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The Implementation of Taguchi Method on EDM Process of Tungsten Carbide

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Abstract

In this paper, the cutting of Tungsten Carbide ceramic using electro-discharge machining (EDM) with a graphite electrode by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experimental layout, to analyse the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as peak current, voltage, pulse duration and interval time. It is found that these parameters have a significant influence on machining characteristic such as metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR). The analysis of the Taguchi method reveals that, in general the peak current significantly affects the EWR and SR, while, the pulse duration mainly affects the MRR. Experimental results are provided to verify this approach.

Keywords: EDM, Taguchi method, Tungsten Carbide, metal removal rate, electrode wear rate, surface roughness

1. Introduction

With the increasing demand for new, hard, high strength, hardness, toughness, and temperature resistant material in engineering, the development and application of EDM has become increasingly important. EDM has been used effectively in machining hard, high strength, and temperature resistance materials. Material is removed by means of rapid and repetitive spark discharges across the gap between electrode and workpiece[1]. Therefore, the merits of the EDM technique become most apparent when machining metal alloy Tungsten Carbide which has the highest hardness in reinforcement. In addition, mechanical and physical properties of tungsten carbide such as hardness, toughness, high wear resistance has made it an important material for engineering components particularly in making moulds and dies. Since the EDM process does not involve mechanical energy, the removal rate is not affected by either hardness, strength or toughness of the workpiece material[2]. Therefore, a comprehensive study of the effects of EDM parameters (peak current, machining voltage, pulse duration and interval time) on the machining characteristics such as electrode wear rate, material removal rate, surface roughness and etc., is of great significance and could be of necessity. Although study of these parameters has been performed by many researchers, most of the studies do not much consider both engineering phylosophy (DOE) and mathematical formulation (ANOVA)[3, 4], particularly in machining very hard materials such as Tungsten Carbide. Therefore, the Taguchi method[3, 4, 5], which is a powerful tool for parametric design of performance characteristics, is used to determine the optimal machining parameters for minimum electrode wear ratio, maximum material removal rate and minimum surface roughness in the EDM operations. The experimental details when using the Taguchi method are described.

2. Experimental Process

Tungsten carbide alloy was the target material used in this investigation. *Table 1* shows the material related properties. Experiments were performed using a Charmilles Electrical Discharge Machine, Series-Roboform. *Figure 1* depicts schematically the experimental set-up. A cylinder of pure graphite with a diameter of 9 mm was used as an electrode to erode a workpiece of tungsten carbide. Kerosene was used as the dielectric fluid in this experiment.

Figure 1:

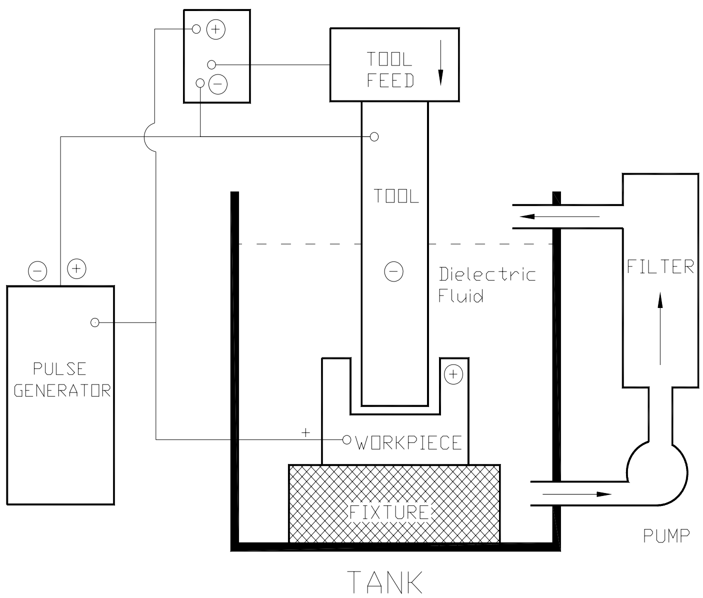


Table 1: Material properties of Tungsten Carbide

Properties	Value
Transverse rupture strength(Mpa)	550
Young's Modulus(Gpa)	620
Vicker's hardness(Gpa)	22
Shear Modulus(Gpa)	262
Poisson's Ratio	0.18
Density(g/cm^2)	15.8
Electrical resistivity(x 10^{-6} Ohmcm)	17
Specific heat(J/molK)	39.8
Melting point(ºC)	2870
Thermal conductivity(W/mK)	63

