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Modelling and Optimization of Electric Discharge Drilling Using Titanium Alloy Grade-5 by Taguchi Method

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Abstract:
Electric Discharge Drilling (EDD) is effectively used in modern manufacturing industries it is a thermo-electric non-traditional machining process. It has the potential to machine electrically non-conductive high-strength, high-temperature-resistant (HSHTR) ceramics. This paper investigates the influence of four different input parameters such as Pulse on time, Pulse off time, Distilled water pressure and Discharge current of electric discharge drilling performance of hole circularity, hole taper and hole dilation using Taguchi methodology. Titanium and its alloys have high demand in different industries due to their superior properties. Brass electrode was selected based on their electrical and thermal property. Experiments were carried out as per Taguchi's L36 orthogonal array. Analysis of variance indicates that the pulse on time is more significant factor for hole circularity, distilled water pressure is more significant for hole taper and Pulse off time is more significant factor for hole dilation.

Keywords: *Electrical discharge drilling, hole circularity, hole dilation, hole taper, taguchi methodology*

1. Introduction

Electrical Discharge Machining, EDM, is a machining technique that works by using electric sparks to remove metal dust from the work piece and gives it a desired shape. This is the reason why it is also known as "spark machining" [1].It is usually used on hard and electrically conductive materials like titanium, Inconel and carbide. This technique lets us create complex shapes, cavities and contours that are almost impossible to achieve with other machining techniques. Despite all its merits, EDM has one major limitation; it only works with electrically conductive materials. EDM is no longer a "non-conventional" or "non-standard" machining process. It is the 4th most popular machining process, selling more than all other processes except milling, turning and grinding. The EDM process is usually used to make die and mould [2], but it is also widely used to make prototypes and production parts in aerospace and electronics industries with smaller amounts of production. Electrical Discharge drilling (EDD) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion.

Ti6Al4V is the most widely used titanium alloy. It features good machinability and excellent mechanical properties. The Ti6Al4V alloy offers the best all-round performance for a variety of weight reduction applications in aerospace, auto motive and marine equipment. Ti6Al4V parts manufactured in the EBM process have a microstructure better than cast Ti6Al4V containing a lamellar α-phase with larger β-grains, and with a higher density and significantly finer grain, thanks to the rapid cooling of the melt pool [3-7].

In the present research work, L_{27} orthogonal array is used for electrical discharge drilling of titanium alloy grade-5 sheet by using brass electrode. Discharge current, pulse on time, pulse off time and dielectric pressure have been selected as machining parameters and hole circularity, hole taper & hole dilation as output parameters.

Dhar and Purohit [8] evaluates the effect of current (c), pulse-on time (p) and air gap voltage (v) on MRR, TWR, ROC of EDM with **Al–4Cu–6Si alloy–10 wt. % SiCP composites**. This experiment can be using the PS LEADER ZNC EDM machine and a cylindrical brass electrode of 30 mm diameter. And three factors, three levels full factorial design was using and analysing the results. A second order, non-linear mathematical model has been developed for establishing the relationship among machining parameters. The significant of the models were checked using technique ANOVA and finding the MRR, TWR and ROC increase significant in a non-linear fashion with increase in current. Tool electrode material such as **Al–Cu–Si–Tic composite** produced using powder metallury

(P/M) technique and using work piece material CK45 steel was shown by Taweel [9]. The central composite second-order rotatable design had been utilized to plan the experiments, and RSM was employed for developing experimental models. Composite electrode is found to be more sensitive to peak current and Pulse on time than conventional electrode. B.Mohan and Satyanarayana [10]

