Parametric Analysis of Rotary Tool Electrical Discharge Machining of Metal Matrix Composite

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***Abstract*— Aluminum-SiC metal matrix composite (Al-SiCp MMC) are now gaining their usage in aerospace and automotive industries. Because of their inherent nature, difficult to machine, they find very little applications in other sectors. The material removal rate (MRR) and tool wear rate (TWR) plays an important role in the analysis of machine outturn during electrical discharge machining (EDM). This work aims at improving the machine output of rotary electrical discharge machining (REDM) on Aluminum-SiC metal matrix composite with a rotary copper tool (electrode). Taguchi's L_{18} orthogonal array is selected to design the experiment and to study the outcome of different parameters like polarity at (two levels) and applied current, gap (distance between electrode tool and work-piece), duty cycle, tool rotation speed at (three levels), for maximizing the material removal rate (MRR), and minimizing the tool wear rate (TWR). Effective parameters are identified with the assistance of the signal-to-noise ratio and ANOVA analysis. The optimum level of each factor is chosen. Thus, this research benefits the EDM process by increased MRR and decreased TWR.**

Keywords*— Tool wear rate(TWR), Material removal rate(MMR), Analysis of variance (ANOVA), Signal to noise ratio(S/N), orthogonal array(OA).

1 INTRODUCTION

1.1 Electrical Discharge Machining

Electrical Discharge Machining (EDM) is an electro-thermal-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. Spark machining, spark eroding, burning, die sinking or wire erosion, is a Electric discharge machining (EDM), sometimes colloquially also referred to as manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Electric discharge machining (EDM) is one of most popular machining methods to manufacture dies and press tools because of its capability to produce complicated shapes and machine very hard materials

1.2 Rotary electrode EDM

Machining by using Rotary Electrode is one of the variant process of electrical discharge machining process based on removing unwanted material in the form of debris from apart by means of a series of recurring electrical discharges (created by electric pulse generators in micro second) between a rotary tool called electrode and the work material in the presence of a dielectric fluid. This fluid makes it possible to flush eroded particles from the gap. Few researches have investigated the effect of rotary tool on machining characteristics in EDM. Soni and Chakraverti [1] analyzed the effect of rotary electrode tool on the EDM of titanium alloy [2].

They found that the rotary motion of the tool increases the MRR and electrode wear rate (EWR) in all levels of current and pulse on time. Mohan et al. [3] conducted the experimental study on Al-SiC composite material. They showed that the rotary electrode improves the MRR and reduce the surface roughness. Kuppan et al. [4] investigated the effects of various rotational speed of electrode on inconel 718. Results show that the increasing of the rotational speed is effective factor in low discharge energy. Ghoreishi and Atkinson [5] studied the influences of vibration and rotation of electrode on machining characteristics in three levels of machining pulse energy. Saha and Chaudhary [6] applied the rotation of the electrode on dry EDM.

Electro Discharge Machining (EDM) is an effective method for machining large variety of products for automotive, defense, and medical industries. Even though the complete nature of the process is not fully understood, the benefits are being increasingly recognized by aircraft and aerospace industries [7].

2 DESIGN AND EXPERIMENTS

The essential requirements of general methodology for the product and process development are experimentation and drawing inferences from the results. The planning in right way for the experiments is most importance for deriving clear and accurate conclusions from the experimental observations [8]. Design of experiments is considered to be a very useful strategy for performing these tasks [9].

2.1 Taguchi Experimental Design Strategy

The full-factorial designs require for all the possible combinations of the factors involved in the study during experimentation, consequently a very large number of experiments need to be performed. The Taguchi method gives a solution to overcome this problem. Taguchi method standardizes and simplifies the fractional factorial design by introducing orthogonal array (OA) for constructing or laying out the design of experiments. It also gives a standard method for the analysis of results [10]. These OA's are called Graeco-Latin squares. Any two columns of an OA make a 2-factor complete factorial design [11]. Therefore, whatever will happen to all the other parameters at one level of parameter being studied will also happen in the same way at other levels being studied? The effect of one parameter under study is different from the effect of other parameters. Thus, the optimum level of each factor and their contribution can be determined. The second advantage is that orthogonal array (OA) experiments reduce the number of experiments. A full-factorial experiment with 4 parameters each having three levels would require (3^4 = 81) total number of experiments whereas Taguchi L_9 OA would require only 9 experiments to providing same information