(Source: Fan Steel VR/Wesson – Hydro carbide)

Changes in electrode weight, material weight and elapsed time were recorded after each machining test. The MRR and the EWR were evaluated for each cutting condition by measuring the average amount of material removed and the required cutting time. Next, the SR of the tungsten carbide was measured by a Taylor Hobson Surface Roughness Tester, series-Talysurf. The cut-off length for each measurement was 0.8 mm. The Ra values were measured three times on each specimen and then, the surface roughness values were averaged. Machining experiments for determining the optimal machining parameters were carried out by setting negative polarity of discharge voltage in the range of 120-200 V, the discharge current in the range of 8.0–64.0 A, the pulse duration in the range of 1.6-50 µs, and the interval time in the range of 3.2-800 µs. Essential parameters of the experiment are given in *Table 2*.

Table 2: Electrical discharge machining condition

Work Condition	Description
Electrode	Graphite, diameter 9 mm, Length 70 mm
Workpiece	Tungsten Carbide ceramic, square shape(100x100x7mm)
Voltage	-120 to -200 v
Peak current	8 to 64 A
Pulse duration	1.6 to 50 µs
Interval time	3.2 to 800
Dielectric Fluid	Kerosene
Technology used	Blank/user tech

3. Design of Experiments and Data Analysis

3.1. Design of Experiments

The experimental layout for the machining parameters using the L_9 orthogonal array was used in this study. This array consists of four control parameters and three level, as shown in table 3. In the taguchi method, most all of the observed values are calculated based on 'the higher the better' and 'the smaller the better'. Thus in this study, the observed values of MRR, EWR and SR were set to maximum, minimum and minimum respectively. Each experimental trial was performed with three simple replications at each set value. Next, the optimisation of the observed values was determined by comparing the standard analysis and analysis of variance(ANOVA) which was based on the taguchi method.

Table 3: Design scheme of experiment of Parameters and levels

Control Parameters	Level			Observed Values
	1	2	3	
	Minimum	Intermediate	Maximum	
Machining voltage, V(volt)	-120	-160	-200	1.Material Removal Rate(cm^3/min)
Peak Current, P(ampere)	8	32	64	2.Electrode Wear Rate(%)
Pulse Duration, A (µs)	1.6	12.8	50	3.Surface Roughness(Ra)
Interval Time, B (µs)	3.2	50	800	

3.2. Analysis of Variance(ANOVA)

Analysis of variance(ANOVA) and the F test(standard analysis) are used to analyse the experimental data as follows [2, 3, 4]:

$$CF = T^2/n \quad (1)$$

$$S_T = \sum_{i=1 to 27} Y_i^2 - CF \quad (2)$$

$$S_z = (Y_{z1}^2/N_{z1} + Y_{z2}^2/N_{z2} + Y_{z3}^2/N_{z3}) - CF \quad (3)$$

$$f_z = (\text{number of levels of parameter z}) - 1 \quad (4)$$

$$f_T = (\text{total number of results}) - 1 \quad (5)$$

$$f_e = f_T - \sum f_z \quad (6)$$

$V_z = S_z/f_z$ (7)
$S_e = S_T - \sum S_z$ (8)
$V_e = S_e/f_e$ (9)
$F_z = V_z/V_e$ (10)
$S_z' = S_z - (V_e * f_z)$ (11)
$P_z = S_z'/ S_T * 100\%$ (12)
$P_e = (1 - \sum P_z) * 100\%$ (13)

Where;

