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ANALYSIS OF MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS IN WEDM OF AL/SIC/MOS_2

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ABSTRACT

The machining parameters of wire cut EDM process for aluminium composites were optimized through this experiment. The optimization was carried out by Taguchi method. The control parameter for the optimization are Reinforcement Size, Volume Fraction, Pulse on, Pulse Off and wire feed for material removal rate and surface roughness. The experimental results optimized the proposed parameter which tends to achieve maximum material removal rate and minimum surface roughness.

Keywords: Wire electrical discharge machining, Material Removal Rate, Surface Roughness, Pulse On, Pulse Off and Wire feed.

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1. INTRODUCTION

Wire electrical discharge machining (WEDM) is an unconventional machining process to manufacture complex shapes and profiles, as well as precise shape, can be obtained through this process. [1]. If machining takes place after heat treatment, dimensional accuracy will not be affected by heat treat distortion.

Results of the experiment are studied by using the analysis of variance (ANOVA) and signal-to-noise (S/N ratio) analysis. ANOVA highlighted that the major affecting machining parameter to improves machining performance of micro WEDM process [2-5]. An optimum parameter combination for the minimum *R*a and the maximum wire feed was obtained by the analysis of signal-to-noise (S/N) ratio and concluded that it is extremely useful for increasing the productivity while concerning surface finish within the desired limit [6-11]. The optimum value obtained by the proposed methodology could serve as a ready reckoned to operate the machine with great ease to achieve the quality [12-15].

Figure 1 WEDM setup

Results of the experiment are studied by using the analysis of variance (ANOVA) and signal-to-noise (S/N ratio) analysis. The analysis of S/N ratio and ANOVA were carried to study the relative influence of the machining parameter on the metal removal rate and surface roughness of the hybrid machine composite. The S/N ratio characteristics can be classified into three categories, 'larger-is-better', 'smaller-is-better', and 'nominal-the-best'. For metal removal rate "larger-is-better" and for surface roughness "smaller-is-better" to optimize better machining characteristics. To calculate multi-objective response parameters grey rational analysis is employed to optimize the parameters in the WCEDM process[19]. Based on numerical results confirmation test is conducted.

2. EXPERIMENTAL SETUP AND PROCEDURE

2.1. WEDM PROCESS

The experiments were carried out on a wire-cut EDM machine. The workpiece material is Al5059-SiC-MoS_2 . The dimensions of the workpiece are 95 x 65 x 50 mm. The different process parameters such as Volume Fraction, Size, Pulse On, Pulse Off and Wire feed were used in experiments and with three levels were shown in table 1. The density of AMMC is 2.72g/cc.

Table 1 Process parameters and their levels.

Parameter	Volume fraction	Reinforcement Size	Pulse On	Pulse off	Wire feed
Unit	**%**	**μm**	**μs**	**μs**	**mm/sec**
Symbol	**A**	**B**	**C**	**D**	**E**
Level 1	5	10	123	50	40
Level 2	10	20	125	55	50
Level 3	15	40	127	60	60

Material Removal Rate can be calculated by using the formula,

MRR= (Initial weight - Final weight) / Time taken

Surface roughness (Ra) of the hybrid composite material can be calculated by using surface roughness tester.

2.2. TAGUCHI EXPERIMENTAL DESIGN

The analysis of S/N ratio and ANOVA were carried to study the relative influence of the machining parameter on the metal removal rate and surface roughness of the hybrid machine composite. For metal removal rate "larger-is-better" and for surface roughness "smaller-is-better" to optimize better machining characteristics.

The S/N ratio for MRR and R_a can be calculated as S/N ratio of MRR = -10*log 10[sum (1/y**2)/N] S/N ratio of R_a = -10*log 10[sum (y**2)/N]

Where

N = number of observation

y = observed data (MRR or R_a)

The objectives are to maximize material removal rate (MRR) and to minimize surface roughness (R_a). Based on the S/N ratio and ANOVA analysis, the input parameter of the material removal rate and surface roughness were obtained and verified. Taguchi based L_{27} orthogonal array is selected. In table no 2 shows the design parameters of input and response parameters

2.3. GREY RATIONAL ANALYSIS

The multi-objective problem can be effectively solved by grey rational analysis. Also to find most affecting parameters by using grey rational grades. In GRA the following steps were employed in order to optimize MRR and surface roughness (Ra) .

