Statistical and Experimental Study on the Influence of Input Parameters on the Dimensional Accuracy of Workpiece in EDM

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Abstract

The creation of side gap between tool and workpiece in machining hole is one of the cardinal obstacles in the electrical discharge machining (EDM) process. ASP30 tool steel is a cobalt alloyed high performance high speed steel that is widely used in tooling making industry. The objective of this study is to evaluate the effects of input variables including pulse on-time (Ti) and pulse current (I) on the side gap at different sections of machined hole and its conicity in electrical discharge machining process of ASP30 tool steel. Based on the experimental results, a regression modeling has been conducted to develop models in order to predict the effects of each parameter on the mentioned outputs of EDM process. The experimental results show that side gap increases with increase in pulse on-time and pulse current, although this variance is not consistent at all sections of machining depth. The other significant finding is that the intensity of pulse current's effect is less than that of pulse on-time. Furthermore, the results represent the direct correlation between the conicity of the machined hole and the discharge energy. On the other hand, the outcomes of acquired models based on the experimental results demonstrate that through utilizing polynomial regression models the mentioned outputs of EDM process, the side gap and conicity of machined hole, can be predicted with high accuracy.

Keywords
Electrical discharge machining; ASP30 tool steel; Side-gap; Conicity; Regression modeling

1. Introduction

Electrical discharge machining (EDM) is a non-conventional machining process and has an extensive application in nuclear, automobile, die-making, and medical-appliance industries employed for machining conductive materials regardless to their degree of hardness [1]. ASP30 tool steel is a cobalt based alloy high speed steel that is produced by powder metallurgy method and has a wide application in tool-making industries. Regarding the high hardness of this metal (60~67HRC) electrical discharge machining is a competent process for its machining [2]. Nevertheless, the creation of side gap between the tool and workpiece, which is one of the prime obstacles in the electrical discharge machining and leads to the conical form of machined hole, exists in application of this process for the ASP30 tool steel as well. Regarding the fact that the complete elimination of side gap is infeasible, the selection of appropriate level of input parameters to achieve an acceptable size of side gape in the range of dimensional tolerance is essential [3]. Some studies have been conducted in the field to investigate the effect of various process conditions on the side gape at different workpiece-tool combinations. Nakaoku and Masuzawa [4] compared the side gapes of for different sintered composites as the workpieces micro-EDMed using the tool made of tungsten carbide and reported that the side gap increases by the increase of pulse on time for all different workpiece-tool combinations. Kibria et al [5] studied the effect of three different carbohydrates as dielectrics in the micro-EDM process of Ti-6Al-4V alloy with tungsten tools and reported that the side gap increases by the increase in pulse current using all the three different dielectrics. Shik Shin et al [6] used micro-WEDM to fabricate micro grooves by moving the tool electrode made of Ø10μm tungsten wire along a programmed tool-path. They applied ultra-short voltage pulses and changed the pulse on-time to investigate the optimal pulse conditions for stable machining and minimize the side gap in fabrication of micro grooves and gears into stainless steel plates. BIN MOHD ISA and Sharif [7] conducted an experiment to investigate the influence of input parameters on the machining characteristics of Ti-6246 titanium alloy using copper impregnated graphite electrode in EDM process. Also, based on analysis of variance (ANOVA) they presented regression models with 15% of marginal errors for predicting the output parameters. Based on the experimental results and the statistically evaluation using analysis of variance it has been shown that the pulse current was the most significant parameter influencing the machining responses. The purpose of this study is to investigate the effect of pulse current and pulse on-time on the side gape, created between the workpiece and tool, at different sections of machining depth as well as the conicity of the machined hole in EDM process of ASP30 tool steel. Furthermore, a regression modeling based on the analysis of variance has been conducted to figure out the correlation of pulse current and pulse on-time with the response surface of the mentioned output parameters of the machined hole in EDM process of this steel.