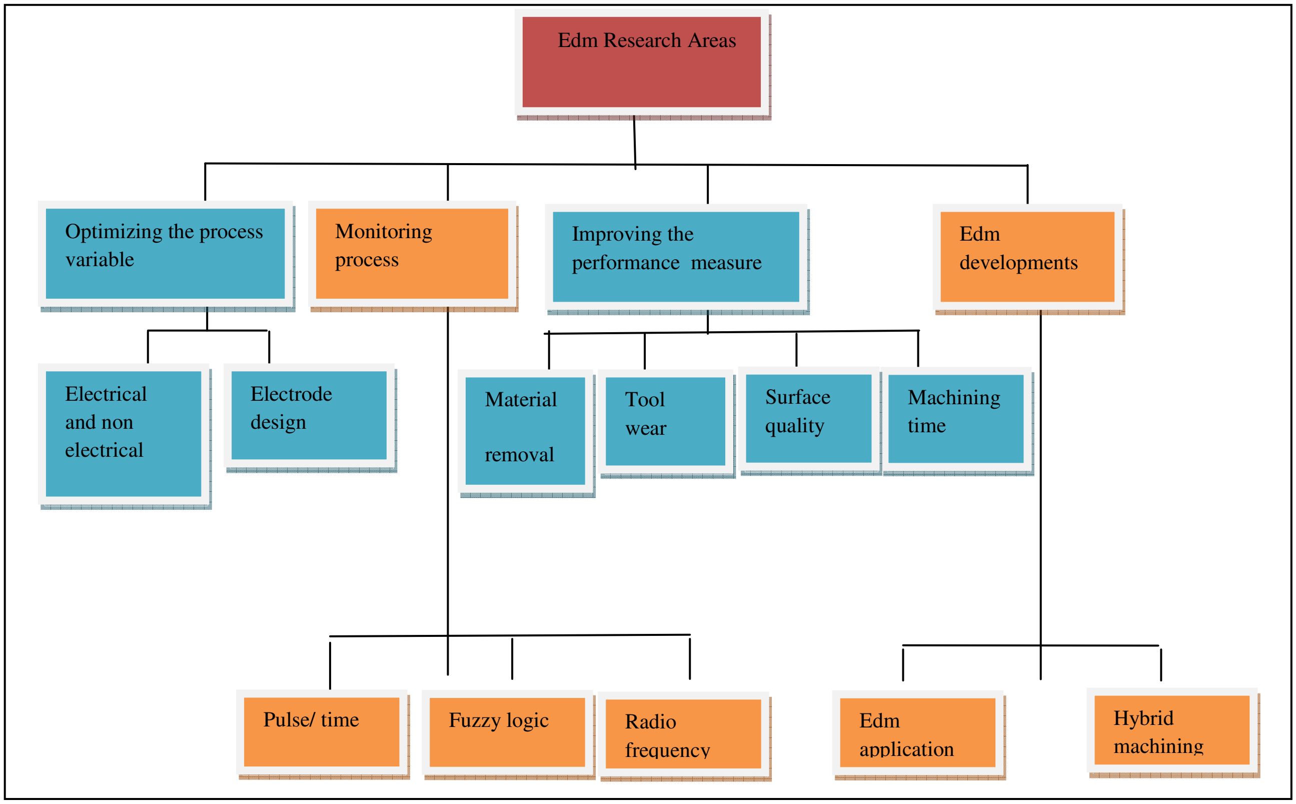


Figure 1: Classification of Major EDM Research Areas

2. Experimental Procedure

2.1. Experimental Setup and Machining Parameter Selection

This experimental work was carried out on EDM, model innovative Automation Product (IAP) 3X-spark DRO (EDM-Drill) with a DC stepper motor which continuously maintaining the constant gap voltage between electrode and work material. Hole were made in a 2mm thick plate of titanium grade-5. Using single hole brass tubular electrode of diameter of 1mm and length 400 mm tool was used for experiments and the chemical compositions of titanium grade-5 and brass are shown in Table 1 and Table 2. The titanium grade-5 plate after drilling is shown in Fig.3. Deionised water was used as dielectric fluid. The machine tool has four process parameters viz. pulse on time, pulse off time, discharge current and distilled water pressure in table 3 [11] and a series of pilot experiments were performed to determine their feasible range in which a desired through hole can be achieved. In the present study (with four machining parameters each at three levels), choice of L_9 and L_{27} orthogonal arrays (OAs), both were possible but for the sake of higher resolution factor L_{27} OA was considered for experimentation.Fig.2 shows the output response hole circularity and hole taper [13].