To analysis grey rational grade for material removal rate (MRR), it is identified as"Larger is better" for MRR and the terms can be expressed as

$$x_i(k) = \frac{x_i^0(k) - \min}{\max x_i^0(k) - \min x_i^0(k)}$$

For surface roughness, the term is expressed as

$$x_i(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)}$$

Step 1:`Evaluate L27 orthogonal array for input parameters like volume fraction, particle size, Pulse ON , Pulse OFF and wire feed rate followed by the response parameters as MRR and Ra. Prefer S/N ratio elements for MRR is "Larger is better "and attributes for surface roughness is "Smaller is better"

Step 2: Standardize the data from 0-1 into single data for Metal Removal Rate(MRR) and surface roughness(Ra).

Step 3: From the normalized data calculate grey rational coefficient from definite and desired values.

Step 4: The grey rational grade is calculated for MRR and surface roughness(Ra)

3. RESULT AND DISCUSSION

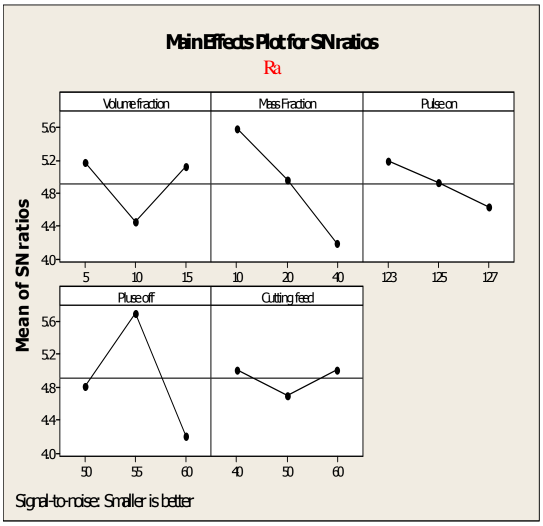
The Minitab 16 software was used to optimize the experimental results. Influencing parameter was found by analysis of variance (ANOVA) were given in Table 2.

Table.2 experimental results of MRR and R_a, calculated S/N ratio by an L_{27} orthogonal array

Expt. No	Volume Fraction (%)	Reinforcement Size (µm)	Pulse On (µs)	Pulse Off (µs)	Wire feed (mm/sec)	MRR (gm/min)	SR (µm)	S/N for MRR (dB)	S/N for SR (dB)
	A	B	C	D	E				
1	5	10	123	50	40	0.082	0.491	-21.72	6.17
2	5	10	123	50	50	0.220	0.512	-13.15	5.81
3	5	10	123	50	60	0.284	0.496	-10.93	6.09
4	5	20	125	55	40	0.084	0.500	-21.51	6.02
5	5	20	125	55	50	0.221	0.512	-13.11	5.81
6	5	20	125	55	60	0.287	0.488	-10.84	6.23
7	5	40	127	60	40	0.087	0.671	-21.20	3.46
8	5	40	127	60	50	0.225	0.683	-12.95	3.31
9	5	40	127	60	60	0.292	0.661	-10.69	3.59
10	10	10	125	60	40	0.091	0.590	-20.81	4.58
11	10	10	125	60	50	0.231	0.613	-12.72	4.25
12	10	10	125	60	60	0.298	0.596	-10.51	4.49
13	10	20	127	50	40	0.098	0.614	-20.17	4.23
14	10	20	127	50	50	0.238	0.637	-12.46	3.91
15	10	20	127	50	60	0.306	0.619	-10.28	4.16
16	10	40	123	55	40	0.115	0.568	-18.78	4.91
17	10	40	123	55	50	0.246	0.597	-12.18	4.48
18	10	40	123	55	60	0.316	0.565	-10.00	4.95
19	15	10	127	55	40	0.125	0.475	-18.06	6.46
20	15	10	127	55	50	0.256	0.497	-11.83	6.07
21	15	10	127	55	60	0.327	0.479	-9.70	6.39
22	15	20	123	60	40	0.142	0.568	-16.95	4.91
23	15	20	123	60	50	0.272	0.591	-11.30	4.56
24	15	20	123	60	60	0.341	0.576	-9.34	4.79
25	15	40	125	50	40	0.175	0.603	-15.13	4.39
26	15	40	125	50	50	0.310	0.621	-10.17	4.13
27	15	40	125	50	60	0.380	0.598	-8.40	4.46