2. Experimental Setup

In the experiment stage, the specimen of ASP30 tool steel were cut in the cubic form (18×18×18 mm) and undergone the hardening and grinding processes (Fig. 1). The main physical properties and chemical analyses of this steel are represented in Table 1. The tool material was selected of copper with the purity of 99.99% controlled using profile projector Kreuztisch KT200/50 at magnitude of 20 times and cut in the cylindrical form with the dimensions of Ø15×45mm (Fig. 2). Regarding the nature of the subject matter of side gape, the conicity of the tool is of paramount importance. As a result, this factor was examined using a three-dimensional measuring instrument DKM 300DP- ZEISS. The machining process was performed on a CNC electro discharge machining Charmilles-Roboform 200. The inner diameter of machined holes measured up to a calibrated *accuracy of 0.001mm* using a Subito. Machining tests were carried out at four pulse current as well as four pulse on-time settings. As a result, 16 experiments could have been designed in a full factorial adaptation. Each machining test was performed for the time of reaching 18mm of depth. Table (2) presents the experimental test conditions.

Table 1. Physical properties and metallurgical analysis of ASP30 tool steel [2].

Physical Properties	Temperature (°C)	20	400		600	
	Density (gr/cm^3)	8.040	7.935		7.880	
	Modulus of Elasticity (MPa)	240 000	214 000		192 000	
	Coefficient of Thermal Expansion (Per °C from 20°C)	------	10^{-6} 11.8×		10^{-6} 12.3×	
	Thermal Conductivity (w/m °C)	22	26		25	
	Specific Heat (J/kg °C)	420	510		600	
Metallurgical Analysis (%)	Co	V	W	Mo	Cr	C
	8.5	3.1	6.4	5.0	4.2	1.28

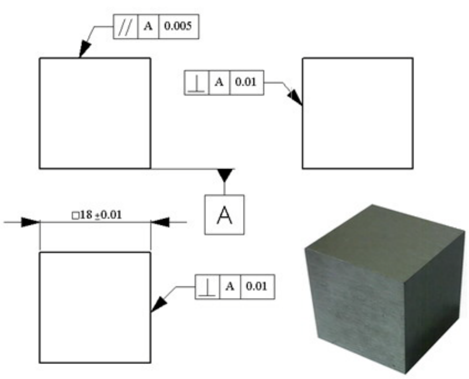

Figure 1. Dimensional size and geometrical tolerance of workpiece

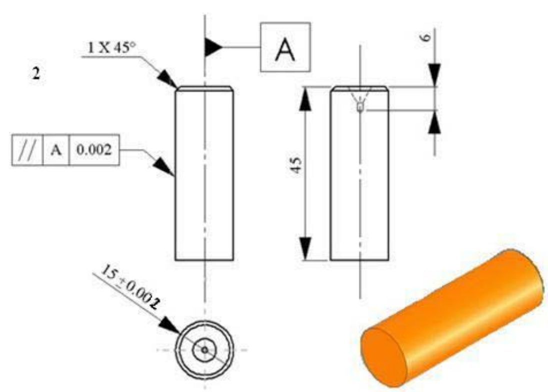

Figure 2. Dimensional size and geometrical tolerance of tool

Table 2. Experimental condition and test variables

Experiment Variable	Descriptions
Generator Mode	ISO pulse (Roboform 200)
Power Supply Voltage (V)	200
Tool Polarity	Positive (+)
Dielectric Fluid	Oil Flux EL F2
Flashing type	Normal Submerged
Gap Distance (µm)	50
Discharge Current (A)	8, 16, 24, 32
Discharge Duration (µs)	12.8, 25, 50, 100
Depth of Cut (mm)	18

The side gap between the tool and workpiece was calculated at three different sections of machining depth (3, 9, and 15mm) according to Eqs. 1 to 3. Also, the average value of side gap and the conicity of EDMd hole in workpiece were obtained by Eqs. 4 and 5 [8].

$$S_U = W_{DU} - T_D \quad (1) \qquad S_M = W_{DM} - T_D \quad (2)$$

$$S_D = W_{DD} - T_D \quad (3) \qquad S_{ave} = (S_U + S_M + S_D)/3 \quad (4)$$

$$D_V = D_{WU} - D_{WD} \quad (5)$$

where T_D is the diameter of tool; W_{DU}, W_{DM}, and W_{DD} are the diameter of EDMed hole at depths of 3, 9, and 15mm, respectively; S_U, S_M, and S_D are the created side-gap between the tool and workpiece at three different sections of 3, 9, and 15mm depths from the top surface of workpiece, respectively; S_{ave} is the average side-gap between the tool and workpiece; and D_V is the conicity of EDMed hole.

3. Results and Discussion

This section represents the quantitative evaluation of the side gap and error of conicity of the machined hole in EDM process of ASP30 tool steel and the statistical model developed using SPSS software base on empirical data to predict the mentioned parameters.