CF	correction factor
T	total of all results
n	total number of experiments
S_T	total sum of squares to total variation
Y_i	value of results of each experiment (i= 1 to 27)
S_z	sum of squares due to parameter z(z= V, P, A and B)
N_{z1}, N_{z2}, N_{z3}	repeating number of each level(1, 2, 3) of parameter z
Y_{z1}, Y_{z2}, Y_{z3}	value of results of each level(1, 2, 3) of parameter z
f_z	degree of freedom(DOF) of parameter z
f_T	total degree of freedom
f_e	degree of freedom(DOF) of error term
V_z	variance of parameter z
S_e	sum of squares of error term
V_e	variance of error term
F_z,	F ratios of parameter z
S_z'	pure sum of square
P_z	percentage contribution of parameter z
P_e	percentage contribution of error term

3.3. Data Analysis

In this study, all the analysis based on the taguchi method is done by Taguchi DOE software(Qualitek-4) to determine the main effects of the process parameters, to perform the analysis of variance(ANOVA) and to establish the optimum conditions. The main effects analysis is used to study the trend of the effects of each of the factors, as shown in figures 2, 3 and 4. The machining performance(ANOVA-significant factor) for each experiment of the L9 can be calculated by taking the observed values of the EWR as an example from table 4. Table 5 lists the ANOVA and F test results for EWR. $F_{0.05;n1,n2}$ is quoted from “Stastitical Tables” [7]. If the calculated F_z values exceed $F_{0.05;n1,n2}$ (Table 5), then the contribution of the input parameters, such as peak current, is defined as significant. Thus, the significant parameters can be categorised into two levels which is significant and subsignificant. All of them are based on the fact that the F_z values are much larger than $F_{0.05;n1,n2}$ and denoted as ** and * respectively. For instance, to evaluate the EWR, the significant parameter is peak current. The remaining parameters only slightly contribute to the evaluation of the EWR. Similar calculations are also applied in evaluating the MRR and SR. Tables 6, 7 and 8 summarised the correlated results, indicating the significant parameters in evaluating the MRR and SR respectively. In addition, the optimum machining condition(ANOVA-optimum condition) of each of the observed values is illustrated in tables 9, 10 and 11.

Table 4: L_9 table and Observed values

No.of Trial	Control Parameter (level)				Result/Observed Value								
	V	P	A	B	EWR (%)			MRR (cm^3/min) X 10^-3			SR (Ra)		
					1	2	3	1	2	3	1	2	3
1	-120(1)	8(1)	1.6(1)	3.2(1)	37.00	37.76	37.40	1.07	1.05	1.03	2.18	2.38	2.25
2	-120(1)	32(2)	12.8(2)	50(2)	17.20	17.95	17.58	3.79	3.83	3.75	3.06	3.02	3.05
3	-120(1)	64(3)	50(3)	800(3)	8.72	8.36	8.54	4.21	4.19	4.26	3.64	3.31	3.38
4	-160(2)	8(1)	12.8(2)	800(3)	28.40	30.90	29.60	0.19	0.23	0.21	2.71	2.97	2.63
5	-160(2)	32(2)	50(3)	3.2(1)	21.28	21.20	21.16	5.23	5.25	5.33	4.40	4.17	4.07
6	-160(2)	64(3)	1.6(1)	50(2)	10.93	11.10	10.83	1.25	1.23	1.30	2.98	2.12	2.89
7	-200(3)	8(1)	50(3)	50(2)	40.93	43.67	42.30	1.89	1.92	1.88	2.56	2.68	2.47
8	-200(3)	32(2)	1.6(1)	800(3)	7.40	7.60	7.50	0.19	0.23	0.21	5.03	5.42	5.27
9	-200(3)	64(3)	12.8(2)	3.2(1)	24.10	22.40	23.24	3.13	3.25	3.10	3.54	3.68	3.58

Table 5: Analysis of variance and F test for EWR

Parameter (z)	DOF (f_z)	Sum of Square (S_z)	Variance (V_z)	F-ratio (F_z)	$F_{0.05;n1,n2}$	Pure Sum (S_z')	Percent (P_z)
V	2	73.487	36.743	73.256 *	3.55	72.483	1.940
P	2	2,806.092	1,403.046	2,797.268**	3.55	2,805.089	75.085
A	2	159.688	79.844	159.186 *	3.55	158.685	4.247
B	2	687.577	343.788	685.415 *	3.55	686.574	18.377
e	18	9.028	0.501				0.351

