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Parametric Optimization on Electrical Discharge Machining of Al6061/Alumina/ Graphite/ Redmud Composite

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Abstract
Aluminium composites are richly assimilated in automobile industries in the recent past, especially in brake rotors, owing to its high strength/ less weight ratio. In the present work, the machining behaviour of aluminium hybrid composite is studied using electrical discharge machining (EDM) process which is a promising method to machine metal matrix composites. Aluminium hybrid composite is fabricated through liquid metallurgy (stir casting) technique, by reinforcing 3% alumina, 3% graphite and 3% redmud with Al6061 alloy. The experiments are designed with Central Composite Design of (CCD) of Response Surface Method (RSM). The output performances likeMaterial Removal Rate (MRR) and Surface Roughness (Ra) are determined by varying the Pulse ON, current and Flushing pressure. The optimal input parameters combination is determined using Response optimization.From the experimental results it is observed that current influences MRR significantly among other factors. Similarly, 'Ra' is primarily affected by flushing pressure.

Keywords:Al6061 alloy, Redmud, EDM, RSM-Central Composite Design.

1. INTRODUCTION
Composite is a combination ofdistinct constituent (the reinforcement) dispersed in a continuousphase (the matrix).It offers unique and improved characteristics than the monolithic materials[1]. Metal Matrix Composites (MMC's) have several advantages over conventional metals such as, higher specific strength, lower coefficient of thermal expansion andbetter wear resistance. SiC is very often reinforced with aluminium and its alloys to get enhanced material properties[2].Aluminium Matrix Composites are extensively implemented even in aerospace, defence and automobile applications. Intricate shapes can be formed bynonconventional machining techniques in aluminum metalmatrix composites. One among them is electrical discharge machining technique [3]. EDM has become very promising technique to machine hard and difficult-to-machine materials/alloys/composites. Any material which is conductive in nature can be machined with high precision by non-conventionalmachining techniques. Electrical Discharge Machining (EDM) anunconventional machining process uses thermo-electric energy to material. The high-frequency electrical sparksremoves the material by erosive action between two electrodes. One among two is a tool and the other one is a work piece. Dielectric fluid is introduced in the sparking zone to flush away the eroded particles and to cool the electrodes [4].Muller and Monaghan experimentally found that EDM is an effective machining process to machine composite materials among all unconventional processes [5]. Number of research works have been carried out which dealt with machining of composites by EDM process, few are discussed below.

Velmurugan et al. (2011) investigated the machining behavior of Al6061 metal matrix composite reinforced with SiC and graphite particles. The effect of input parameters (current, pulse ON, voltage and flushing pressure) on MRR, TWR and SR was discussed in this work. Experimental results evident that MRR increases with current, pulse ON and flushing pressure but decreases with voltage. TWR was mainly influenced by current and voltage and reduced with the increase in pulse on time and flushing pressure. The surface roughness found an increasing trend with the increase in all input parameters. Electrical Discharge Machining of Microwave post heat treated Al6061 reinforced with boron carbide and graphite composite was compared with conventionally heat treated same composite to determine the effect of input parameters on the output performances of proposed composites. It is found that pulse ON and current influences the output of composites heat treated by either methods [6].Machining behaviour of Al6061 reinforced with 30% of Al_2O_3(Alumina) was assessed through EDM process to find the influence of key process parameters on output characteristics like MRR and TWR. Experimental results reveal that peak current and pulse ON affects the MRR crucially but increase in pulse off time decreases the MRR. It is noted that TWR increases rapidly in AMMC than Al6061 as AMMC has hard alumina ceramic particle [7].

Pure aluminium alloy is mixed with 12% SiCto explore the effect of process parameters (pulse on time(Ton), peak current (Ip) and flushing pressure (Fp))on metal removal rate (MRR), tool wear rate (TWR)and surface roughness (SR) through electrical discharge machining (EDM).Central composite design is adopted for designing the experiments and ANOVA is equipped to ensure the significance of model. Thepeak current is identified as the most significant parameterand MRR, TWR and Raincreases linearly with it [8]. 6061Al/Al2O3p/20Pcomposites are fabricated and L_{18}OA and grey relational analysis are used toinvestigate the effects of pulse current, pulse on time,duty cycle, gap voltage and tool electrode lift time overthe responses such asMRR, TWR and surface roughness during EDM process.Pulse current significantly affects the output performances thanother parameters [9].

The present work focuses onfabrication of Redmud reinforcedAluminium Hybrid Metal Matrix Composite (RM-AlHMMC) through stir casting method. These compositeis further tested for its machining behaviour by Electrical Discharge Machining (EDM) process and later the process parameters are optimized by Response optimization technique.