3.1 The effect of pulse on-time and pulse current on side-gap

Figures 4, 5, and 6 show the effect of pulse on-time on the side-gap at three different machining depths (S_U, S_M, and S_D) in various levels of pulse currents, respectively. As it is clear from these figure, the side gap increases with the increase in pulse on-time in different levels of pulse current at all of the three levels of machining depths. Furthermore, by the comparison of slopes of the contours in these figures, it becomes cleare that the intensity of pulse on-time effect on the S_U is more than that on the S_M and S_D. On the other hand, the effect of pulse current on the S_D is less than its effect on the S_U and S_M. This phenomenon reveals the fact that the effect of pulse on-time out weighes the effect of pulse current on side gap. This matter could also be conformed through the models acquired using regression modling methods in this study.

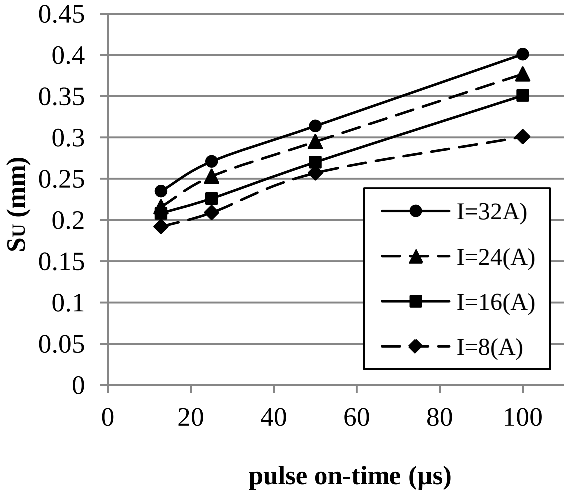

Figure 4. The S_U vs. pulse on-time at different pulse currents

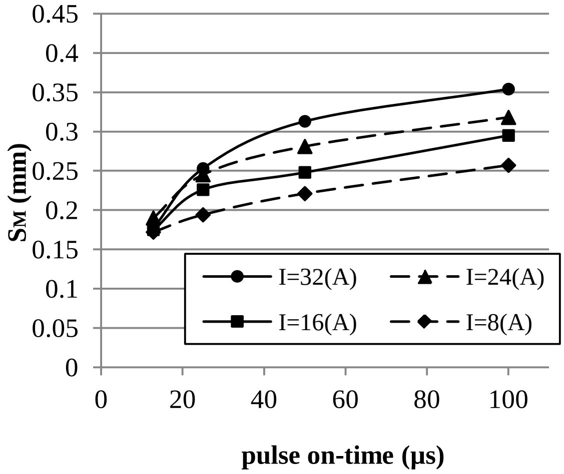

Figure 5. The S_M vs. pulse on-time at different pulse currents

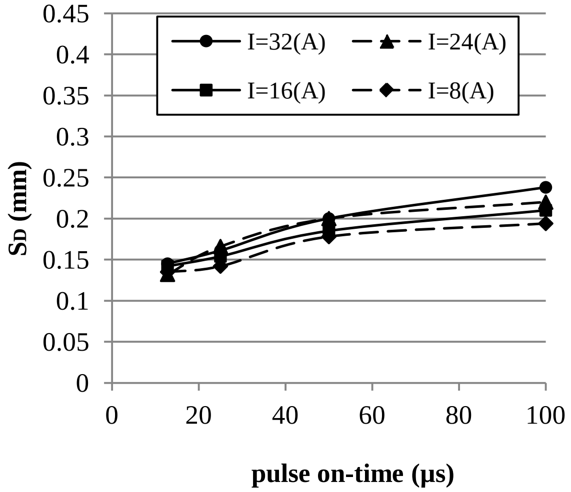

Figure 6. The S_D vs. pulse on-time at different pulse currents

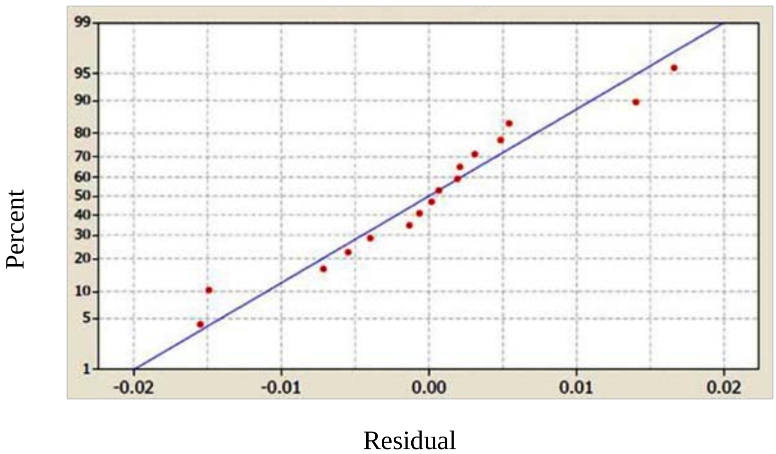

Figure 7. Plot of deviation from the normal distribution of residues for S_{ave}

The average side gap (S_{ave}) has been calculated using Eq. (4) and the deviation from normal distribution and the dispersion of errors related to S_{ave} have been assessed through bilateral variance analysis and utilizing Minitap software. Figs. 7 and 8 show the deviation from normal distribution of residues and dispersion of data related to S_{ave}, respectively. It can be deduced from fig. 7 that the deviation of residues from normal distribution is within the acceptable limites.