** Significant Parameter; * subsignificant parameter

Table 6: Analysis of variance and F test for MRR

Parameter (z)	DOF (F_z)	Sum of Square (S_z)	Variance (V_z)	F-ratio (F_z)	$F_{0.05;n1,n2}$	Pure Sum (S_z')	Percent (P_z)
V	2	7.314	3.657	2,201.500 *	3.55	7.310	9.024
P	2	22.612	11.306	6,806.095 *	3.55	22.608	27.907
A	2	39.337	19.668	11,840.221**	3.55	39.334	48.551
B	2	11.721	5.860	3,528.034 *	3.55	11.718	14.464
e	18	0.028	0.001				0.054

** Significant Parameter; * subsignificant parameter

Table 7: Analysis of variance and F test for SR

Parameter (z)	DOF (f_z)	Sum of Square (S_z)	Variance (V_z)	F-ratio (F_z)	$F_{0.05;n1,n2}$	Pure Sum (S_z')	Percent (P_z)
V	2	3.647	1.823	43.234 *	3.55	3.562	16.255
P	2	12.019	6.009	142.486 **	3.55	11.935	54.456
A	2	0.414	0.207	4.907 *	3.55	0.329	1.504
B	2	5.077	2.538	60.188 *	3.55	4.993	22.780
e	18	0.758	0.042				3.55

** Significant Parameter; * subsignificant parameter

Table 8: Summarization of significant parameters on the machinablity of EDM

	EWR	MRR	SR
V	*	*	*
P	**	*	**
A	*	**	*
B	*	*	*

** significant parameter; * subsignificant parameter

4. Results and Discussion

The following discussion focuses on the effects of process parameters to the observed values(EWR, MRR and SR) based on the Taguchi methodology.

4.1. Electrode Wear Rate

Figure 2 shows the main effects of EWR of each factor for various level condition. According to figure 2, the EWR decreases with the two major parameters, P and B. And also we notice that minimum machining voltage (negative polarity), maximum peak current, minimum pulse duration and maximum interval time may imply a smaller EWR. Thus, according to J.L. Lin, etc.[8], discharge current, workpiece polarity and discharge voltage are the important machining parameters affecting the electrode wear ratio. According to this figure, for initial value of pulse duration (1.6 μs) with negative polarity (electrode, -ve), EWR was smaller. Thus according to B.Thomas[9], in such a case the polarity is reversed (negative polarity) so that maximum material removal is on the workpiece and the electrode suffers the least possible amount of wear. For this reason, the electrode is given negative polarity for short pulse duration and positive polarity is used when the pulse duration is longer.