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2. EXPERIMENTAL DETAILS

2.1. Composite preparation

Al6061-T6 alloy is selected as matrix material and Alumina (Al_2O_3) of size 22-25µm, Graphite (Gr.) of size 14-17µm and Redmud of size 20-25µm particles are chosen as reinforcements for the present work.Among different composite fabrication routes, stir-casting - the most economic and effective production method which is opted to synthesizeredmud reinforced aluminium hybrid metal matrix composites (RM-AlHMMC). In which, 1 kg of Al6061-T6 alloy was reinforced with 3wt.% Alumina (Al_2O_3), 3wt.% Graphite and 3wt.% Redmud to fabricate RM-AlHMMC. 1wt.% of magnesium is added during fabrication to obtain good bonding and also1wt.% of hexacholroethane is added as degasifying agent to avoid porosity. A PID controller isemployed to measure and control the temperature inside the furnace by thermocouple. A graphite crucible is used as a melting chamber to melt the Al6061-T6 alloy and a 1 HP DC motor with a mild steel stirrer is used for stirring. The molten metal was kept at a temperature range of 750 to 800°C for an hour. The pre heated reinforcements (600°C) were then sensibly added into the molten metal at a constant stirring speed of 450 rpm. Then, the fabricated composite was poured into preheated (300°C) steel die and allowed to air cool [10].

2.2. Experimental Design

Three input process parameters are chosen to design the experiments by Central Composite Design (CCD) of RSM method and are: Pulse ON in µs, Current (peak) in Ampere and Flushing pressure in Kg/cm^2. CCD contains20 number of experiments to measure the influence of process parameters on the MRR and R_a.The input process parameters with their levels are shown in the Table 1.

Table 1: Input process parameters and their levels

Parameters	Levels		
Pulse ON (µs)-T_{on}	20	40	60
Current (A) -I_p	4	8	12
Flushing Pressure (Kg/cm^2) -F_p	0.3	0.6	0.9

Also, the design of experiments based on the RSM - CCD is given in Table 2. As there are three input parameters and have three levels each CCD designs 20 number of experiments with 3 blocks. Table 3 represents the experimental results of MRR and R_a for the given process parameter combinations.

2.3. Evaluation of MRR & Ra

The machining performance ofRedmud reinforced AlHMMCisevaluatedby studying the effect of process parameters (Pulse ON, Current and Flushing pressure) on Material Removal Rate (MRR) and Surface Roughness (R_a). Material removal rate isdefined as ratio of product of area of electrode and depth of cut to the machining time.Mathematically it is expressed as [11, 12]

$$MRR = \frac{Area\ of\ electrode \times Depth\ of\ cut}{Machining\ time} \quad (\text{mm}^3/\text{min}) \qquad (1)$$

Where,

Area of electrode = $\pi/4 \times d^2$ (mm^2)

Depth of cut = 0.5 (mm)

Machining time in (min)

Surface roughness (R_a): Three different values of $R_a$taken at different places of work piece are noted. Mitutoyo SJ-201 (P) surface roughness tester isutilized to measure the average surface roughness (R_a) values.

Table 2: Design of Experiments

Run Order	Pulse ON (µs)	Current (A)	Flushing Pressure (Kg/Cm^2)
1	60	12	0.9
2	40	8	0.6
3	20	12	0.3
4	60	4	0.3
5	20	4	0.9
6	40	8	0.6
7	7.34	8	0.6
8	40	1.468	0.6
9	40	8	0.1101
10	40	8	0.6
11	72.66	8	0.6
12	40	8	1.0899
13	40	14.532	0.6
14	40	8	0.6
15	60	4	0.9
16	20	4	0.3
17	40	8	0.6
18	60	12	0.3
19	20	12	0.9
20	40	8	0.6

Table 3: Experimental results of responses

Run Order	Pulse ON (µs)	Current (A)	Flushing Pressure (Kg/Cm^2)	Experimental Value		Predicted Value	
				MRR (mm^3 /min)	Ra (µm)	MRR (mm^3 /min)	Ra (µm)
1	60	12	0.9	24.139	11.05	23.442	10.774
2	40	8	0.6	14.878	7.24	15.450	8.227
3	20	12	0.3	12.998	6.62	12.656	6.043
4	60	4	0.3	6.553	6.51	6.132	5.797
5	20	4	0.9	6.019	5.11	7.227	5.236
6	40	8	0.6	15.771	7.76	15.450	8.227
7	7.34	8	0.6	8.157	6.06	7.420	5.707
8	40	1.468	0.6	3.552	4.34	2.911	4.157
9	40	8	0.1101	12.787	6.90	14.044	7.585
10	40	8	0.6	17.142	8.27	15.470	8.525
11	72.66	8	0.6	14.603	9.08	16.294	9.396
12	40	8	1.0899	15.771	9.21	15.468	8.498
13	40	14.532	0.6	18.627	8.92	20.222	9.066
14	40	8	0.6	16.659	8.68	15.470	8.525
15	60	4	0.9	6.740	6.05	6.445	6.653
16	20	4	0.3	4.558	5.45	4.619	5.748
17	40	8	0.6	12.257	9.69	13.533	9.025
18	60	12	0.3	22.317	10.84	20.473	10.740
19	20	12	0.9	10.467	7.16	10.252	7.902
20	40	8	0.6	12.517	9.90	13.533	9.025