Al%	Fe%	Mn%	V%	Ti%
6.47%	0.08%max	0.05%	3.53%	89.87%

Table 1: Chemical composition of Titanium alloy (Grade-5)

Chemical Composition	Percentage
Copper	56.7
Aluminium	0.03
Tin	0.02
Phosphorous	0.02
Lead	3
Iron	0.1
Zinc	39.85
Nickel	0.08

Table 2: Chemical composition of brass electrode

Symbol	Parameter	Unit	Levels		
			1	2	3
X_1	Pulse on time(T_{on})	(μs)	8	9	10
X_2	Pulse off time(T_{off})	(μs)	2	4	6
X_3	Dist. Pressure(P_d)	(kg/cm^2)	60	70	80
X_4	Current(I)	(Amp)	14	15	16

Table 3: Control factors and their levels

Evaluation of response variable

The average diameter of hole was calculated by using Eq. (1):

$$\Delta D = \frac{D_1 + D_2 + \ldots\ldots\ldots + D_n}{n} \quad (1)$$

Where n is the number of measurement. The dilation of holes (*Hd*) was determined by the following equation [12].

$$H_d = \Delta D - D_e \quad (2)$$

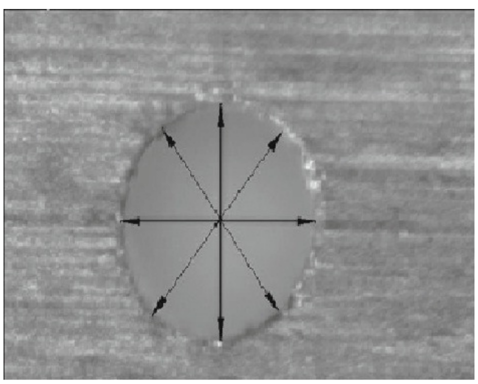
Where *De*is the original electrode diameter

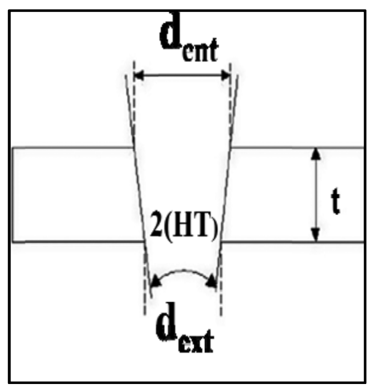
The mathematical values of *HT* and C_{ent} have been calculated using equations (3) and (4) as follows [12]:

$$Hole\ Taper\ (HT)\ (°) = \left[tan^{-1}\left[\frac{d_{ent} - d_{ext}}{2t}\right]\right] \quad (3)$$

$$C_{ent} = \frac{(d_{min.})entrance}{(d_{max.})entrance} \quad (4)$$

Weren't' is the sheet thickness and d_{ent} is the diameter of hole at entrance. The d_{min} and d_{max} are the values of minimum and maximum diameters respectively, out of the four readings (i.e., d_1 to d_4) for each hole.


(a)



(b)

Figure 2(a): Circularity measurement of the drilled holes *Figure 2(b): Assessment of hole taper*