3 EXPERIMENTAL PROCESER

The electric discharge machine, (ELECTRONICA, EDM die sinking type, with servo controlled, which can keep constant gap between tool and work piece during experiment), have been used for the experiment. The positive polarity is connected with work piece and negative is connected to tool electrode

3.1 Machining Parameters

The ranges of input parameters selected for experiments are given in (Table 1)

S.No	Parameters	Units	Levels		
			L1	L2	L3
1	Current	A	09	12	15
2	Gap	µm	05	06	07
3	Duty cycle	----	0.7	0.75	0.8
4	Tool rotation speed	RPM	200	400	600
5	Polarity	±	1	2	0

Table 1: Process parameters and their Levels used for experiment

S. No.	Polarity (±)	Current (A)	Gap (µm)	Duty	Tool rotation speed (rpm)
	1	2	5	6	7
01	1	9	5	0.7	200
02	1	9	6	0.75	400
03	1	9	7	0.8	600
04	1	12	6	0.75	600
05	1	12	7	0.8	200
06	1	12	5	0.7	400
07	1	15	5	0.8	400
08	1	15	6	0.7	600
09	1	15	7	0.75	200
10	2	9	7	0.75	400
11	2	9	5	0.8	600
12	2	9	6	0.7	200
13	2	12	7	0.7	600
14	2	12	5	0.75	200
15	2	12	6	0.8	400
16	2	15	6	0.8	200
17	2	15	7	0.7	400
18	2	15	5	0.75	600

Table 2: Experimental layout using an L_{18} orthogonal array

3.2 Data Collection

The following data are collected in experiment:

1. Mass of work piece before and after machining in gram (g).
2. Mass of tool before and after machining in gram (g).
3. Machining time (2 min) in each experiment.

3.3 Responsible Variables

A mathematical relation was developed to measure the output parameters of EDM machining process. To measure the material removal rate of work piece its final weight was subtracted by initial weight and then it's divided by machining time (2 min for each experiment). Similarly, tool wear rate was calculated by subtracting final weight of tool after each machining from initial weight of tool before machining and then divided it by machining time[12]. After completion of each machining process, the work piece and tool was dried by blower to ensure no dielectrics present inside the work piece and tool. A precise balance (Shimadzu) model AUX 220 was used to measure the initial and final weight of the work piece. Similar procedure was used to measure the weight of tool electrode.

The relation of MRR and TWR with material removal was given as:

MRR (g/min) = WRW/T (1)

TWR (g/min) = TRW/T (2)

Where,

MRR = material removal rate,

WRW = work piece removal weight,

TWR = tool wear ratio.

TRW = tool removal weight, T = time in min.

Higher the material removal rate better is the machining performance. While, lower the tool removal rate during machining of EDM is considered as better and accurate performance of machine.

This section will discuss about the result obtained during experiment and the effects of each parameter i.e. current, gap, duty cycle, polarity and tool rotation speed on output parameter, material removal rate (MRR) and tool wear rate (TWR). Further graph will plotted between input parameters and output parameters and optimum level of each factor is chosen. Thus, this research benefits the EDM process by increased MRR and decreased TWR

4 RESULTS AND DISCUSSION

This section discuss about the result obtained during experiment and the effects of each parameter i.e. current, gap, duty cycle, polarity and tool rotation speed on output parameter, material removal rate (MRR) and tool wear rate (TWR). Further graph will plotted between input parameters and output parameters and optimum level of each factor is chosen. Thus, this research benefits the EDM process by increased MRR and decreased TWR

