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Study the Effect of Tungsten Carbide Electrode on Stainless Steel (AISI 304) Material in Die Sinking EDM

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Abstract: **Among all the nonconventional machining methods, electric discharge machining (EDM) is one of the most popular machining methods based on removing material from a part by means of a series of repeated electrical discharges between a tool, called electrode, and the part being machined. This study investigates the influence of EDM parameters on Tool Wear Rate (TWR), Material Removal Rate (MRR), Surface Roughness (R_a) while machining of Stainless Steel (AISI 304) material. The parameters considered are pulse-on time (T_{on}), peak current (I_p), duty factor (t) and gap voltage (V_g). The experiments planned, conducted and analyzed using Taguchi method. An L_{27} orthogonal array (OA), for the four machining parameters at three levels each, was opted to conduct the experiments. Experiments were performed on the die-sinking EDM machine (ELECTRONICA- ELECTRAPULS PS 50ZNC) with servo-head (constant gap) fitted with a Tungsten Carbide electrode. Analysis of variance (ANOVA) was performed and the optimal levels for maximizing the responses were established. Surface roughness were measured using this Portable style type profilometer, Talysurf (Model: Taylor Hobson, Surtronic 3+).Optical microscope (OM) analysis was done to study the surface characteristics.**

Keywords: **Die sinking EDM machine; AISI 304 material; Taguchi method; Tungsten Carbide Electrode.**

1. INTRODUCTION

With the increasing demands of high surface finish and machining of complex shape geometries, conventional machining process are now being replaced by non-traditional machining processes[1]. Electrical discharge machining utilizes rapid, repetitive spark discharges from a pulsating direct current power supply between the workpiece and the tool submerged into a dielectric liquid [2]. A.A. Khan found that electrode wear increased with an increase in both current and voltage, but wear along the cross-section of the electrode is more compared to the same along its length. It was also found that the wear ratio increased with an increase in current [3]. S. Dhar et al. [4-5] observed that EDM operation in the past twenty years, materials R&D has shifted from monolithic to composite materials, adjusting to the global need for reduced weight, low cost, quality, and high performance available readily in structural materials. Approximately 50% of all carbide production is used for machining applications but tungsten carbides are also being increasingly used for non machining applications, such as mining, oil and gas drilling, metal forming and forestry tools [6-7].

2. EXPERIMENTAL PLANNING AND PROCEDURE

In the present investigation, the EDM operation of stainless steel AISI 304 has been carried out using Tungsten Carbide Electrode. Experiment has been conducted as per L_{27} orthogonal array.

2.1 Materials

Material used for this experiment is Stainless Steel (AISI 304) plate of 100 × 50 × 4.5 mm. Density of this material is 8.00 g/cm^3, melting temperature is 1450^0C and Thermal conductivity is 16.2W/m.k.

For this investigation tungsten carbide is used as tool material of diameter 10mm. Length of electrode is 100 mm. Density of this electrode is 15.63 g/cm^3 and melting temperature is 2870^0C.

2.2 EDM Machine

The machine is used for this investigations is ELECTRONICA-ELECTRAPLUS PS 50 ZNC (die-sinking type) with servo head (constant gap).EDM oil is used as dielectric fluid specific gravity= 0.763, freezing point= 94°C).

2.3 Experiment Planning

Taguchi methodology has been applied to plan and analyze the experiments The Taguchi method is devised for process optimization and identification of optimal combinations of factors for given responses. The steps involved are:

i) The response functions and the process parameters to be evaluated are identified, ii). The number of levels for the process parameters and possible interaction between them are determined,

iii). Selection of the appropriate orthogonal array with process parameters is done and experiment is conducted accordingly,

iv). The experimental results are analyzed and the optimum levels of process parameters are determined.

v). The optimal process parameters are verified through a confirmation experiment.

The process parameters chosen for the experiments are: (i) Peak Current(I_p), (ii) pulse-on time (T_{on}), (iii) Gap Voltage (V_g), (iv) Duty Factor (t) while the response functions are:

(i) Material Removal Rate (MRR) (mm^3/min),

(ii) Tool Wear Rate (TWR) (mm^3/min),

(iii) Surface Roughness (R_a) (µm)

The experimental parameters and their levels selected for present investigations are tabulated in Table 1. The experimental layout for the machining parameters using the L_{27} orthogonal array is shown in Table 2.

