EFFECT OF MACHINING PARAMETRS ON METAL REMOVAL RATE DURING ELECTRIC DISCHARGE DRILLING OF Al 6061 WITH HOLLOW Cu ELECTRODE

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Abstract

Electric Discharge Drilling (EDD) is a spark erosion machining process used to produce micro holes in those materials which are electrically conductive. Materials science have developed many high strength and temperature resistant (HSTR) metal alloys that are difficult to machine by the conventional machining. In this study Aluminium alloy 6061 (50*75*6) mm is used as workpiece and drilling is done with hollow copper electrode as tool. Machining parameters such as Peak current, pulse on-time, pulse off-time, tool polarity, and duty cycle's effects were observed on the metal removal rate. Experiments were planned based on L_{18}orthogonal array by Taguchi method of Design of experiments. Micro holes and micro-grinding are profusely used in the aviation, automobile and medical industry.

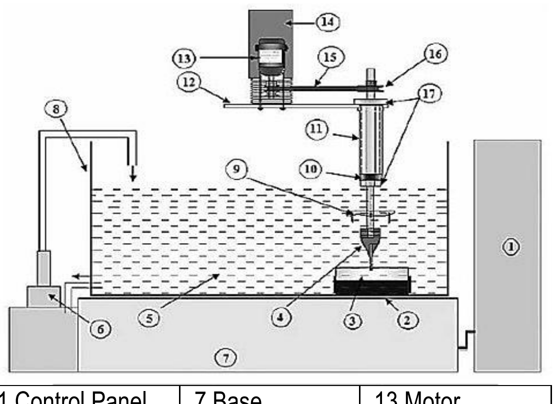
Key words: Electric Discharge Drilling (EDD); Pulse om-time; Pulse off-time; Metal removal rate (MRR); Tool polarity; Aluminium Alloy 6061; Di-electric.

I. INTRODUCTION

EDM, an un-conventional machining process has shown its potential as economical machining of hard to machine alloys with adequate surface finish. Surface finish is an important parameter because high surface finish improves the material's fatigue strength, corrosion resistance and wear strength [1].Electric discharge machining techniques have been improved such improved method is Electric Discharge Drilling (EDD). In this study EDD is carried out on Aluminium alloy 6061. With EDD, Holes can be drilled in any electrically conductive material, whether hard or soft.EDD uses the same principles as EDM, the applied voltage creates a channel of plasma in the working gap between work piece and electrode. During the discharging process, electrical energy from a pulse generator is turned in to thermal energy which generates a channel of plasma in the working gap. The area where the discharge takes place is heated to an extremely high temperature that leads to melting and removing of surface material. The melted material is removed in the form of debris by the flowing dielectric fluid. Also, here the electrode is given rotation and through the electrode pressurized dielectric is passed. The rotation of the tool electrode favors clean cuts and reduces under-cutting.

A. Electric Discharge Drilling (EDD)

EDD is carried out producing minute holes with machining time ranging from 7-10 mins. Experiments performed with low current value and higher machining time resulted in through holes.



1.Control Panel	7.Base	13.Motor
2.Vice	8.Dielectric	14.Servo system
3.Work piece	9.Stirrer	15.V-belt
4.Tool Holder	10.Bearing	16.V-pulley
5.Dielectric fluid	11.Shaft casing	17.Chuck nut
6.Dielectric pump	12.Al plate	

Fig. 1. Schematic setup of EDD. [2]

Both electrode and work-piece are immersed in dielectric fluid and separated by a certain distance. High pressure di-electric is flushed between electrode tool and workpiece. Recast layer depends upon the di-electric properties. Material once evaporated from workpiece turns into spherical globules due to the cooling effect by di-electric and is removed through the strainer. Pulse off-time is also very pivotal in the EDD after Current as a parameter because frivolity managing pulse 0ff-time leads to arcing.

II. EXPERIMENTAL DETAILS

Experiments were conducted on ZNC/ENC35 EDM machine originally manufactured by Sparkonix(India) Pvt. Ltd. The machine works at maximum sparking ratings of 35A and supply of 415V, 3Phase, 4.5KVA. Aluminium alloy 6061, two slabs of dimensions (50*75*6) mm were used to drill holes. Tool used was hollow copper tube with normal flow of di-electric.