S. No.	MRR (mm^3/min)			TWR (mm^3/min)		
	R1	R2	R3	R1	R2	R3
1	0.049	0.045	0.067	0.002	0.014	0.01
2	2.841	2.803	2.881	0.483	0.476	0.542
3	0.7	0.652	0.591	0.348	0.279	0.26
4	3.305	3.372	3.465	5.63	5.637	5.655
5	2.246	2.315	2.335	0.142	0.148	0.156
6	2.149	1.976	2.076	0.101	0	0.016
7	7.85	7.807	7.845	3.303	3.286	3.288
8	3.578	3.628	3.694	2.968	2.976	3.008
9	3.426	3.393	3.319	0.238	0.221	0.216
10	9.453	9.452	9.55	0.016	0	0.081
11	2.581	2.67	2.582	0.068	0.087	0.087
12	3.474	3.368	3.42	0.024	0.01	0.012
13	1.866	1.815	1.798	0.025	0.014	0.001
14	7.479	7.5	7.511	0.003	0.012	0.014
15	59.41	59.482	59.354	1.24	1.33	1.225
16	56.889	56.801	56.954	0.537	0.529	0.541
17	14.911	14.88	14.831	0.08	0.019	0.012
18	26.256	26.358	26.283	1.254	1.292	1.258

Table 3: Data of MRR, TWR

Machining variables have been finalized from the study, and their levels the proper orthogonal array can be selected, selected orthogonal array is L_{18}. L_{18} orthogonal array has been adapted to design the experiment The experimental design has 2 & 3 levels and 5 factors. Process parameters have been optimized by Taguchi method, Experiment has been performed on EDM machine model 5030. Rotary EDM processes parameter has been optimized by L_{18} OA.

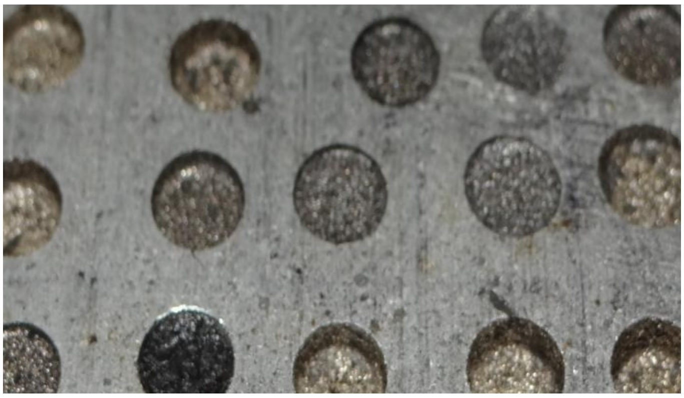

Figure 1: Work piece after removal of material

4.1 Design of experiment and parameter assignment

L_{18} orthogonal array has been adopted to design the experiment. The experiment design has 2 & 3 level and 5 factors. Experiment has been performed on EDM model 5030 Rotary EDM processes parameter has been optimized by L_{18} OA.

S.No	Parameters	Units	Levels		
			L1	L2	L3
1	Current	A	09	12	15
2	Gap	μm	05	06	07
3	Duty cycle	----	0.7	0.75	0.8
4	Tool rotation speed	RPM	200	400	600
5	Polarity	±	1	2	0

Table 1: Process parameters and their Levels used for experiment

Applied Current levels: A1=9A, A2=12A, A3=15A, Gap levels: B1=5mm, B2=6mm, B3=7mm, Duty cycle levels: C1=0.7, C2=0.75, C3=0.8, Tool Rotation Speed levels: D1=200 RPM, D2=400RPM, D3=600RPM, Polarity (±)
R1, R2, R3, represent response values for three repetition of each trial. The 1^{st}, 2^{nd} and 3^{rd} represent levels 1, 2, 3 of the variables, which appear at the top of the column.

