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Experimental Investigation of Process Parameters of Micro EDM Drilling on Carbide (K20) material

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Abstract: The main objective of this thesis is to identify optimum parameter for micro drilling on carbide (K20) material using Micro EDM. To achieve this first experiments are performed by full factorial design. DOE is used for full factorial design. Output parameters like MRR, EWR and Taperness are calculated from experimental result. These parameters are compared with each other for finding our optimum values of parameters. With the help of ANOVA percentage contribution of process parameter on output parameters is generated using MINITAB 16 software. Finally, from ANOVA plot optimum value are found out and noted.

Keyword: Micro-EDM, DOE, ANOVA, Carbide (K20), parametric optimization.

I. INTRODUCTION

Electro Discharge Machining (EDM) is one of the most widely used non-conventional machining processes in manufacturing industry. It is also used for harder material when general conventional processes are not possible to machine. During EDM process tool and work piece are not in contact with each other. And hence it will not create any vibration during machining as compared to other conventional machining processes. Dielectric fluid is used to provide insulation between tool and work piece, for flushing eroded particles from the machining gap and for cooling of heated section [12]. EDM drilling with hollow tube type electrode will give higher Material Removing Rate (MRR), low electrode wear and surface finish with injection flushing [9]. Micro-holes are found various applications like fuel injection nozzles, spinneret nozzle holes, standard defects for testing material, biomedical filters and so on [1]. Creating cooling channels in turbine blades made of hard alloys is a typical application of EDM drilling. [12]

II. LITERATURE REVIEW

M.P. Jahan et. al [1] investigated the influence of major operating parameters on the performance of micro-EDM of WC (tungsten carbide) with focus in obtaining quality micro-holes in both transistor and RC-type generators. **Hung-Sung Liu et al [2]** checked the feasibility of fabricating micro-holes in the high nickel alloy using micro-electro-discharge machining (micro-EDM) was investigated. **G. Kibria et. al [3]** investigated micro-EDM characteristics such as material removal rate (MRR), tool wear rate (TWR), overcut (OC), taperness and machining time (MT) during micro-machining of through holes on Ti-6Al-4V super alloy employing de-ionized water based dielectric other than conventional hydro-carbon oil i.e. kerosene. **E. Ferraris et. al [4]** checked experimentally performance obtained in micro EDM deep drilling with standard and electrically insulated tools. **M.P. Jahan et. al [5]** introduces a simplistic analytical model to evaluate the effectiveness of low frequency work piece vibration during the micro- EDM drilling of deep micro-holes. **L. Romoli et. al [6]** did several experiments and concluded in a comparison between ultrashort pulsed laser and EDM for drilling spray holes.

III. EXPERIMENTATION

This experiment is done on micro Electro Discharge Machine (EDM). The process parameter used for experiments were Current, Pulse ON (P-ON) and Pulse OFF (P-OFF).

3.1 Workpiece

In this study the workpiece material selected for experiments is Cemented carbide(K20). This is one of the harder materials and could not be easily drilled by using conventional drilling process. And hence it is selected for experiments in this thesis. The dimension of a workpiece is 60mm x 16mm x 6.35mm. During drilling of micro holes work piece polarity is taken as (+ve).

3.2 Electrode

Electrode used for drilling of through micro hole on Cemented Carbide is brass and diameter of these electrodes is 0.4mm. The length of electrode is 400mm. the electrode used are of tube type i.e. electrode are hollow. Dielectric fluid is flowing through these electrodes and hence it is hollow in cross-section. Brass electrodes are preferred material for all High Speed Small Hole applications involving aerospace alloys as well as Carbide. During drilling of micro holes electrode polarity is taken as (–ve).

3.3 Dielectric Fluid

The dielectric fluid flushes the minute spherical chips eroded from the workpiece and the electrode. The dielectric fluid also provides an insulating medium between the electrode and the workpiece so that sufficient energy can be built. For safe environmental effect also deionised water should be used as a dielectric fluid in micro EDM drilling.