3. RESULTS AND DISCUSSIONS

3.1 Results from Analysis of Variance (ANOVA)

The experimental results are then analyzed by ANOVA and F-test to ensure the acceptability of the model. ANOVA results for MRR and R_a is displayed in Table 4. The significance level of α=0.05, (i.e. confidence level of 95%) is taken for consideration during ANOVA. It is understood that the parameter which has P value less than 0.05 is statistically significant and more than 0.05 has less influence to the model. It is important in ANOVA that the R^2 values of responses should be desirably close to 1 and the observed R^2 values for MRR and Ra are 0.96 and 0.92 respectively. The predicted R^2 values are quite coherent with adjusted R^2.

Table 4: ANOVA results for MRR& R_a

Source	DF	MRR		Ra	
		F-Value	P-Value	F-Value	P-Value
T_{on}	1	37.31	0	23.99	0.001
I_p	1	141.93	0	42.48	0
F_p	1	0.96	0.356	1.47	0.26
$T_{on}*T_{on}$	1	9.18	0.016	2.48	0.154
I_p*I_p	1	10.72	0.011	9.59	0.015
F_p*F_p	1	0.36	0.566	0.61	0.456
$T_{on}*I_p$	1	19.47	0.002	6.57	0.034
$T_{on}*F_p$	1	0.45	0.522	0.04	0.853
I_p*F_p	1	0.26	0.622	0.42	0.533
Error	8				
Lack-of-Fit	5	22.49	0.014	13.46	0.029
Pure Error	3				
Total	19				
		R-Sq = 96.57%, R-Sq (adj) = 91.84%		R-Sq = 91.79%, R-Sq (adj) =86.49%	

3.2 Full Quadratic (Second order) Mathematical Model

The process parameters integrated empirical mathematical equations are definedfor the output responses. Full quadratic (second order) mathematical model is tailored for this work which concerns the linear and quadratic interactions of input processparameters.The mathematical modelrelationnormallydenoted by a function (f) i.e.

$$Y = f(T_{on}, I_p, F_p)$$

Where,

Y- response of the model; Ton - pulse on time;

I_p–current;F_p- flushing pressure

The empirical mathematical equations for MRR and R_a are given in equations 2 and 3 respectively.

$$MRR = -3.93 + 0.115\, T_{on} + 1.669\, I_p + 4.42\, F_p - 0.00339\, T_{on} * T_{on} - 0.0915 I_p * I_p - 2.97\, F_p * F_p + 0.03168\, T_{on} * I_p + 0.0641\, T_{on} * F_p - 0.246\, I_p * F_p \quad (2)$$

$$Ra = 1.31 + 0.0589\, T_{on} + 0.615\, I_p + 2.44\, F_p - 0.000913\, T_{on} * T_{on} - 0.0449\, I_p * I_p - 2.02\, F_p * F_p + 0.00954\, T_{on} * I_p - 0.0095\, T_{on} * F_p + 0.161\, I_p * F_p \quad (3)$$

3.3 Explanation of Plots

The main effects plot interprets the significance of individual parameters (Pulse ON, Current and Flushing pressure) over the responses (MRR and R_a)shown in Figure 1. It is observed from the plot that MRR increases with the increase in all the input process parameters.Among these parameters, current influences the MRRsignificantly,since,rich discharge of current flows atthe interface of work piece and tool, similar behavior was reported by [4]. The material is eroded from the surface as the sparks melts and evaporates the material. Increase in pulse ON timealso increases the duration of spark productionthus resulted increased MRR. Flushing pressure of dielectric fluid also plays a vital role in MRR. As the F_p increases it washed-out the wear debris in the sparking gaps, hence there is no disturbance in sparkdischarge that increases the MRR, such behavior was noticed by [5].It is also witnessed that increase in pulse ON time increases the surface roughness value. Higher the pulse ON time increases the MRR and R_a. Main effect plot of R_a revealed that increase in flushing pressure creates more chance to produce intensesparks
that increases the MRR. As MRR and R_a are directly proportional, more the MRR more the roughness.