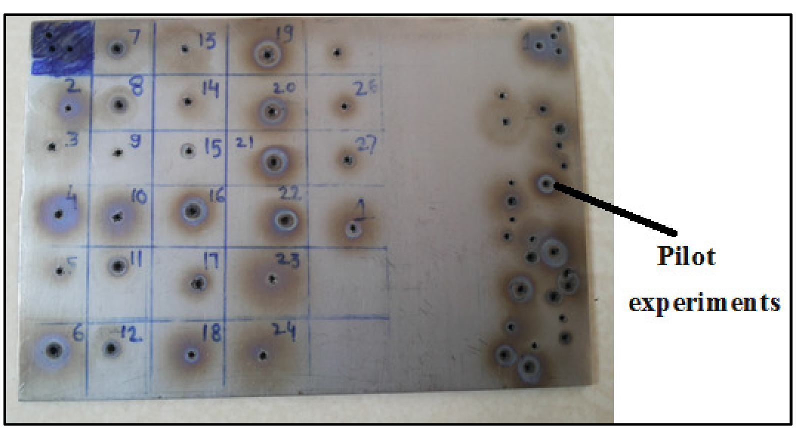


Figure 3: Titanium grafe-5 work piece after EDM –Drill process

Experiment no.	Pulse on time (µs)	Pulse off time (µs)	Distilled water pressure (kg/cm^2)	Discharge Current (Amp.)	Circularity (Ent.) (mm)	Hole Taper (radian)	Hole Dilation (µm)
1	8	2	60	14	0.71	2.15	0.32
2	8	2	70	15	0.62	3.46	0.29
3	8	2	80	16	0.63	2.76	0.12
4	8	4	60	15	0.6	0.12	0.10
5	8	4	70	16	0.61	2.72	0.24
6	8	4	80	14	0.6	0.14	0.24
7	8	6	60	16	0.72	1	0.27
8	8	6	70	14	0.59	0.79	0.23
9	8	6	80	15	0.66	2.22	0.05
10	9	2	60	15	0.66	1.19	0.08
11	9	2	70	16	0.69	1.43	0.27
12	9	2	80	14	0.66	3.15	0.28
13	9	4	60	16	0.56	2.58	0.20
14	9	4	70	14	0.9	1.72	0.03
15	9	4	80	15	0.66	4.12	0.30
16	9	6	60	14	0.69	3.01	0.12
17	9	6	70	15	0.66	1.56	0.38
18	9	6	80	16	0.65	0.57	0.38
19	10	2	60	16	0.63	4.57	0.41
20	10	2	70	14	0.61	0.43	0.23
21	10	2	80	15	0.6	0.43	0.19
22	10	4	60	14	0.93	0.14	0.47
23	10	4	70	15	0.69	3.72	0.19
24	10	4	80	16	0.64	1.14	0.41
25	10	6	60	15	0.62	2	0.29
26	10	6	70	16	0.9	0.86	0.48
27	10	6	80	14	0.64	1.93	0.14

Table 4: Experiments layout using an L_{27} orthogonal array

3. Design Matrix and Corresponding Experimental Results

S. no.	P_{on}	P_{off}	W_P	I	C_{entry}	HT	HD	S/N 1.	S/N 2	S/N 3
1	8	2	60	14	0.71	2.15	0.32	2.97	-6.64	9.76
2	8	2	70	15	0.62	3.46	0.29	4.15	-10.78	10.75
3	8	2	80	16	0.63	2.76	0.12	4.01	-8.81	18.41
4	8	4	60	15	0.6	0.12	0.10	4.43	18.41	20
5	8	4	70	16	0.61	2.72	0.24	4.29	-8.69	12.39
6	8	4	80	14	0.6	0.14	0.24	4.43	17.07	12.39
7	8	6	60	16	0.72	1	0.27	2.85	0	11.37
8	8	6	70	14	0.59	0.79	0.23	4.58	2.04	12.57
9	8	6	80	15	0.66	2.22	0.05	3.60	-6.92	25.19
10	9	2	60	15	0.66	1.19	0.08	3.60	-1.51	21.93
11	9	2	70	16	0.69	1.43	0.27	3.22	-3.10	11.37
12	9	2	80	14	0.66	3.15	0.28	3.60	-9.96	11.05
13	9	4	60	16	0.56	2.58	0.20	5.03	-8.23	13.76
14	9	4	70	14	0.9	1.72	0.03	0.91	-4.71	30.45
15	9	4	80	15	0.66	4.12	0.30	3.60	-12.29	10.31
16	9	6	60	14	0.69	3.01	0.12	3.22	-9.57	18.41
17	9	6	70	15	0.66	1.56	0.38	3.60	-3.86	8.29
18	9	6	80	16	0.65	0.57	0.38	3.74	4.88	8.40
19	10	2	60	16	0.63	4.57	0.41	4.01	-13.19	7.74
20	10	2	70	14	0.61	0.43	0.23	4.29	7.33	12.57
21	10	2	80	15	0.6	0.43	0.19	4.43	7.33	14.19
22	10	4	60	14	0.93	0.14	0.47	0.63	17.07	6.46
23	10	4	70	15	0.69	3.72	0.19	3.22	-11.41	14.19
24	10	4	80	16	0.64	1.14	0.41	3.87	-1.13	7.74
25	10	6	60	15	0.62	2	0.29	4.15	-6.02	10.75
26	10	6	70	16	0.9	0.86	0.48	0.91	1.31	6.37
27	10	6	80	14	0.64	1.93	0.14	3.87	-5.71	17.07

Table 5: Experimental values and S/N ratios for C_{entry}, HT, and HD

4. Analysis of Variance for Response Variable

Analysis of variance indicates that the pulse off time is more significant factor for hole circularity from table 6, distilled water pressure ismore significant for hole taper from table 7 and Pulse off time is more significant factor for hole dilation from table 8.