3.4 Experimental procedure

During drilling process Length of the electrode used is 400 mm. diameters of electrodes are 0.4mm and all the electrode are of tube type. Voltage during drilling process is fluctuating from the range of 50-100 on dial. The pressure of dielectric fluid pumped inside the electrode is 55 kg/cm^2. During drilling of through micro hole above mention parameters are kept constant and current, Pulse ON time and Pulse OFF time are varying

Table:1 Process Parameters and levels for drilling of micro hole

Sr. no.	Process parameters	Levels		
1	Current (Amp)	12	17	26
2	Pulse ON time (μs)	20	30	40
3	Pulse OFF time (μs)	10	15	20

Number of experiments required for above mention process parameters and levels is achieved by using full factorial design in Minitab 16 software. 27 experiments are performed on carbide material and during these experiments time in minute and electrode wear in mm are measured. From these data, output parameters like MRR, EWR and taperness are calculated as per given equations. The performance of micro-EDM processes is evaluated by calculating MRR, accuracy of micro-holes i.e., taper angle of micro-holes produced. After experiments micro hole's top and bottom diameters are checked on profile projector for further calculation.

Fig 1: Final micro hole Drilled Components

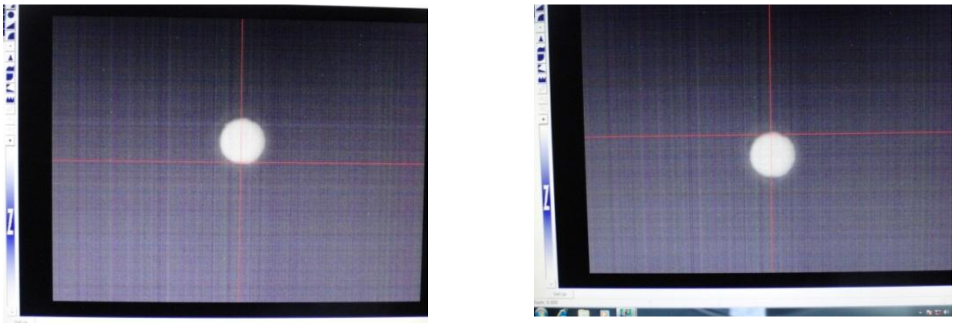


Fig 2: Point selection of micro hole in profile projector

3.5 CALCULATION

MRR

The MRR is calculated as the average volume of material removed over the machining time which is expressed as mm^3/min.

$$MRR = \frac{\left[\frac{\pi}{3}\left(r^2{}_{Top} + r_{Top}r_{Bottom} + r^2{}_{Bottom}\right)\times h\right]}{t} \qquad 3.1$$

Where

r_{Top} = radius at the entrance side,

r_{Bottom} = radius at exit side,

h = workpiece thickness and

t = machining time to make a hole at a particular setting.

EWR

EWR is expressed as the ratio of volume of the material removed from electrode to the volume of material removed from workpiece at the same unit time.

$$EWR = \frac{TW}{MRR} \qquad 3.2$$

Where TW is the volumetric tool wear rate given by

$$TW = \frac{\pi D^2 T}{4t} \qquad 3.3$$

T = frontal electrode wear in mm and

D = tool diameter in mm.

Taperness

Taperness is one of the criteria for evaluating the accuracy of micro hole. Taperness is measured as the difference between the entrance diameter and the exit diameter of micro-hole and the angle between them is known as taper angle and it is given as

$$\theta = \tan^{-1}\left(\frac{D_{Top} - D_{Bottom}}{2h}\right) \qquad 3.4$$

Where

θ is the taper angle,

D_{Top} is the entrance diameter and

D_{Bottom} is the exit diameter of the micro-hole and h is the machined depth.

IV. RESULT, DISCUSSION AND ANALYSIS

4.1 RESULT

Micro hole performance is cheked by using equation number 3.1 to 3.4. For calculating MRR equation number 3.1 is used. After calculating Equation number 3.1. Equation number 3.2 and 3.3 are used for finding out EWR. And finally equation number 3.4 for taperness.