Table 1. Level values of input factor

Sl.No.	Factors	Levels		
		1	2	3
1	I_p (Amp)(A)	2	4	6
2	T_{on} (µs)(B)	50	100	150
3	V_g(Volts)(C)	50	60	70
4	t (%)(D)	60	65	70

Table 2. Taguchi L_{27} Orthogonal Array design Matrix

Trial No.	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	1
8	1	3	2	2
9	1	3	3	3
10	2	1	2	3
11	2	1	3	1
12	2	1	1	2
13	2	2	2	3
14	2	2	3	1
15	2	2	1	2
16	2	3	2	3
17	2	3	3	1
18	2	3	1	2
19	3	1	3	2
20	3	1	1	3
21	3	1	2	1
22	3	2	3	2
23	3	2	1	3
24	3	2	2	1
25	3	3	3	2
26	3	3	1	3
27	3	3	2	1

2.4 Experimental Procedure

In the present study, the experiment was carried out using ELECTRONICA make electrical discharge machine. Experiment was performed randomly according to the design matrix. Machining time is set for 20 minutes. Material removed from the workpiece and electrode was obtained using the weight loss method and converted to volumetric material loss.

Fig. 1. Die Sinker EDM Model: PS 50ZNC

3. RESULT AND DISCUSSION

The different response factors like MRR, EWR, R_a of the machining holes are calculated from the observed data.

Material Removal Rate (MRR)

$$= \frac{\text{Volumetric material loss from workpiece (mm3)}}{\text{Machining Time(min)}}$$

Tool Wear Rate (TWR)

$$= \frac{\text{Volumetric material loss from electrode (mm3)}}{\text{Machining time (min)}}$$

For the present investigation, higher is better quality characteristic is chosen for MRR, and Lower is better is chosen for EWR, R_a.

For higher the better

S/N ratio = - 10 log $\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}\right)$

For lower the better

S/N ratio = - 10 log $\left(\frac{1}{n}\sum_{i=1}^{n} yi^2\right)$

Where y_i represents the experimental observed value of the i^{th} experiment and n is the number of repetitions of each experiment.

In EDM, material is removed by a series of electrical discharge between the electrode (tool) and workpiece that develops a temperature of about 8,0000^{0}C to 12,0000^{0}C. Due to the high temperature of the sparks, the work material is melted and vaporized, and at the same time the electrode material is also eroded by melting and vaporization. So tool wear plays a significant role in dimensional stability and tooling cost. For optimal condition maximum MRR is analyzed for "the higher is the better quality" and minimum TWR and R_a is analyzed for "the lower is the better quality" characteristics of loss function of further transformed into an S/N ratio.

3.1 Effect of input factor on MRR

The response table for signal-to-noise ratio for material removal rate is shown in Table 3 and corresponding analysis of variances (ANOVA) is shown in Table 4.

Table 3. Response table for S/N Ratio for MRR

Level	I_P (A)	T_{on} (µs)	V_g (V)	t (%)
1	-3.120	6.771	8.338	8.386
2	13.369	9.506	9.192	9.138
3	17.082	11.053	9.800	9.807
Delta	20.202	4.282	1.462	1.421
Rank	1	2	3	4

From Table 3. It is seen that material removal rate is greatly influenced by pulse current followed by pulse-on time. Duty factor and gap voltage has almost no influences on MRR.