4.2 Analysis and discussion of results

The REDM experiments were conducted by using the parametric approach of the Toughies method. The effects of individual REDM process parameters, on the selected quality characteristics MRR and TWR have been discussed in this section. The average value and S/N ratio of the response characteristics for each variable at different levels were calculated from experimental data. The main effects of process variables S/N data were plotted. The response curves (main effects) are used for examining the parametric effects on the response characteristics. The analysis of variance (ANOVA) of S/N data is carried out to identify the significant variables and to quality their effects on the response characteristics. The most favorable value (optimal setting) of process variables in terms of mean response characteristics are established by analyzing the response curve and the ANOVA tables

4.3 Effects of Process Parameters on MRR

In order to see the effect of process parameters on the MRR, experiments were conducted using L_{18} OA is and S/N data plotted are in Figures 2 (a, b, c, d, e) and shows that MRR increases with the increase of duty, gap and current. This is because the discharge energy increases with the duty and current (increase duty means, increase pulse on time decrease pulse off time) and applied current leading to a faster material removal rate. As the pulse off time decreases, the number of discharges within a given period becomes more which leads to a higher MRR. It is also clear that MRR is minimum at minimum level of duty and maximum at last level of duty. Further MRR increases when the gap level from (1 to 2) and then there is a decrease in MRR, when the gap level from (2 to 3). Again when the polarity is at level 1, there is less MRR, and the MRR is more is polarity at level 2.