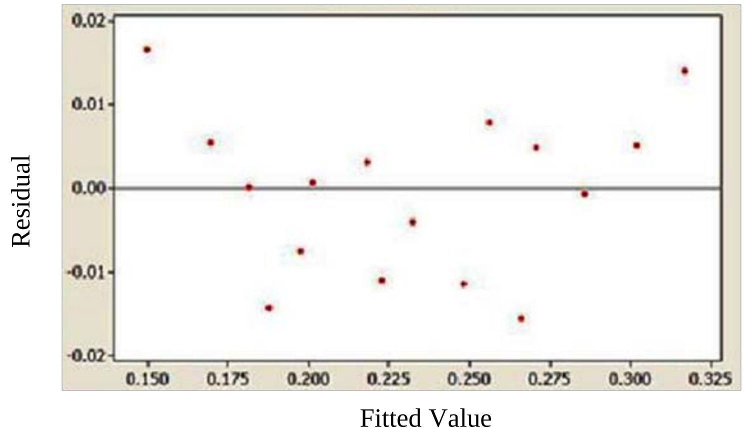

Figure 8. Plot of dispersion of data for S_{ave}

Furthermore, it has been proved that using regression modeling it is possible to predict the S_{ave} with a high accuracy. The acquired model in this study (Eq. 6) has the capacity to predict the S_{ave} with a 99% accuracy as 99% of variations of the S_{ave} are influenced by the variables defiened in the model. The statistical features of this model have been represnted in tables 3 to 5.

$$S_{ave}\times 10^3 = 150 + 0.8163\times Ti + 0.0819\times I\times Ti - 0.0005\times I\times Ti^2 \quad (6)$$

Table 3. Correlation coeficient, determination coeficient, corrction factor, and standard error for S_{ave}.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
4	0.996a	0.992	0.991	0.00482460

a. Predictors: (Constant), Ti, (I×Ti), (I×Ti×Ti)

Table 4. Analysis of variance of the presented regression model for S_{ave}.

Sum of Squares	df	Mean Square	F_0	Sig.
0.0369	3	0.0123	528.148	0.000a
0.0003	12	0.0000		
0.0372	15			

Table 5. Regression coefficeints of represented model for S_{ave}.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
4	(Constant)	0.150	0.003		45.383	0.000
	Ti	8.163E-4	0.000	0.566	11.782	0.000
	I.Ti	8.189E-5	0.000	1.435	14.402	0.000
	I.Ti.Ti	-5.086E-7	0.000	-0.966	-8.439	0.000
Dependent Variable: Side Gap average(mm)						

According to the H_0 correlation [9] in order to evaluate the authenticity of presented regression model for S_{ave} from the statistical tables with the level of α=0.01 it would be:

$F_0 = 528.15 > 5.95$ =From Statistical Tables $F_{0.01, 3, 12}$

The surface plots of S_{ave} versus pulse current and pulse on-time is shown in Fig. 9

