point etc.) and investigations on the surface characteristics produced by this process are of importance [5,6].

This study presents the application of this method in the analysis of EDM'ed textures of steel by carrying out factorial design of experiments; data mining techniques are recommended for estimating the response variables in highly complicated technological systems and machining systems are as such. Pulse current and pulse-in time, considered to be the dominant machining conditions, were varied over a representative range.

2. Experimental - Statistical Analysis

2.1 Material - Equipment

The workpiece material was a Ck45 plain carbon steel.

EDMachining was performed on a HOSTEK SH-38GP (ZNC-P type) electro-discharge machine-tool with working voltage (V_e) of 30V and open circuit voltage of 100V. Experiments were conducted in a typical oil dielectric (BP250) with electrolytic copper being used as the tool electrode (anode).

The pulse current, i_e and the pulse-on time, t_p considered to be the main operational parameters varied over a range from roughing to finishing, namely: i_e: 5, 10, 20, 30 A and t_p: 100, 300, 500 μsec, thus resulting in 12 discrete pulse energies; the pulse energy was calculated by the formula: $W_e = V_e\ I_e\ t_p$ (V_e = 30V).

The surface texture analysis was performed using a Rank Taylor-Hobson Surtronic 3+ profilometer equipped with the Talyprof software. The cut-off length was selected at 0.8 mm whilst 40 measurements were conducted on every specimen at random directions as it is known that EDMachining generates geometrically isotropic textures.

2.2 Statistical models

The postulated model proposes that roughness or waviness or raw profile expressed by the selected parameters is a function of the machining independent variables, namely pulse current, I_e and pulse-on time, t_p

This relationship can be expressed as

$$R_i \text{ or } W_i \text{ or } P_i = C_i\ I_e^{m_i}\ t_p^{n_i} \quad (1)$$

C, m_i, n_i are constants.

Eq.(1) can be written as a linear combination of the following form in order to facilitate the determination of the aforementioned parameters. So the mathematical model is linearized by performing logarithmic transformation, as

$$\ln R_i \text{ or } W_i \text{ or } P_i = \ln C_i + m_i \ln I_e + n_i \ln t_p \quad (2)$$

which presents the following linear mathematical model :

$$\eta = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 \quad (3)$$

The linear model of (3) in terms of the estimated response can be written as:

$$y' = y - \varepsilon = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 \quad (4)$$

where ε is the experimental error.

3. Results and Discussion

All the motif parameters considered increase when the pulse energy increases and the rate of variation is higher at the lower pulse energies. This means regarding the roughness characteristics, that increased pulse energies lead to higher profile amplitudes and longer spacing between subsequent peaks. The same tendencies were also detected for waviness probably due to intensified vibration between the workpiece and the electrode. Indicative behaviour of the parameters variation is presented in Figs 1 and 2. Nevertheless, the other parameters employed show similar patterns.

In this way, by applying analysis of variance and statistical multi-regression analysis to the experimental data, close correlation was detected between the motif parameters and the machining conditions and predictive models can be formulated, as will be seen in the following.

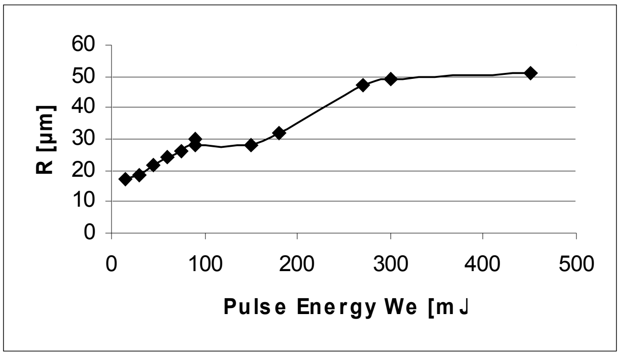

Figure 1: Variation of the R parameter against pulse energy

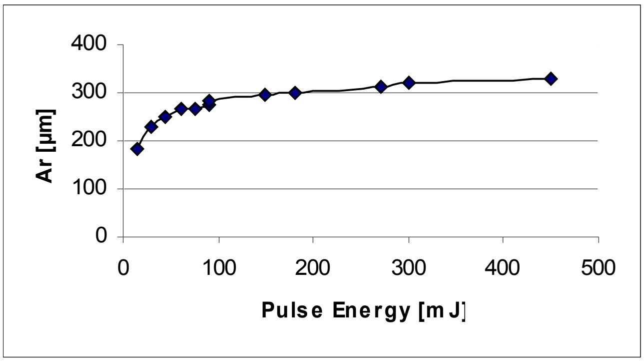

Figure 2: Variation of the A_r parameter against pulse energy

The results of the analysis of variance (ANOVA) in order to test the statistical and physical significance of the design factors on the parameters employed are listed in Table 2.