The mean S/N ratio graph for material removal rate is shown in fig.2. From this graph, it is found that the optimum parametric combination is A3, B3, C2, D1, E3 (larger-is-better) i.e., volume fraction 15%, Size 40µm, Pulse on 125µs, pulse off 50µs and wire feed 60mm/sec. The mean S/N ratio graph for surface roughness is shown in fig.3. from this graph, it is found that the optimum parametric combination is A1, B1, C1, D1, E1 (smaller-is-better) i.e., volume fraction 5%, size 10µm, pulse on 123µs, pulse off 50µs and wire feed 40mm/sec.

Material Removal rate increases with increasing Wire feed and Volume Fraction, obviously Material Removal Rate slightly decreases if changing the Wire feed and Volume Fraction. So, Wire feed plays the major factor to determining the Material Removal Rate and is followed by Volume Fraction shows in fig.2. Increasing Pulse Off time and Reinforcement Size tends to minimize the Surface Roughness while other parameters are independent compared to Pulse Off and Reinforcement Size shows in fig.3. So, Pulse Off time plays the major factor to determine the Surface roughness and is followed by Reinforcement Size.



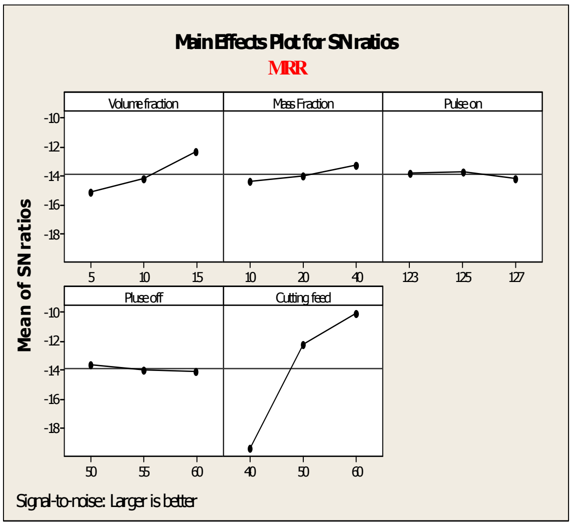


Figure.2 S/N ratio graph for MRR **Figure.3** S/N ratio graph for R_a

The S/N ratio response table for Material Removal Rate is shown in below table.3. Wire feed is the most significant factor which is influencing Material removal Rate and is followed by volume fraction, having delta values of Wire feed and Volume fraction is **9.29** and **2.80**.

Table.3 S/N Ratio response table for material removal rate

Level	Volume fraction	Reinforcement Size	Pulse On	Pulse Off	Wire feed
	A	B	C	D	E
1	-15.13	-14.39	-13.82	-13.61	-19.38
2	-14.22	-14.00	-13.69	-14.01	-12.21
3	-12.33	-13.28	-14.15	-14.06	-10.08
Delta	2.80	1.10	0.46	0.45	9.29
Rank	2	3	4	5	1

The S/N ratio response table for surface roughness is shown in below table.4. Pulse Off is the most significant factor which is influencing the Surface roughness and is followed by Reinforcement Size, having delta value of Pulse Off time and Reinforcement Size is **1.486** and **1.402.**

Table.4 S/N ratio response table for Surface roughness

Level	Volume fraction	Reinforcement Size	Pulse On	Pulse Off	Wire feed
	A	B	C	D	E
1	5.169	5.594	5.190	4.822	5.019
2	4.445	4.962	4.933	5.706	4.708
3	5.134	4.191	4.625	4.219	5.021
Delta	0.725	1.402	0.565	1.486	0.313
Rank	3	2	4	1	5

Table .5 shows the ANOVA result for Material Removal Rate. Wire feed (89.54) and Volume Fraction (8.13) is the most significant parameter affecting the Material Removal Rate. Wire feed and Volume Fraction plays a major role in determining the Material Removal Rate and are independent on Pulse On and Pulse Off time shows in table.5.