Figure 2: Main effects of each factor on EWR

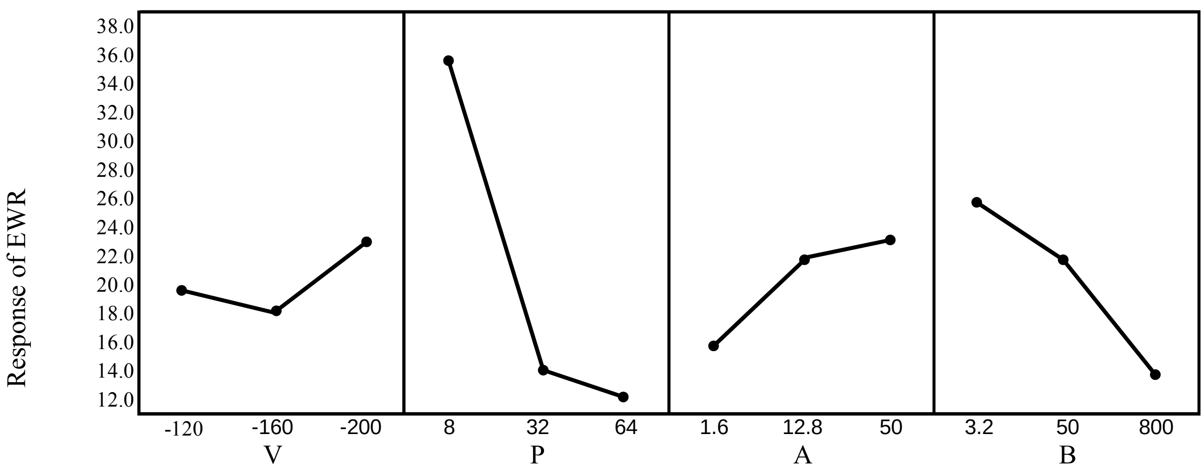


Figure 3: Main effects of each factor on MRR

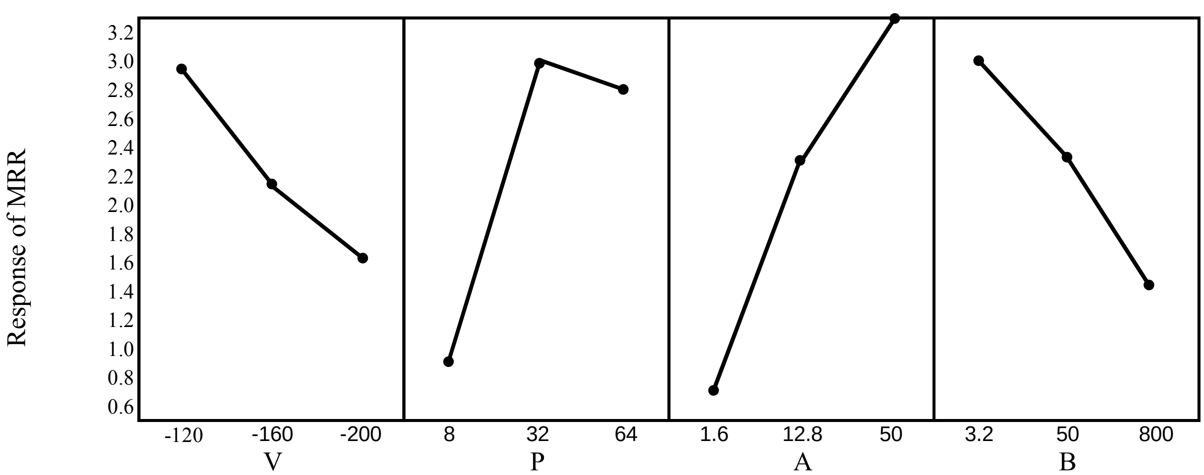


Figure 4: Main effects of each factor on SR

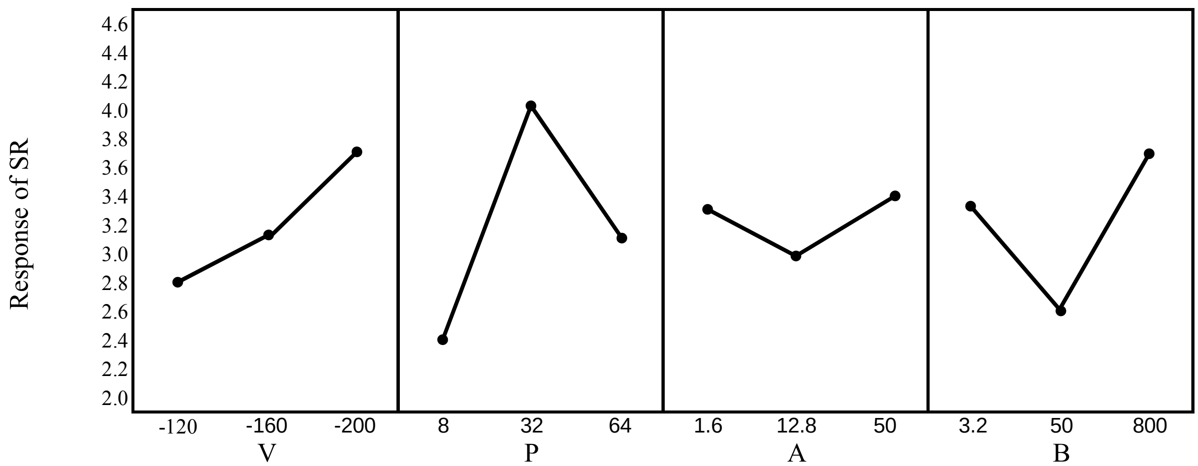


Table 9: Optimum Machining Condition based on results of EWR

Factors	Level Description	Level	Contribution
V: Machining Voltage	-160 V	2	-1.439
P: Peak Current	64 A	3	-7.793
A: Pulse Duration	1.6 µs	1	-3.426
B: Interval Time	800 µs	3	-6.815
Total contribution from all factors			-19.472
Current grand average of preformance			22.038
Expected result at optimum condition			2.567

Table 10: Optimum Machining Condition based on results of MRR

Factors	Level Description	Level	Contribution
V: Machining Voltage	-120 V	1	0.679
P: Peak Current	32 A	2	0.749
A: Pulse Duration	50 µs	3	1.454
B: Interval Time	3.2 µs	1	0.819
Total contribution from all factors			3.702
Current grand average of preformance			2.340
Expected result at optimum condition			6.043

Table 11: Optimum Machining Condition based on results of SR

Factors	Level Description	Level	Contribution
V: Machining Voltage	-120 V	1	-0.394
P: Peak Current	8 A	1	-0.776
A: Pulse Duration	12.8 µs	2	-0.175
B: Interval Time	50 µs	2	-0.554
Total contribution from all factors			-1.899
Current grand average of preformance			3.312
Expected result at optimum condition			1.414

4.2. Material Removal Rate

Figure 3 shows the main effects of MRR of each factor for various level condition.It was observed the MRR increases with pulse duration and slightly increases with peak current. According to B.H. Yan, etc.[2], using a negative polarity in EDM caused higher MRR with a higher discharge energy (P>3A or A>5µs), in contrast a positive polarity caused a higher MRR with lower discharge energy (P<3A or

A<5μs). According to this figure, MRR increases with short interval time (3.2 μs) and peak current. The possible reason for the higher MRR may be due to more frequency discharges per unit cycle time.