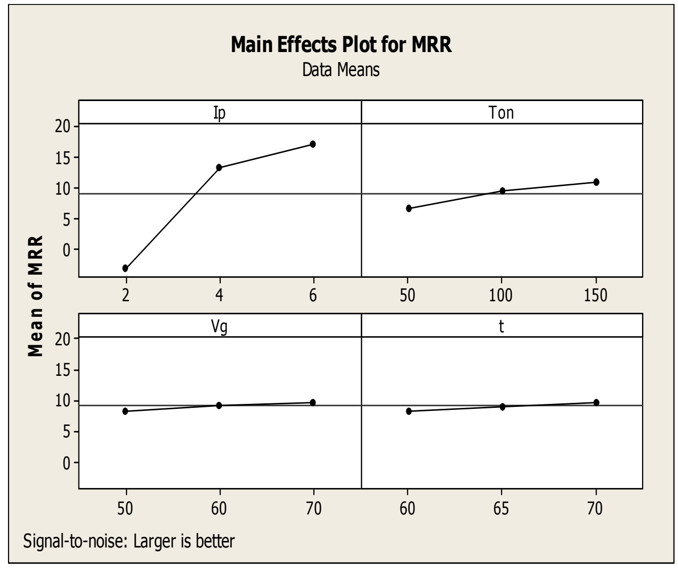


Fig. 2. S/N Ratio curve for MRR

From Figure. 2 it is seen that S/N ratio increases gradually with the increase of pulse current and pulse on time. S/N ratio increases slightly with the increase of gap voltage and duty factor.

Table 4. ANOVA table for S/N Ratio for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
I_P	2	2081.43	2081.43	1040.71	272.82	0.000	92.36
T_{on}	2	84.64	84.64	42.32	11.09	0.001	3.75
V_g	2	9.71	9.71	4.86	1.27	0.304	0.43
t	2	9.10	9.10	4.55	1.19	0.326	0.40
Residual Error	18	68.66	44.24	3.81			3.04
Total	26	2253.54					100

From Table 4. it is clear that peak current (I_p) has the largest contribution to the total sum of square i.e. 92.36% and pulse on time has 3.75% contribution. Gap voltage has almost no contribution with 0.43%. The larger the contribution of any factor to total sum of squares, larger is its ability to influence the material removal rate. Here all the interactions are neglected because they are insignificant.

3.2 Effect of input factor on TWR

The response table for signal-to-noise ratio for tool wear rate is shown in Table 5 and the corresponding analysis of variances (ANOVA) Table is shown in Table 6.

Table 5. Response table for S/N Ratio for TWR

Level	Ip (A)	T_{on} (µs)	V_g (V)	t (%)
1	29.46	17.54	20.67	20.85
2	17.63	21.23	20.44	21.13
3	14.51	22.82	20.49	19.61
Delta	14.94	5.28	0.23	1.52
Rank	1	2	4	3

From Table 5. It is seen that tool wear rate is greatly influenced by pulse current followed by pulse-on-time, duty factor and gap voltage. The higher the delta value the larger the influences of that factor on response factor.

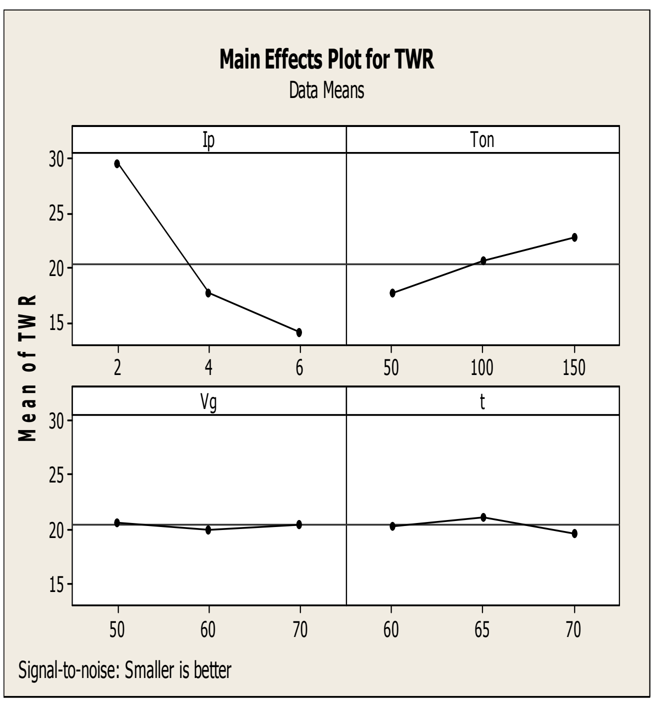


Fig. 3. S/N Ratio curve for TWR

From Figure 3. it is seen that S/N ratio decreases with the increase of peak current. S/N ratio increases with the increase of pulse-on-time. S/N ratio deflected with the increase of gap voltage and duty cycle.