Table 2: Calculated Output Parameters

Hole Number	Time (min)	Frontal electrode wear (mm)	Top diameter (mm)	Bottom diameter(mm)	MRR (mm^3/min)	EWR (%)	Taperness (Degree)	Overcut (mm)
1	10.88	458	0.501	0.428	0.099	53.354	0.329	0.032
2	13.38	337	0.502	0.436	0.082	38.524	0.297	0.035
3	10.12	329	0.491	0.429	0.104	39.101	0.279	0.030
4	12.90	456	0.494	0.439	0.084	52.714	0.248	0.033
5	12.36	433	0.493	0.447	0.089	49.330	0.207	0.035
6	10.10	383	0.479	0.429	0.102	46.754	0.225	0.027
7	11.01	426	0.493	0.444	0.100	48.838	0.221	0.034
8	12.03	557	0.499	0.456	0.095	61.487	0.193	0.039
9	15.35	492	0.513	0.472	0.079	51.059	0.184	0.046
10	18.51	830	0.502	0.469	0.064	88.654	0.148	0.043
11	22.32	810	0.478	0.453	0.048	94.066	0.112	0.033
12	14.98	656	0.491	0.471	0.077	71.403	0.090	0.041
13	14.67	846	0.505	0.488	0.084	86.428	0.077	0.048
14	15.14	842	0.497	0.486	0.080	87.784	0.050	0.046
15	14.23	817	0.482	0.462	0.078	92.351	0.090	0.036
16	15.82	812	0.490	0.484	0.075	86.230	0.027	0.044
17	14.29	821	0.487	0.481	0.082	88.270	0.027	0.042
18	15.20	984	0.525	0.506	0.087	93.251	0.085	0.058
19	13.24	985	0.535	0.512	0.103	90.511	0.103	0.062
20	12.11	886	0.534	0.519	0.114	80.496	0.067	0.063
21	10.30	840	0.547	0.525	0.139	73.630	0.099	0.068
22	7.30	855	0.490	0.467	0.156	94.034	0.103	0.039
23	7.21	813	0.490	0.470	0.159	88.861	0.090	0.040
24	8.45	872	0.524	0.510	0.158	82.163	0.063	0.059
25	7.32	818	0.498	0.486	0.165	85.108	0.054	0.046
26	6.57	755	0.498	0.482	0.182	79.192	0.072	0.045
27	5.50	800	0.468	0.457	0.194	94.192	0.049	0.031

4.2 DISCUSSION

The results shows that the material removal rate is found to increase sharply with increasing discharge current, and reaches a maximum at a discharge current of 26 Amp when the pulse ON time is set as 40µs and pulse OFF time is set as 20 µs. time taken for drilling of through hole for these parameter is noted 5.5 Minute. Above results show that as current is increase, EWR is also increase at certain level.

From table it is clear that maximum EWR could be found out at 26 Amp (Maximum current used for experiments) current and minimum at 17 Amp current (Minimum current used for Experiments). Result mentioned in table shows that taperness is found minimum at hole number 13. Where current, Pulse-ON and Pulse-OFF time are accordingly 17 amps, 30 µsec and 10 µsec.

4.3 Analysis by using ANOVA

ANOVA is performed on MINITAB 16 software for Current, P (ON) and P (OFF) parameters. In MINITAB 16 software by using General linear Model different graphs for above mention parameters are generated. Mainly residual plot and main effect plot are generated to check the effect of current, P(ON) and P(OFF) on MRR, EWR, and Taperness. Along with graph one table also generated which shows the significant level of each parameter on that particular factor.

4.3.1 ANOVA RUN FOR MRR

General Linear Model: MRR versus CURRENT, P (ON), P (OFF)

Table 3: Types of factor and their levels

Factor	Type	Levels	Values		
Current	Fixed	3	12	17	26
P(on)	Fixed	3	20	30	40
P(off)	Fixed	3	10	15	20

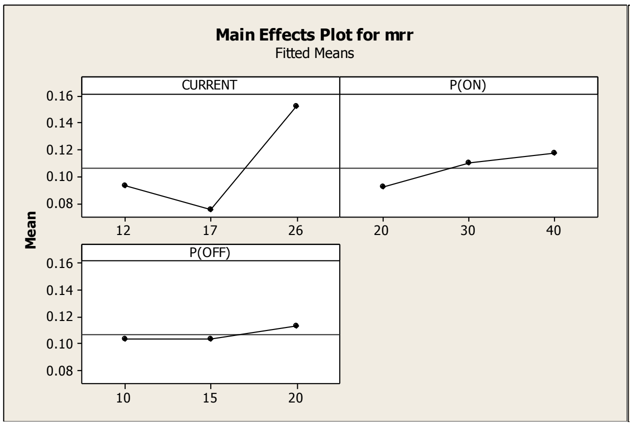
Analysis of Variance for MRR, using Adjusted SS for Tests