Source	DF	Seq SS	Adj MS	F	P
Pulse on time	2	0.016274	0.008137	0.86	0.440
Pulse off time	2	0.009274	0.004637	0.49	0.621
Water pressure	2	0.016585	0.008293	0.88	0.433
Discharge current	2	0.017452	0.008726	0.92	0.416
Error	18	0.170356	0.009464		
Total	26	0.229941			

Table 6: Analysis of Variance for Hole Circularity

Source	DF	Seq SS	Adj MS	F	P
Pulse on time	2	1.210	0.605	0.29	0.753
Pulse off time	2	1.770	0.885	0.42	0.663
Water pressure	2	0.005	0.003	0.00	0.999
Discharge current	2	1.761	0.880	0.42	0.6645
Error	18	37.859	2.103		
Total	26	42.605			

Table 7: Analysis of Variance for Hole Taper

Source	DF	Seq SS	Adj MS	F	P
Pulse on time	2	0.05722	0.02861	1.81	0.192
Pulse off time	2	0.00172	0.00086	0.05	0.947
Water pressure	2	0.00315	0.00157	0.10	0.906
Discharge current	2	0.04901	0.02451	1.55	0.239
Error	18	0.28474	0.01582		
Total	26	0.39585			

Table 8: Analysis of Variance for Hole Dilation

5. Regression Modelling

Usually, regression analysis method is used to obtain the relation between machining parameters and performances. In this study, linear regression analysis was used to establish a mathematical model between the experimentally obtained hole taper, hole circularity and hole dilation values and micro drilling parameters. The regression equation of grey relational grade can be calculated as follows [6].

The regression equation is

$\mathbf{C_{entry}}$ = 6.36+1.11* X(1) - 0.332* X(2) -0.0289* X(3)-1.19 *X(4)-0.0306* X(1)*X(1)-0.00139* X(2)*X(2)-0.000239* X(3)*X(3)+0.0311* X(4)*X(4)-0.00167* X(1)*X(2)-0.00267* X(1)*X(3) - 0.0227 *X(1)*X(4)+0.00153* X(2)*X(3)+0.0167* X(2)*X(4)+0.00533* X(3)*X(4) (5)

The regression equation is

HT = -178+3.34 *X(1)-0.96 *X(2)+0.969* X(3)+18.0* X(4)-0.246* X(1)*X(1)-0.172* X(2)*X(2)+ 0.00392 *X(3)*X(3)-0.470* X(4)*X(4)+0.327 *X(1)*X(2)-0.0458* X(1)*X(3)+0.170 *X(1)*X(4) +0.00344* X(2)*X(3)-0.0686* X(2)*X(4)-0.0737* X(3)*X(4) (6)

The regression equation is

HD = 25.7-1.26 X1 - 0.595 X2 + 0.0281 X3 - 2.70 X4 + 0.0172 X1*X1 + 0.00720 X2*X2 - 0.000123 X3*X3 + 0.0660 X4*X4 + 0.00488 X1*X2 - 0.00153 X1*X3 + 0.0720 X1*X4 + 0.000683 X2*X3 + 0.0298 X2*X4 - 0.000011 X3*X4 (7)

6. Model Validation

To validate the developed models, the S-values and coefficients of determination ($R^2$and adjusted- R^2 values) have been calculated for each model [6]. These values for all three responses are mentioned in Table 8.