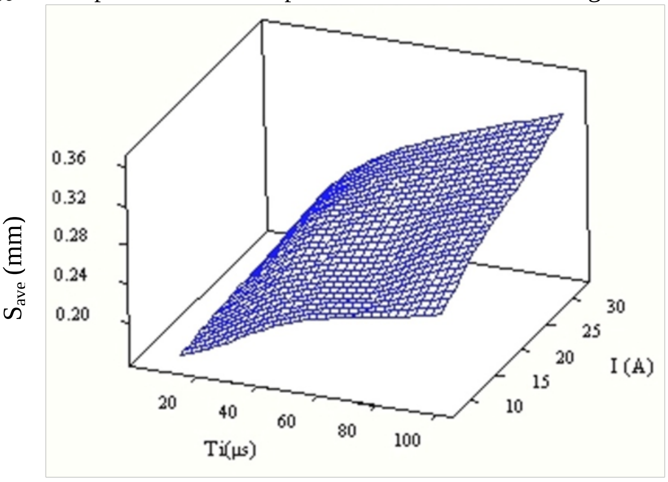

Figure 9. Surface plot of S_{ave} vs. pulse current and pulse on-time

The reliability of acquired model in this study for the prediction of side gap has been represented in Figs. 10 and 11, as it is clear through these figures there is a close proximity between the experimental data and the predicted values of side gap of the EDMed hole.

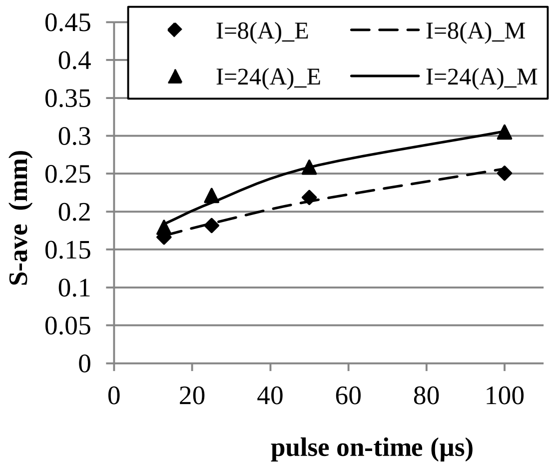

Figure 10. S_{ave} vs. pulse on-time at pulse currents of 8 and 24A for both experimental of statistical results

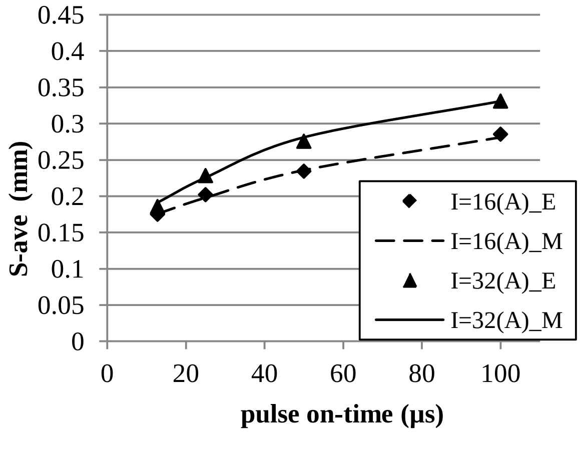

Figure 11. S_{ave} vs. pulse on-time at pulse currents of 16 and 32A for both experimental of statistical results

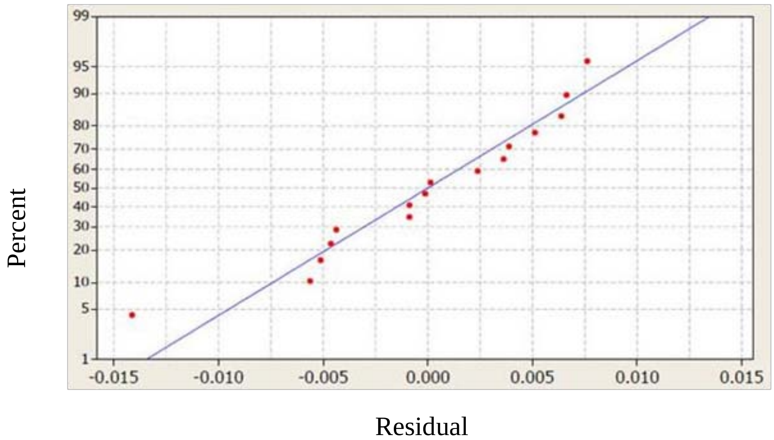

Figure 12. Plot of deviation from the normal distribution of residues for D_V

3.2 The effect of pulse on-time and pulse current on the conicity of EDMed hole

Regarding the fact that the side-gap is not even in the diffirent depths of machining hole and considering the phenomenon of tool wear during the EDM process, the conicity of the EDMed hole wouldn’t be conserved.