It is obvious that pulse current exerts the strongest influence. By using factorial design of experiments, we develop the models for all the motif parameters considered, listed in Table 3 together with the corresponding coefficients of determination.

Table 2. Results of analysis of variance (ANOVA) on the experimental data

Surface Motif Parameter	**Source of variance**	**DF**	**SS**	**MS**	**F**	**P**
lnR	I_e	1	0.996	0.996	31.38	0.000
	t_p	1	0.191	0.191	28.02	0.006
	Error	9	0.286	0.286		
	Total	11	1.474			
lnRx	I_e	1	1.567	1.567	44.78	0.000
	t_p	1	0.446	0.446	12.76	0.006
	Error	9	0.314	13.53		
	Total	11	2.327			
lnAr	I_e	1	0.014	10.014	12.18	0.005
	t_p	1	0.005	0.005	8.50	0.008
	Error	9	0.024	0.002		
	Total	11	0.043			
lnW	I_e	1	1.184	1.184	15.99	0.005
	t_p	1	0.242	0.242	10.44	0.006
	Error	9	1.198	0.133		
	Total	11	2.624			
lnWx	I_e	1	3.418	3.418	83.83	0.000
	t_p	1	1.259	1.259	30.88	0.000
	Error	9	0.367	0.040		
	Total	11	5.044			
lnWte	I_e	1	3.388	3.388	115.36	0.000
	t_p	1	0.665	0.665	22.66	0.001
	Error	9	0.264	0.029		
	Total	11	4.317			
lnAw	I_e	1	0.023	0.023	12.86	0.006
	t_p	1	0.007	0.007	10.63	0.008
	Error	9	0.112	0.012		
	Total	11	0.143			
lnKr	I_e	1	1.004	1.004	26.82	0.001
	t_p	1	0.077	0.077	23.08	0.003
	Error	9	0.337	0.037		
	Total	11	1.419			
lnKw	I_e	1	3.892	3.892	40.21	0.000
	t_p	1	1.590	1.590	16.43	0.003
	Error	9	0.871	0.096		
	Total	11	6.354			
lnPt	I_e	1	1.911	1.911	80.70	0.000
	t_p	1	0.474	0.474	20.02	0.002
	Error	9	0.213	0.023		
	Total	11	2.597			
	Total	11	240.664			

Table 3. Predictive models for the surface motif parameters

$R = 0{,}22\ I_e^{\ 0{,}43}\ t_p^{\ 0{,}13}$	r^2=0.926
$R_x = 0{,}31\ I_e^{\ 0{,}53}\ t_p^{\ 0{,}27}$	r^2=0.965
$A_r = 1{,}68\ I_e^{\ -0{,}03}\ t_p^{\ 0{,}52}$	r^2=0.890
$W = 0{,}38\ I_e^{\ 0{,}45}\ t_p^{\ 0{,}42}$	r^2=0.893
$W_x = 0{,}37\ I_e^{\ 0{,}73}\ t_p^{\ 0{,}44}$	r^2=0.927
$W_{te} = 1{,}44\ I_e^{\ 0{,}66}\ t_p^{\ 0{,}35}$	r^2=0.939
$A_w = 2{,}02\ I_e^{\ -0{,}067}\ t_p^{\ -0{,}03}$	r^2=0.898
$K_r = 1{,}21\ I_e^{\ 0{,}65}\ t_p^{\ 0{,}21}$	r^2=0.963
$K_w = 2{,}09\ I_e^{\ 0{,}84}\ t_p^{\ 0{,}54}$	r^2=0.913
$P_t = 0{,}34\ I_e^{\ 0{,}55}\ t_p^{\ 0{,}27}$	r^2=0.948

The corresponding estimated response surfaces of the motif parameters in association with pulse current and pulse-in-time are shown in Figures 3 to 12.

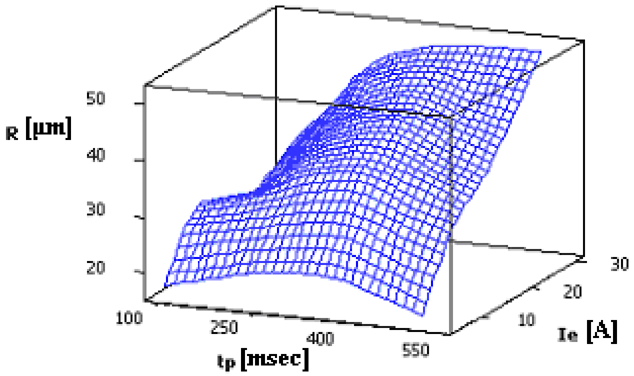

Figure 3: Estimated response surface of R variation versus I_e and t_p.