Table 6. ANOVA table for S/N Ratio for TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
I_P	2	1118.87	1118.87	559.437	83.73	0.000	80.9
T_{on}	2	131.90	131.90	65.948	9.87	0.001	9.5
V_g	2	0.26	0.26	0.13	0.02	0.98	0.02
t	2	11.82	11.82	5.909	0.88	0.430	0.86
Residual Error	18	120.27	120.27	6.682			8.69
Total	26	1383.12					100

Referring to Table 6 it is noted that factor peak current (I_p) has the largest contribution to total sum of square i.e.80.9%. The factor pulse-on-time (T_{on}) has also some contribution to total sum of square of 9.5%.The gap voltage has almost no effect on tool wear rate. All the interactions are neglected because they are insignificant.

3.3 Effect of input factor on Surface Roughness

The response table for signal-to-noise ratio for surface roughness (R_a) is shown in Table 7. For surface roughness (R_a), the calculation of S/N Ratio follows “Smaller the Better” model.

Table 7. Response table for S/N Ratio for R_a

Level	I_P (A)	T_{on} (µs)	V_g (V)	t (%)
1	-12.88	-15.25	-16.56	-16.64
2	-16.96	-16.64	-16.20	-16.17
3	-18.86	-16.81	-15.94	-15.90
Delta	5.98	1.56	0.62	0.74
Rank	1	2	4	3

From the Table 7 it is seen that surface roughness is mostly influenced by peak current followed by pulse on time and duty cycle. But gap voltage has almost very less effect on surface roughness.

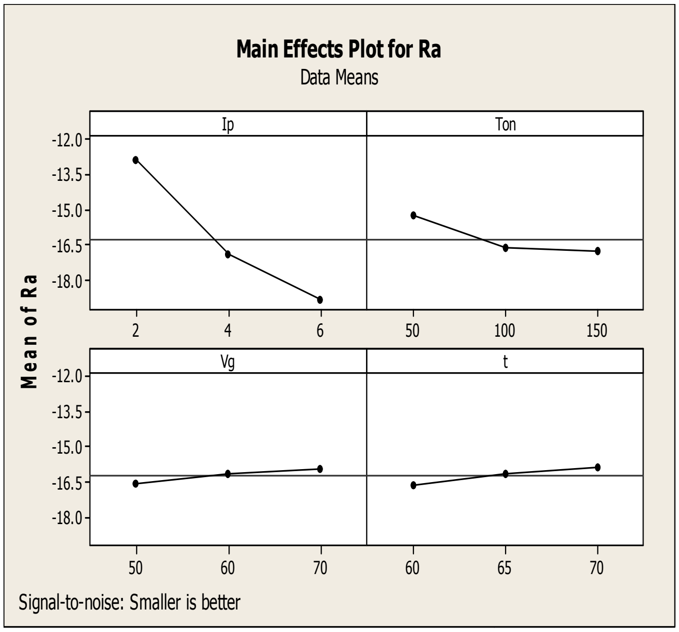


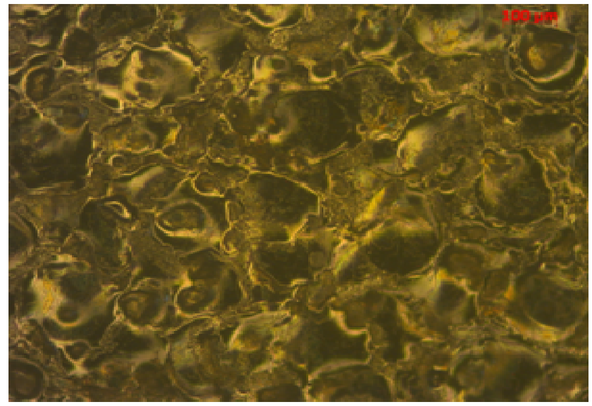
Fig. 4. S/N Ratio curve for R_a

From Figure 4 it is seen that S/N ratio decreases with the increase in peak current and pulse-on-time. S/N ratio increases with the increase of gap voltage and duty cycle.