Table 1. Chemical Composition of Alloy 6061

Element	Composition (%)
Aluminium	95.85–98.56
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron	0.7 max
Copper	0.15-0.4
Manganese	0.15 max
Chromium	0.04-0.35
Zinc	0.25 max
Titanium	0.15 max
Other elements	0.05 each max

A. Selection of Tool Electrode

Tool used for the electric discharge drilling should be Electrically Conductive Material so copper is used as tool electrode for the Electric Discharge Drilling (EDD) of Alloy 6061. It is a quotidian tool used for the EDD process in the Industries, due to low cost, good electrical conductivity, good surface finish. Copper is also stable under the sparking conditions. The shape of tool electrode highly affects the machining process.

Table 2. Tool electrode properties

PROPERTIES	VALUE
Melting Point	$1084.62\,^{\circ}C$
Elastic Modulus	$1.24\text{x}10^5$ N/mm^2
Poisson's Ratio	0.26
Density	8.9gm/cm^3
Diameter	2 mm

B. Parameters influencing EDD

An Ishikawa cause and effect diagram is used to figure the process parameters. There are two types of parameters are available in EDD process: a.) Electrical parameters. b.) Non-electrical parameters.

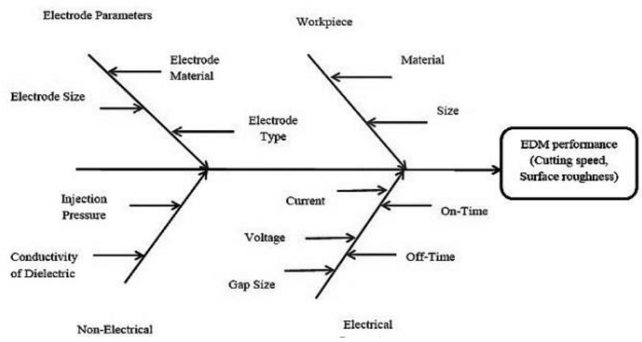


Fig. 2. Ishikawa Cause and effect diagram of parameters [3].

C. Design of Experiments

Taguchi method is used for optimization of machining parameters in EDD process. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost.

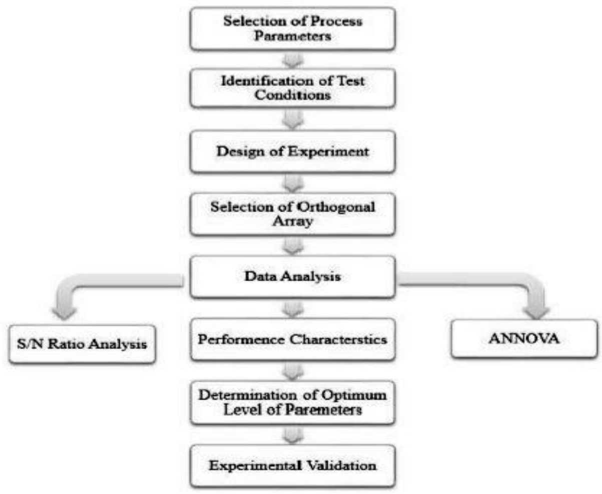


Fig. 3. Taguchi'sDOE flow chart.

L_{18}orthogonal array was chosen based upon specific parameters considered and their sub-levels; D.O.F. Parameters chosen in this study were Tool polarity, Current, Pulse on-time, Pulse off-time.

D. Rotary attachment of EDDM

Rotary attachment makes the EDM a drilling machine by rotating the tool electrode. The chuck of an EDM and the tool electrode is connected to attachment.

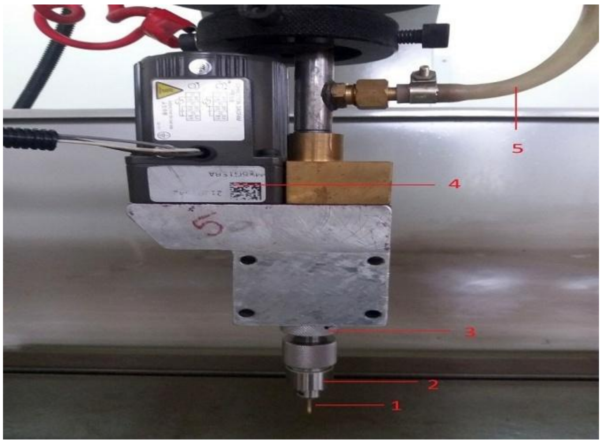


Fig. 4. Rotary attachment of EDDM

The rotary attachment comprises of namely these parts: 1.) Tool electrode, 2.) Tool chuck, 3.) Tool holder, 4.) DC servo motor, 5.) Flushing pipe.

E. Process Parameters Levels

Before experimentation, the work-piece faces had been rectified to have good surface finish using a surface grinding machine. The bottom of the electrode rod has been polished for best electric contact at every experiment.