Main Effects Plot (data means) for S/N ratio

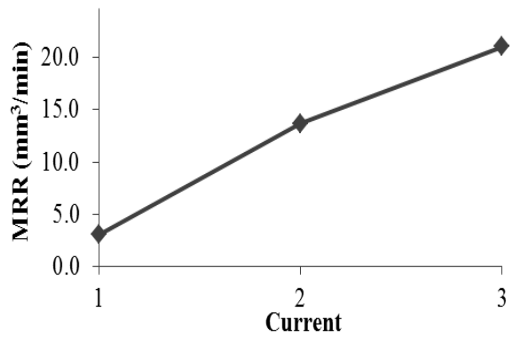

Figure 2: (a) Effect of current on MRR

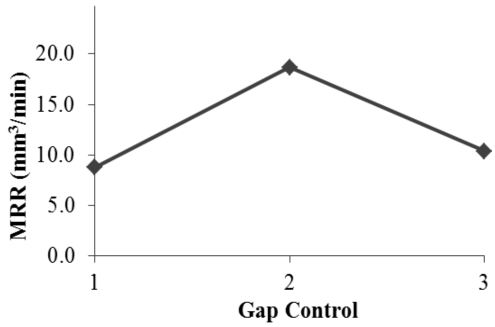

Figure 2: (b) Effect of gap control on MRR

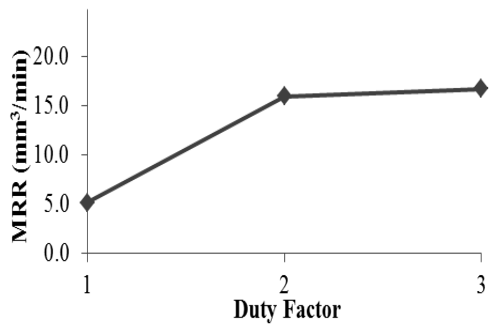

Figure 2 (c) Effect of duty factor on MRR

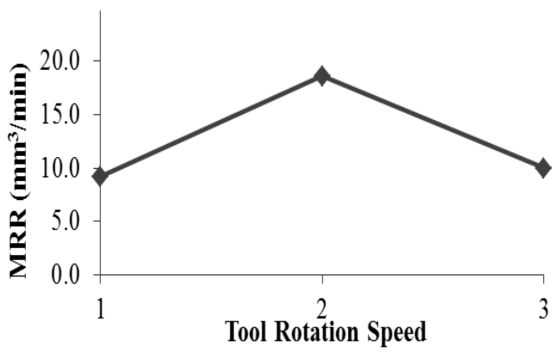

Figure 2 (d) Effect of tool rotation speed on MRR

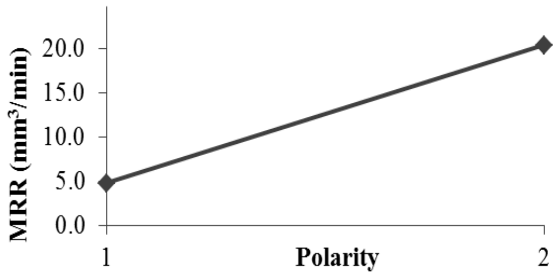

Figure 2 (e) Effect of polarity on MRR

	Factors	Level 1	Level 2	Level 3	L2 - L1
1	Polarity	8.412	20.726	0	12.313
2	Current	23.399	16.502	3.806	-6.898
3	Gap control	18.886	3.414	21.408	- 15.472
4	Duty factor	25.452	11.272	6.983	- 14.181
5	Tool rotation speed	24.982	11.832	6.893	-13.15

Table 7: Main Effects of Parameter on TWR

S. N O	Factor s	DOF	Sums of Squares	Varianc e	Fraction Ratio	Pure Sum	Percent contributi on
1	Polari ty	1	682.303	682.303	25.703	655.7 58	12.168
2	Curre nt	2	1,185.213	592.606	22.324	1,132. 12	21.007
3	Gap contro l	2	1,139.097	569.548	21.456	1,086. 01	20.151
4	Duty factor	2	1,121.177	560.588	21.118	1,068. 09	19.819
5	Tool rotati on speed	2	1,049.047	524.523	19.759	995.9 58	18.48
	Oth. Err.	8	212.358		26.544		8.375
	Total.	17	5,389.2				100.00%
Significant at 95% confidence level							

Table 8: Analysis of variance for TWR

4.5 Selection of optimal levels for TWR

In order to study the significance of the process variables toward TWR, analysis of variance (ANOVA) was performed. From Table 8, shows the ANOVA for different factors (polarity, current, gap control, duty factor, tool rotation speed). The percentage contribution towards the TWR by each factor is shown here. From this table it is clear that, current and gap most significant factors for the TWR in compression to the other factors. In the present work, we have used Qualitek-4 software for ANOVA. This software shows the effect of each factor on TWR in the percentage. From the table there all factors are significant, i.e. which effect the TWR.

As TWR is the "lower the better" type quality characteristics, it can be seen from Figures 3 (a, b, c, d, e) that the third level of current (A3), second level of gap (B2), third level of duty (C3), third level of tool Rotation (D3), and first level of polarity (E1) provide minimum value of TWR. The S/N data analysis in Figures 3 (a, b, c, d, e) also suggests the same levels of the variables (A3, B2, C3, D3, E1) as the best levels for maximum in REDM process.

5 CONCLUSIONS

In this research, an attempt is made to machine the Aluminum-SiC metal matrix composite work material using rotary electro discharge machining (REDM). Taguchi's L_{18} orthogonal array is chosen to design the experiment for maximizing MRR and minimizing TWR by considering the effect of various parameters like polarity, applied current, gap (distance between electrode tool and work piece), Duty cycle, tool rotation, as the parameters. ANOVA results have shown that significant factors. The experiments were conducted under various parameters settings of analysis of L_{18} orthogonal array was performed in Qualitek-4 software.

Finding the result of MRR most important factor are polarity, applied current and duty factor is most influencing factor and then tool RPM and last is gap. As MRR is the ' higher the better' type quality characteristic, that the third level of current (A3), second level of gap (B2), third level of duty (C3),second level of Tool Rotation (D2) and second level of polarity (E2) provide maximum value of MRR. The S/N data analysis also suggests the same levels of the variables (A3, B2, C3, D2 and E2) as the best levels for maximum MRR in REDM process.

In the case of Tool wear rate the most important factor are applied current, gap (distance between electrode and work-piece) and duty factor is most influencing factor and then tool RPM and last is polarity. As tool wear rate is the 'lower the better' type quality characteristic, the third level of current (A3), second level of gap (B2), third level of duty (C3), third level of Tool Rotation (D3) and first level of polarity (E1) provide minimum value of TWR. The S/N ratio analysis also suggests the same levels of the variables (A3, B2, C3, D3 and E1) as the best levels for minimum TWR in REDM process.

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