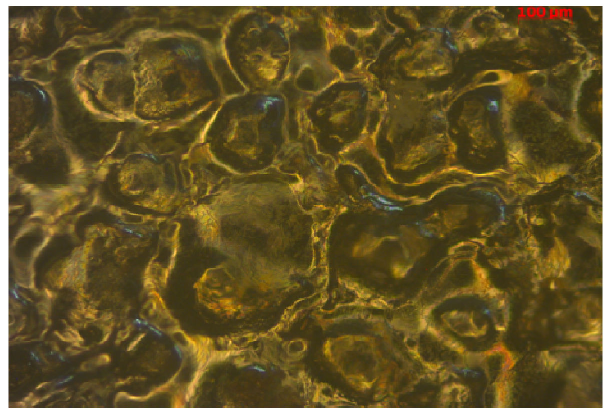
Table 8. ANOVA table for S/N Ratio for R_a

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
I_P	2	167.871	167.871	83.9357	121.61	0.000	84.89
T_{on}	2	13.176	13.176	6.5879	9.55	0.001	6.66
V_g	2	1.773	1.773	0.8866	1.28	0.301	0.89
t	2	2.506	2.506	1.2529	1.82	0.191	1.27
Residual Error	18	12.423	12.423	0.6902			6.28
Total	26	197.750					100

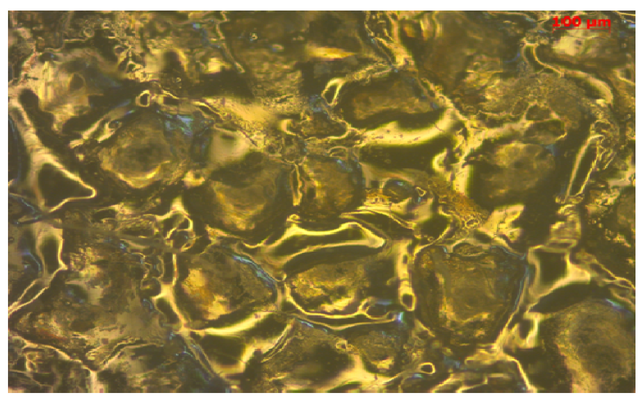
From Table 8 it is seen that peak current has 84.89% contribution on total sum of square. Pulse on time has 6.66% contribution on total sum of square. Gap voltage and duty factor has almost no contribution on total percentage.



Trial 6



Trial 14



Trial 23

Fig.4. Microstructural analysis

Microstructural analysis

The EDM surface shows rough and porous texture with craters assigned to the collapse of plasma columns during machining. Craters are as deeper as the material volume affected by the heat flow increases. This volume is directly proportional to the discharge current. As the discharge current increases the roughness also increases simultaneously. For Trial 6,14,23 spark on time is for 100µs discharge current is 2A, 4A, 6A respectively at 100µs. So from the above images it is clearly shown that as the discharge current increases the crater size also increases. So the surface roughness also increases.

4. CONFIRMATION TEST

The confirmation experiment is the final step is to predict and verify the improvement of the quality characteristics using the optimal level of the design parameter. The confirmation experiments were conducted by setting the process parameters at optimum level.

Table 9. Confirmation Test Result

Optimal machining parameter		
	Predicted	Experimental
Level	A3B3C3D3	A3B3C3D2
Higher MRR	8.343	7.729

Optimal machining parameter		
	Predicted	Experimental
Level	A1B3C1D2	A1B2C2D2
Lower TWR	0.025	0.029

Optimal machining parameter		
	Predicted	Experimental
Level	A1B1C3D3	A1B1C2D2
Lower R_a	3.8	4.005

From Table 9, it is show a comparison of predicted result and actual result using the optimal machining parameter. A good correlation between the predicted and actual is observed.

5. CONCLUSIONS

- The material removal rate (MRR) is mainly affected by peak Current (I_P). Pulse on time (T_{on}) and gap voltage (V_g) have considerable effect on MRR. The effect of duty cycle (t) on MRR is negligible.
- Electrode wear rate is mainly affected by peak Current (I_P). Pulse on time (T_{on}) and duty cycle (t) have considerable effect on MRR. The effect of gap voltage (V_g) on electrode wear is very negligible.
- Surface roughness (R_a) is mainly influenced by peak current (I_P) and pulse on time (T_{on}). Gap voltage (V_g) and duty cycle (t) have less influence on R_a.

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