Table 3. Process Parameters

Parameter	Unit	Level 1	Level 2	Level 3
Polarity		+	-	
Current	Ampere (A)	1	2	3
Pulse on-time	Micro-Seconds (μs)	10	12	14
Pulse off-time	Micro-Seconds (μs)	10.5	11.5	12.5

III. RESULTS AND DISCUSSIONS

All the experiments were conducted as per design of experiment plan and each trial run was conducted upto 7 min. The following table shows the various trials designed as per Taguchi's L18 orthogonal Array and Mean MRR is also observed. The trail 9 with positive tool polarity has the highest MRR of 0.0098 g/min and the trail 18 with negative tool polarity has the highest MRR of 0.0091 g/min.

Taguchi's method, the deviation of quality characteristics from the desired value is measured using SN ratios. Desirable mean value of output characteristics is represented by the signal and the undesired value or standard deviation is represented by the term noise.

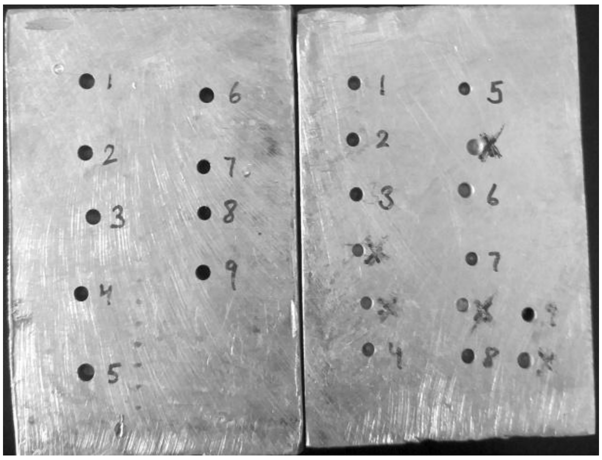


Fig. 5. Machined workpiece after EDD.

Design of experiments approach by L18 orthogonal array by Taguchi method.

Table 4. Experimental Results for MRR

S. no.	Polarity	Current	On Time (μs)	Off Time (μs)	MRR (g/min)
1	+	1	10	10.5	0.0042
2	+	1	12	11.5	0.0035
3	+	1	14	12.5	0.0032
4	+	2	10	10.5	0.0051
5	+	2	12	11.5	0.0044
6	+	2	14	12.5	0.0038
7	+	3	10	10.5	0.0061
8	+	3	12	11.5	0.0079
9	+	3	14	12.5	0.0098
10	-	1	10	10.5	0.0040
11	-	1	12	11.5	0.0034
12	-	1	14	12.5	0.0030
13	-	2	10	10.5	0.0048
14	-	2	12	11.5	0.0042
15	-	2	14	12.5	0.0036
16	-	3	10	10.5	0.0054
17	-	3	12	11.5	0.0072
18	-	3	14	12.5	0.0091

Upon analysis with software MINITAB V.17 the signal to noise ratio plots created indicating the parameter which has highest effect from our selected parameters on the EDD process.

Process parameter current has high influence over EDD machining. Higher current helps in high MRR but affects the Surface roughness of the allow. Recast layer is also of higher depth with higher current settings.

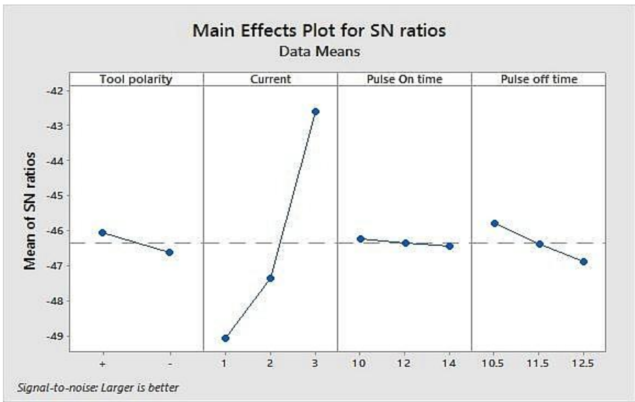


Fig. 6. Main Effect Plot for SN ratio.

In Fig 6. the curve which has larger inclination from the mean line have greater impact on MRR than the curve that is horizontal to the mean line. It can be clearly observed that the Current has the largest inclination thus the most significant with the mean line followed by Pulse off time.

Higher the current higher the MRR due to higher thermal energy incidented on workpiece.