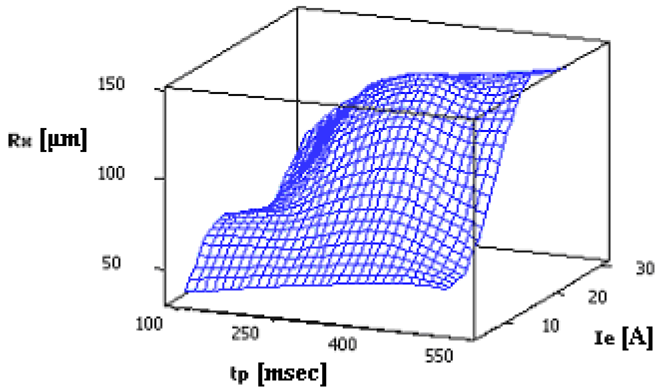

Figure 4: Estimated response surface of Rx variation versus I_e and t_p.

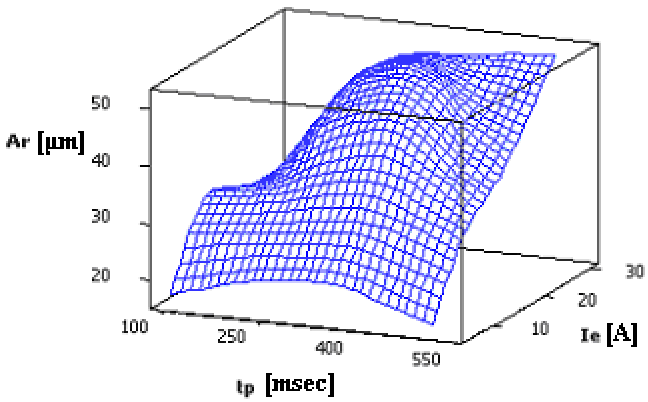

Figure 5: Estimated response surface of Ar variation versus I_e and t_p.

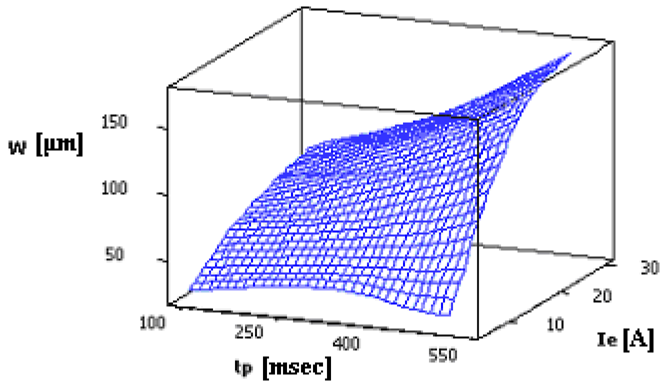

Figure 6: Estimated response surface of W variation versus I_e and t_p.

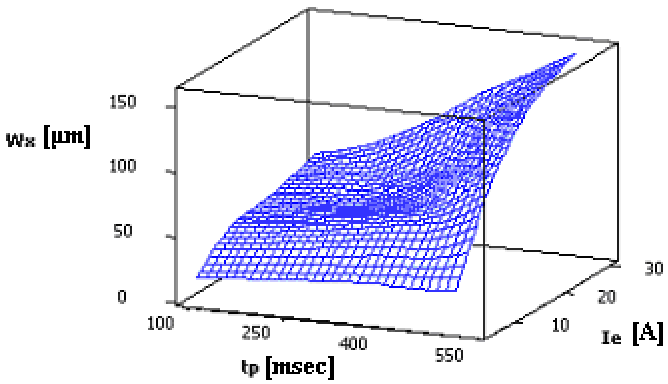

Figure 7: Estimated response surface of Wx variation versus I_e and t_p.