In this research, in order to evaluate the conicity of the EDMed hole, Eq. 5 has been utilised taking into account the differece between the opening and ending diameters (at machining depths of 3 and 15mm) of the machined hole.

Furthermore, the the deviation from normal distribution and the dispersion of errors related to D_V have been calculated using Minitab software and employing bilateral variance analysis. Figs. 12 and 13 show the achieved deviation from normal distribution and dispersion of errors related to D_V through the conducted analysis, respectively.

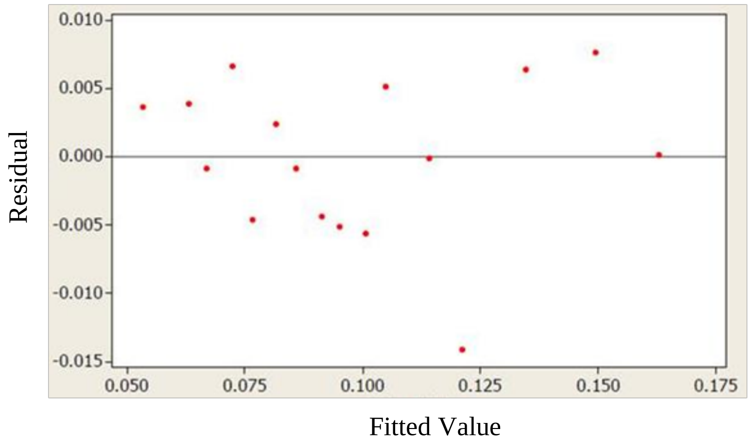

Figure 13. Plot of dispersion of data for D_V

Also, it has been proved that using regression modeling it is possible to predict the D_V with a high accuracy. The acquired model in this study (Eq. 7) has the capacity to predict the D_V with a 99% accuracy as 98% of variations of the D_V are influenced by the variables defiened in the model. The statistical features of this model have been represnted in tables 6 to 8.

$$D_V \times 10^3 = 380 + 1.717 \times I + 1.352 \times Ti - 0.01118 \times Ti^2 - 0.1263 \times I \times Ti + 0.00284 \times I^2 \times Ti + 0.00175 \times I \times Ti^2 - 0.00003914 \times I^2 \times Ti^2 \quad (7)$$

Table 6. Correlation coeficient, determination coeficient, corrction factor, and standard error for D_V.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
5	0.995a	0.991	0.983	.00414910

a. Predictors: (Constant), I, Ti, (Ti×Ti), (I×Ti), (I×I×Ti), (I×Ti×Ti), (I×I×Ti×Ti)

Table 7. Analysis of variance of the presented regression model for D_V.

Model		Sum of Squares	df	Mean Square	F_0	Sig.
5	Regression	0.0151	7	0.0022	125.433	.000a
	Residual	0.0001	8	0.0000		
	Total	0.0153	15			

According to the H_0 correlation [9] in order to evaluate the authenticity of presented regression model for D_V from the statistical tables with the level of α=0.01 it would be:

F_0 = 125.43 > 6.84 = From Statistical Tables $F_{0.01, 8, 7}$

The surface plots of D_V versus pulse current and pulse on-time is shown in Figure 14.

Table 8. Regression coefficeints of represented model for D_V

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
5	(Constant)	0.038	0.008		4.608	0.002
	I	1.717E-3	0.000	0.497	4.518	0.002
	Ti	1.352E-3	0.001	1.464	2.661	0.029
	Ti.Ti	-1.118E-5	0.000	-1.432	-2.287	0.052
	I.Ti	-1.263E-4	0.000	-3.454	-2.876	0.021
	I.I.Ti	2.840E-6	0.000	2.427	2.835	0.022
	I.Ti.Ti	1.750E-6	0.000	5.189	3.703	0.006
	I.I.Ti.Ti	-3.914E-8	0.000	-3.384	-3.500	0.008
Dependent Variable: Diameter Variance (mm)						