Response	Regression parameters		
	S value	$R^{2\,(\%)}$	Adjusted-R^2 (%)
C_{entry}	0.0387285	93.5%	86.0%
HT	0.407881	85.2%	68.0%
HD	0.0293188	95.5%	90.2%

Table 9: Regression parameters of reduce models

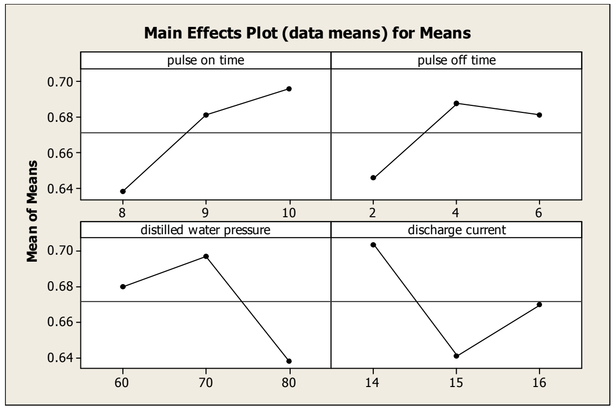


Figure 3: Main effects plot for means (Centry)

Figure 3 Mean effect plot for hole circularity vs pulse on time, pulse off time, water pressure and discharge current

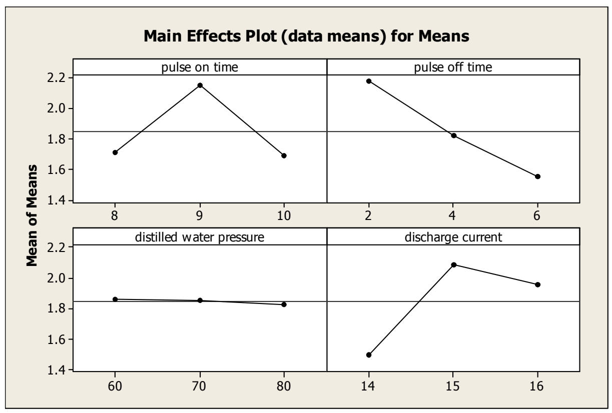


Figure 4: Main effects plot for means (HT)

Figure 4 Mean effect plot for hole taper vs pulse on time, pulse off time, water pressure and discharge current

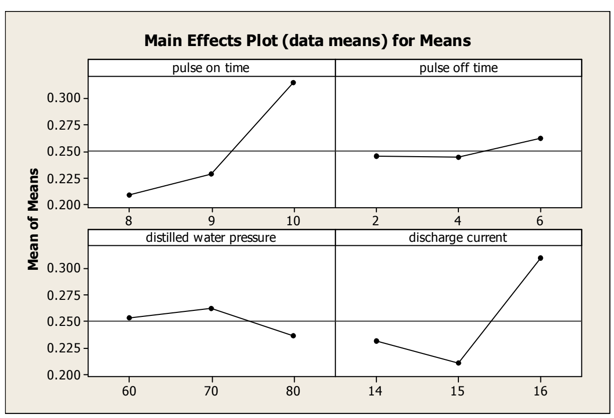


Figure 5: Main effects plot for means (HD)

Figure 5 Mean effect plot for hole dilation vs pulse on time, pulse off time, water pressure and discharge current

7. Conclusion

In this study, the effects of EDD parameters such as pulse on time, pulse off time, distilled water pressure and discharge current on machining characteristics of Titanium alloy grade-5 was investigated. Summarizing the main features of the results, the following conclusions may be drawn:

1) Based on the analysis it was foundthat the pulse on time is more significant factor for hole circularity, distilled water pressure is more significant for hole taper and Pulse off time is more significant factor for hole dilation.
2) The optimal parameters combination were determined as A3B2C2D1 for hole circularity i.e. pulse on time at 10µs, pulse off at time 4µs, distilled water pressure at 70kg/cm^2 and discharge current at 14Amp.A2B1C1D2 for hole taper i.e. pulse on time

at 9µs, pulse off at time 2µs, distilled water pressure at 60kg/cm^2 and discharge current at 15Amp. A3B3C2D3 for hole dilation i.e. pulse on time at 10µs, pulse off at time 6µs, distilled water pressure at 70kg/cm^2 and discharge current at 16Amp.

3) The practical benefit of this study is that the use of obtained optimum condition improves the hole circularity, hole taper and hole dilation of Titanium alloy grade-5.

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