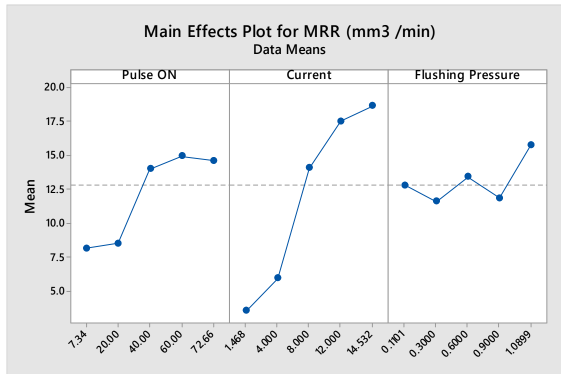

Fig. 1. Main effect plot for MRR

It is explored from Figure 2 that surface roughness (R_a)is increases due to increase in the input process parameters values. It is commonly found that increase in current increases the MRR which in turn increases the surface roughness.

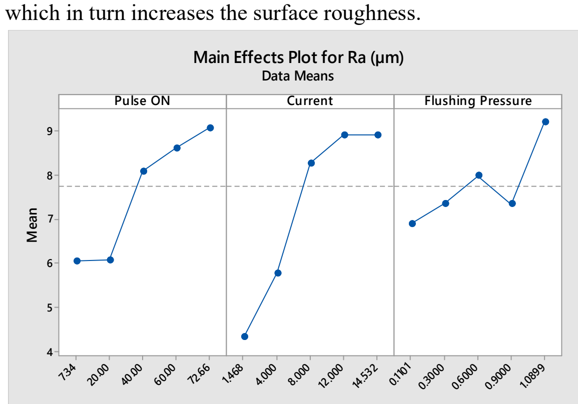

Fig. 2. Main effect plot for R_a

4 RESPONSE OPTIMIZATION

Optimized results from response optimization method is shown in Figure 3. In which, the optimized values of MRR and $R_a$are found to be 6.48 and 15.81 respectively. In order to obtain these optimized responses, RSM offers optimized parameter combinations.

4.1 Confirmation test

From the response optimization, a new set of optimized parameter combination is attained (T_{ON} =30.8929, I_p =14.532 and F_p = 0.1101) and the optimized responses are R_a- Fit = 6.47609 And MRR- Fit =15.8134. In order to validate the results, a confirmation experiment is carried out with the new optimized parameters but within the range of existing process variables. The predicted values of confirmation are determined by using the derived mathematical equations 2 and 3. These predicted values are further compared with the experimental values.

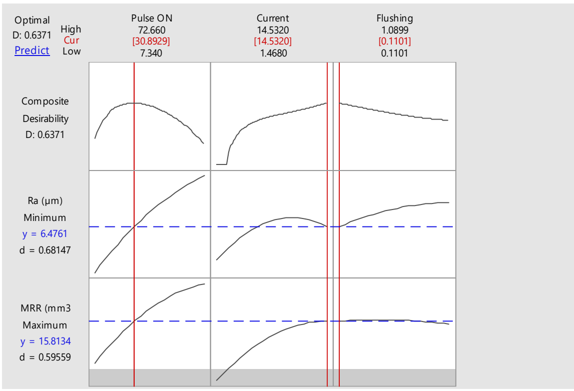

Table 6. Confirmation results

Test	T_{on}	I_p	F_p	MRR		R_a	
				Pred.	Exp.	Pred.	Exp.
1	30.89	14.53	0.11	15.81	16.02	6.48	6.72
Error %				1.3		3.7	

It is found from the confirmation result that the error % of MRR and $R_a$are within 1.3 to 3.7. These confirmation result ensures that the model has retained its 95% of accuracy.

5 CONCLUSIONS

- The MRR of 3% Redmud reinforced AlHMMC increases as pulse ON time, current and flushing pressure increases. Among all parameters, current (peak) influences MRR more.
- Surface roughness (Ra) of composite increases with the increase in all the input process parameters and mainly by current (peak).
- It is observed from the ANOVA results that pulse ON and current have significant effect on the responses whereas flushing pressure has low significance.
- Response optimization technique is used to obtain the optimized process parameters and are: T_{on}=30.8929, I_p=14.532 and F_p=0.1101.
- The confirmation experiment result revealed that the error value for predicted and experimental value of MRR and R_a is within 1.3 to 3.7 and that ensures that the model has retained its 95% of accuracy.

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