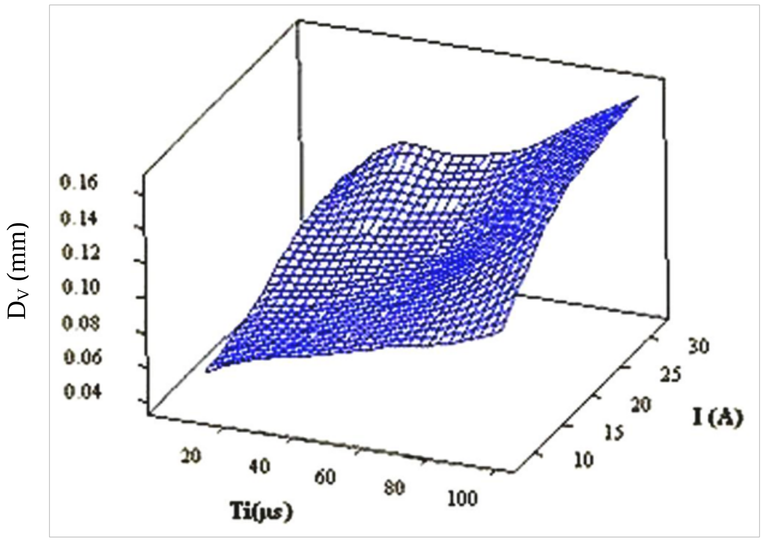

Figure 14: Surface plot of D_V vs. pulse current and pulse on-time

Overall, in order to corroborate the capacity of represented model in this study for prediction of D_V, Figs. 15 and 16 have been depicted showing the proximity of experimental data to the predicted values.

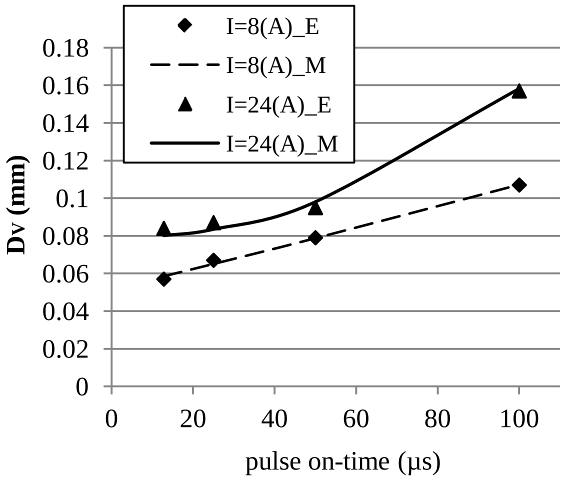

Figure 15. D_V vs. pulse on-time at pulse currents of 8 and 24A for both experimental of statistical results

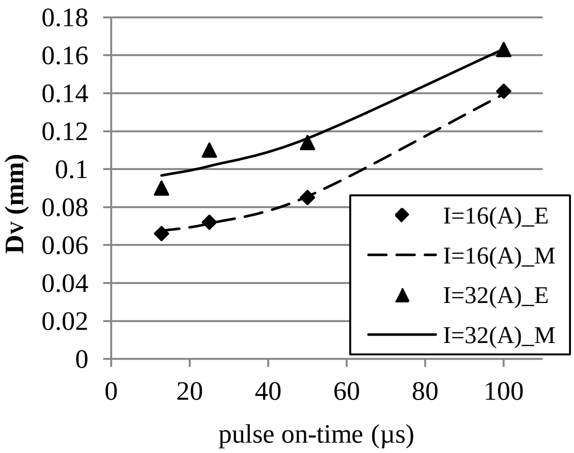

Figure 16. D_V vs. pulse on-time at pulse currents of 16 and 32A for both experimental of statistical results

Additionally, according to Figs. 15 and 16, the D_V increases by the increases in pulse current and pulse on-time as this phenomenon shows the fact that D_V has a dirrect correlation with the pulse energy and increases by the increase in the level of dischage energy.

4. Conclusions

The results of conducted experimental and statistical study on the influence of input variables on the side-gap and conicity of machined hole in the electrical discharge machining of ASP30 tool steel have been presented. The leading conclusions are as follows:

- The side-gap increases by the increase in pulse on-time at all different machining sections.
- By the increase of machining depth in one hand the side-gap decreases and on the other hand the effect of pulse on time on this characteristic decreases as at machining depth of 15mm the side-gap is just influenced by pulse on-time.
- The conicity of EDMed hole had a direct correlation with the discharge energy as it increases by the increase in discharge energy.
- Using a suitable regression model it is feasible to predict the side-gap and conicty of the EDMed hole with a high accuracy.

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