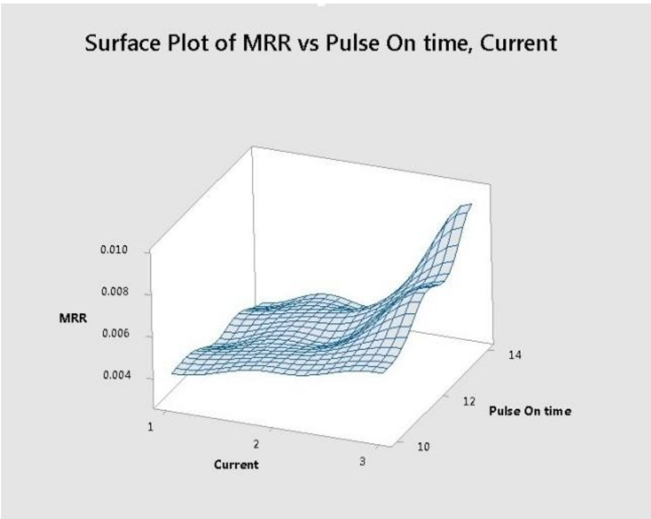


Fig. 7. MRR vs Current and Pulse on-time.

In fig 7, the units of current are ampere and Pulse on-time is Micro-seconds. Higher the pulse on-time means higher is the window of time available for thermal energy to indent over workpiece.

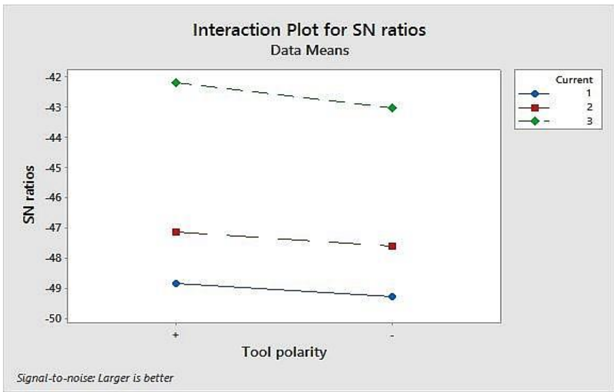


Fig. 8. Interaction Plot for SN ratio

Signal to noise ratios are predicted with MINITAB V.17 based on taguchi DOE with Larger is Better mode.

Table 5.ANOVA Table for Means

Source	DF	Seq.SS	Adj.SS	F	P	Adj.MS
Polarity	1	0.000 001	0.000 001	0.35	**0.568**	0.000 001
Current	2	0.000 055	0.000 055	16.13	**0.002**	0.000 055
Pulse on-time	2	0.000 001	0.000 001	0.21	0.813	0.000 001
Pulse off-time	2	0.000 002	0.000 002	0.56	0.591	0.000 002
Polarity* current	2	0.000 000	0.000 000	0.07	0.929	0.000 000
Residual error	8	0.000 014	0.000 014			0.000 014
Total	17	0.000 072				

S=0.001306; R-Sq=81.1 %; R-sq (Adj)= 59.8 %.

The first column of the table enlists the variable source such as Tool Polarity, Current, Pulse ON time and Pulse Off time. The other column represents the Degree of freedom (DF), Sum of Squares (Seq. SS), adjusted means of Square (Adj. MS), F distribution and probability. The Standard deviation of error in modelling S=0.001306 and R^2 = 81.1%, which indicates that the model is acceptable for predicting the response.

P value of current is minimum in table suggesting current has highest impact of the MRR.

Table 6.Response table for Signal to Means

Level	Tool Polarity	Current	Pulse On Time (μs)	Pulse Off Time (μs)
1	0.00533	0.003550	0.004933	0.005550
2	0.004967	0.004317	0.005100	0.005150
3		0.007583	0.005417	0.004750
Delta	0.000367	0.004033	0.000483	0.000800
Rank	4	1	3	2

From above table it is easily noted that Current had the largest impact on MRR, followed by Pulse off time, Pulse off time and Tool Electrode. Delta denotes the difference between the highest average value of each parameter and the lowest average value of same parameter.

IV. CONCLUSIONS

In this report effect of current, pulse on time, pulse off time on material removal rate of Al alloy 6061 is concluded. Taguchi's L18 orthogonal array is used for design of experiments. ANOVA analysis was carried out to study the Experiments Results.

Following conclusions were drawn from the study:

- Drilling of Al alloy 6061 is effectively achieved through developed EDD set up with selected control parameters.
- Peak current influences most the MRR followed by Pulse off-time, Pulse on-time and Tool polarity.
- Maximum MRR (0.0098 gm/min.) was observed at 3A current, 14μs pulse on time, 12.5μs pulse off time and positive tool polarity by copper tool electrode.

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