Table 4: ANOVA for MRR

Source	DF	Seq SS	Adj MS	F	p	% contribution
Current	2	0.0297	0.0148	57.12	0.000	77.34
P(ON)	2	0.0030	0.0015	5.80	0.010	7.81
P(OFF)	2	0.0006	0.0002	1.10	0.352	1.56
Error	20	0.0052	0.0002			
Total	26	0.0384				

DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

S = 0.0161061   R-Sq = 86.49%   R-Sq (adj) = 82.44



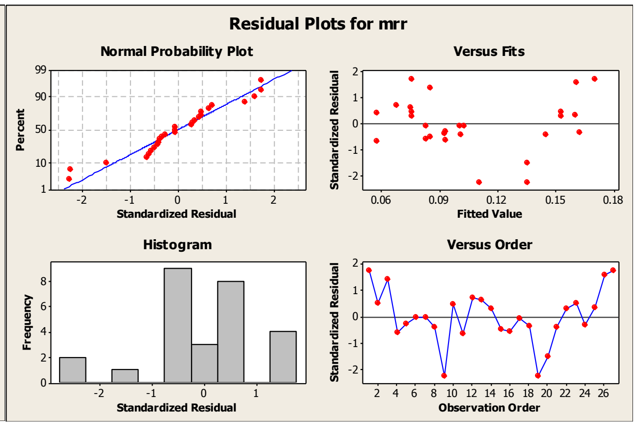


Fig : 4 Main effects plot for MRR

Fig : 5 Residual plots for MRR

4.3.2 ANOVA RUN FOR TAPERNESS

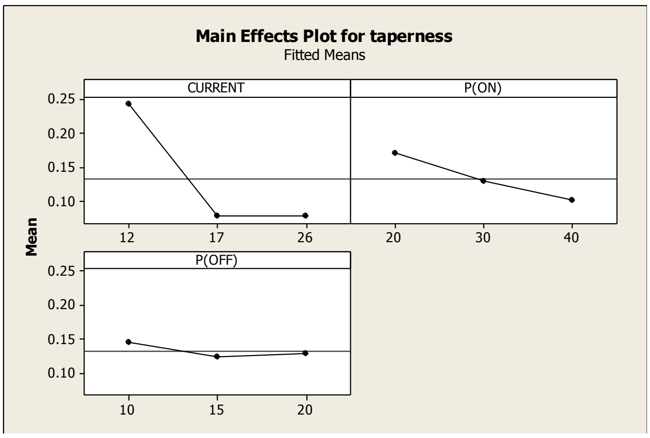
Analysis of Variance for taperness, using Adjusted SS for Tests

Table 5: ANOVA for Taperness

Source	DF	Seq SS	Adj MS	F	p	% contribution
Current	2	0.1623	0.0811	131.70	0.000	81.96
P(ON)	2	0.0211	0.0105	17.14	0.000	10.65
P(OFF)	2	0.0023	0.0011	1.86	0.182	1.161
Error	20	0.0123	0.0006			
Total	26	0.1980				

DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

S = 0.0248196 R-Sq = 93.78% R-Sq (adj) = 91.91%



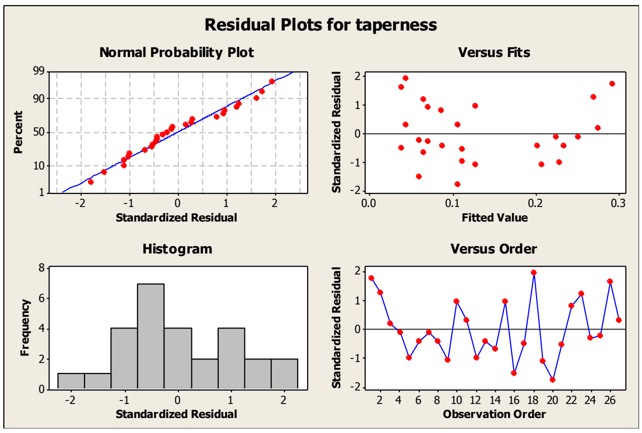


Fig : 6 Main effects plot for Taperness

Fig 7 Residual plots for Taperness

6.3.3 ANOVA RUN FOR ERW

Analysis of Variance for EWR, using Adjusted SS for Tests

Table 6 : ANOVA for EWR

Source	DF	Seq SS	Adj MS	F	p	% contribution
Current	2	8442.8	4221.4	99.19	0.000	87.82
P(ON)	2	221.2	110.6	2.60	0.099	2.30
P(OFF)	2	98.6	49.3	1.16	0.334	1.02
Error	20	851.2	42.6			
Total	26	9613.7				

DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

S = 6.52369 R-Sq = 91.15% R-Sq (adj) = 88.49%

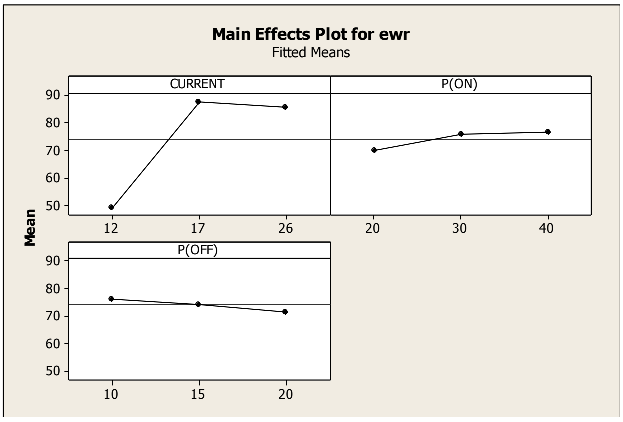


Fig: 8 Main effects plot for EWR

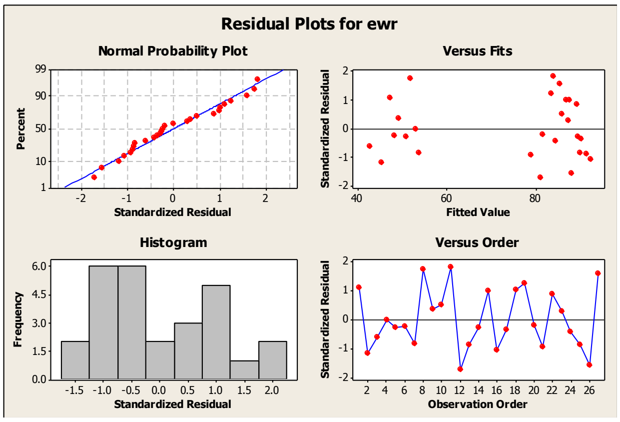


Fig: 9 Residual plots for EWR

V. Conclusion

Through DOE, ANOVA and experimental results following observation are made.
The maximum value of MRR is found as 0.194 mm^3/min. this value is highest among all this experiments. It is also clear from main effect plot generated from ANOVA that maximum MRR would be at 27th experiment where value of Current, P (ON) and P (OFF) are 26 Amp, 40 µSec and 20 µSec respectively. ANOVA table shows that Current is having higher contribution (77%) for MRR. From result it is clear that Minimum taperness (0.027 Degree) would be achieved at experiment number 16 and 17. But at this stage the value of MRR is very low as compared to other experiments. The value of taperness (0.049 degree) is found low at experiment number 27 and the value of MRR also would give such higher value. Hence last experiment also would be selected for minimum taperness. The percentage contribution of Current in this case is 81.96% and which is higher than other factors. Minimum ERW (38%) is found at experiment number 2 but at this experiment the value

of MRR (0.080 mm^3/min) is having low value and degree of taperness (0.297 degree) is also having very higher value. Which is not practically good for micro hole performance. The percentage contribution for EWR is found higher in current and value is 87.82%.

As mention above it is clear that maximum MRR, Minimum taperness and minimum EWR are not found for one hole all these values are found in different holes. as shown in table number 7.1 MRR is higher in hole number 27 while taperness is lower at hole number 16 and 17 while EWR is found lower at hole number 2. For selecting any one hole only one parameter can be satisfied so, such hole is selected which gives nearer values of minimum or maximum of parameter. Hole number 27 is selected for maximum MRR and minimum taperness only EWR values of this hole is higher than other hole but if MRR is maximum and taperness is good than it can be compromise in the case for EWR.

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