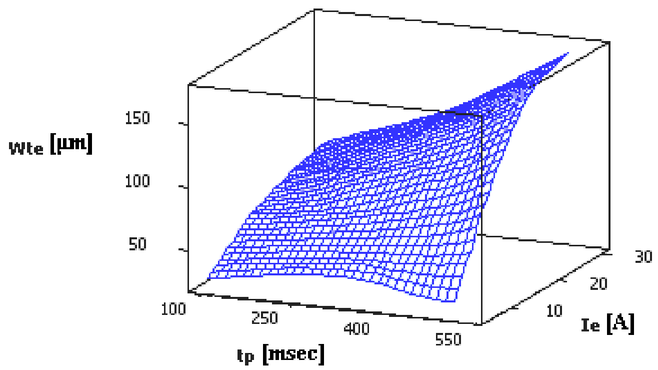

Figure 8: Estimated response surface of Wte variation versus I_e and t_p

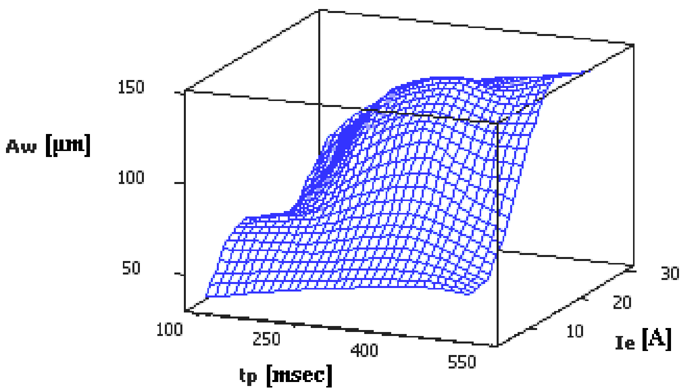

Figure 9: Estimated response surface of Aw variation versus I_e and t_p

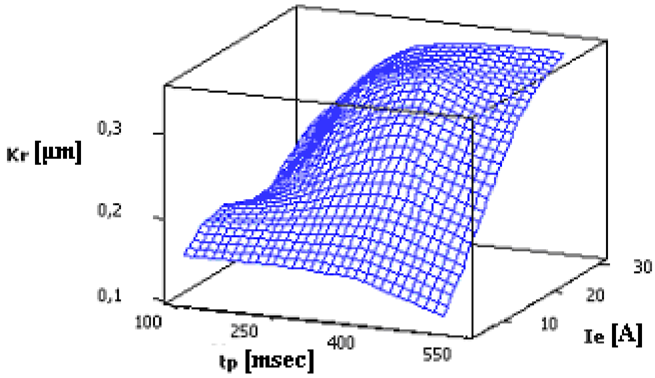

Figure 10: Estimated response surface of Kr variation versus I_e and t_p

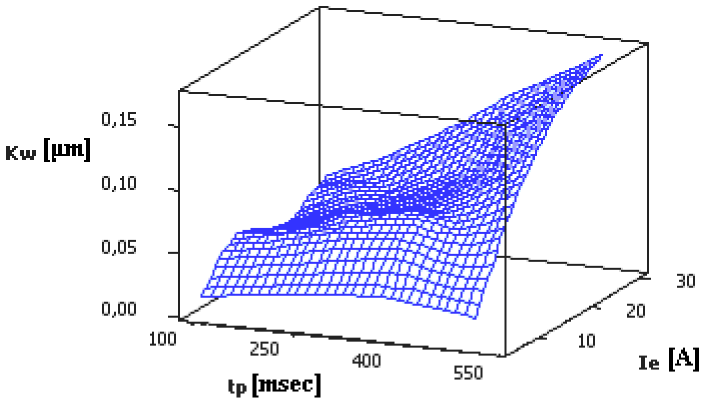

Figure 11: Estimated response surface of Kw variation versus I_e and t_p

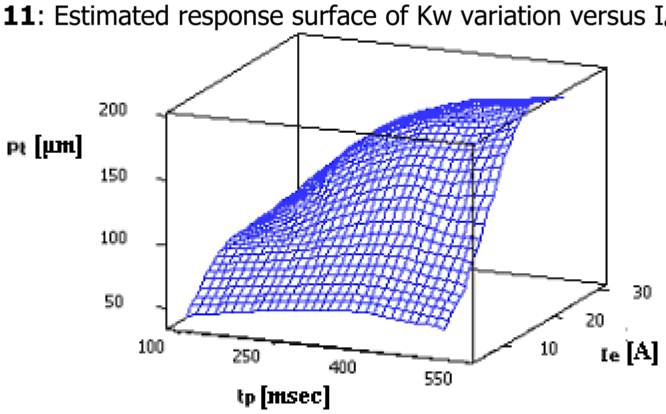

Figure 12: Estimated response surface of Pt variation versus I_e and t_p

4. Conclusions

In the present contribution EDM'ed surfaces are characterized using the surface motif method. The authors believe that it is an appropriate surface metrology technique, supplementary or alternative to the popular central line ''M" system, as is function oriented through the determination of the significant roughness peaks and the correct interpretation of waviness.

All the parameters proposed in the French standard NF05-015 were considered and relevant models were formulated via response surface methodology possessing high degrees of correlation with the machining conditions.

Using these models the appropriate conditions for successful finish can be selected, as well as functional surface characteristics are quantified.

References

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