Figure 5: Influence of Peak current(8 A) on discharging crater

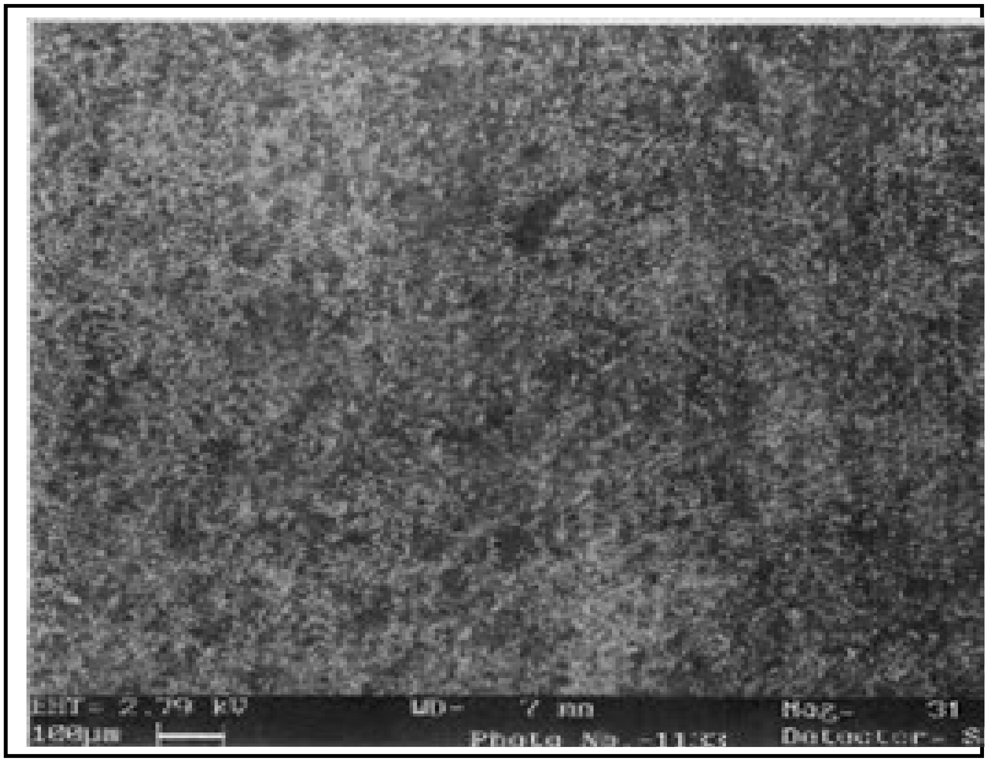
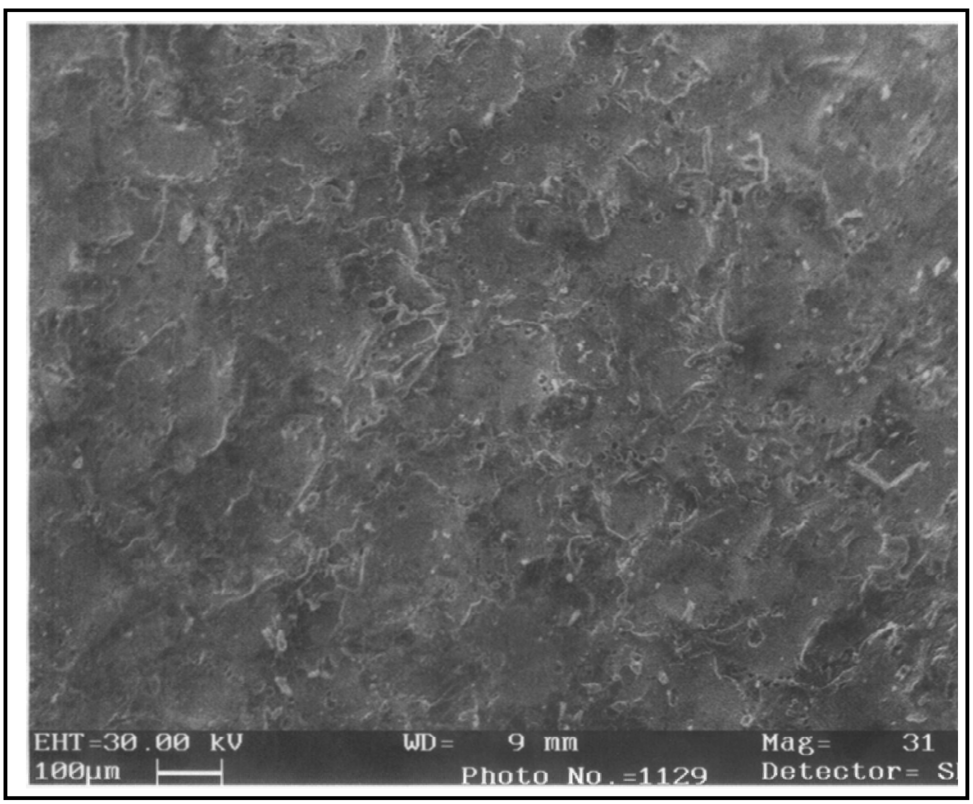


Figure 6: Influence of Peak current(64 A) on discharging crater



4.3. Surface Roughness

Figure 4 evaluates the main effects of SR of each factor for various level condition. According to this figure the SR increases with voltage and slightly increases with peak current. Larger craters were produced by a larger power supply voltage, possibly producing a larger discharging energy. The influence of peak current with various setting is shown in figures 5 and 6. According to K.P.Rajurkar, etc.[10], The variation of crater diameter, depth and volume with respect to peak current is consistent with the general findings in EDM literature that higher currents generate larger crater and therefore produces rough surfaces.

5. Conclusion

This paper has discussed the feasibility of machining Tungsten Carbide ceramics by EDM with a graphite electrode. Taguchi method has been used to determine the main effects, significant factors and optimum machining condition to the performance of EDM. Based on the results presented herein, we can conclude that, the peak current of EDM mainly affects the EWR and SR. The pulse duration largely affects the MRR.

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