Table.5 Result of ANOVA for Material Removal Rate

Parameter	Degree Of Freedom	Sum Of Squares	Mean Sum Of Squares	Percentage Contribution
Volume Fraction	2	0.017559	0.008779	8.134
Size	2	0.003115	0.001557	1.443
Pulse On	2	0.000841	0.000420	0.390
Pulse Off	2	0.000980	0.000490	0.454
Wire feed	2	0.193303	0.096651	89.544
Error	16	0.000078	0.000005	0.035
Total	26	0.215875	-	100

Table .6 shows the ANOVA result for Surface Roughness. Pulse off (41.70) and Reinforcement Size (36.89) is the most significant parameter affecting the Surface Roughness. Pulse Off and Reinforcement Size play an important role in determining the Surface roughness and are independent on Pulse On and Wire feed shows in table.6.

Table.6 Result of ANOVA for Surface Roughness

Parameter	Degree Of Freedom	Sum Of Squares	Mean Sum Of Squares	Percentage Contribution
Volume Fraction	2	0.011153	0.005577	11.00
Reinforcement Size	2	0.037382	0.018691	36.89
Pulse On	2	0.007750	0.003875	7.64
Pulse Off	2	0.042285	0.021142	41.70
Wire feed	2	0.002508	0.001254	2.47
Error	16	0.000305	0.000019	0.30
Total	26	0.101383	-	100

Table 7:Grey rational process parameters

Expt. No	Volume Fraction	Reinforcement Size	Pulse On	Pulse Off	Wire feed	MRR	SR	Normalization MRR	Normalization Ra	co mrr	co surf
1	5	10	123	50	40	0.082	0.491	0.013245	0.923077	0.336303	0.866667
2	5	10	123	50	50	0.22	0.512	0.470199	0.822115	0.485531	0.737589
3	5	10	123	50	60	0.284	0.496	0.682119	0.899038	0.611336	0.832
4	5	20	125	55	40	0.084	0.5	0.019868	0.879808	0.337808	0.806202
5	5	20	125	55	50	0.221	0.512	0.47351	0.822115	0.487097	0.737589
6	5	20	125	55	60	0.287	0.488	0.692053	0.9375	0.618852	0.888889
7	5	40	127	60	40	0.078	0.671	0	0.057692	0.333333	0.346667
8	5	40	127	60	50	0.225	0.683	0.486755	0	0.493464	0.333333
9	5	40	127	60	60	0.292	0.661	0.708609	0.105769	0.631799	0.358621
10	10	10	125	60	40	0.091	0.59	0.043046	0.447115	0.343182	0.474886
11	10	10	125	60	50	0.231	0.613	0.506623	0.336538	0.503333	0.429752
12	10	10	125	60	60	0.298	0.596	0.728477	0.418269	0.648069	0.462222
13	10	20	127	50	40	0.098	0.614	0.066225	0.331731	0.34873	0.427984
14	10	20	127	50	50	0.238	0.637	0.529801	0.221154	0.515358	0.390977
15	10	20	127	50	60	0.306	0.619	0.754967	0.307692	0.671111	0.419355
16	10	40	123	55	40	0.115	0.568	0.122517	0.552885	0.362981	0.527919
17	10	40	123	55	50	0.246	0.597	0.556291	0.413462	0.529825	0.460177
18	10	40	123	55	60	0.316	0.565	0.788079	0.567308	0.702326	0.536082
19	15	10	127	55	40	0.125	0.475	0.155629	1	0.371921	1
20	15	10	127	55	50	0.256	0.497	0.589404	0.894231	0.549091	0.825397
21	15	10	127	55	60	0.327	0.479	0.824503	0.980769	0.740196	0.962963
22	15	20	123	60	40	0.142	0.568	0.211921	0.552885	0.388175	0.527919
23	15	20	123	60	50	0.272	0.591	0.642384	0.442308	0.583012	0.472727
24	15	20	123	60	60	0.341	0.576	0.870861	0.514423	0.794737	0.507317
25	15	40	125	50	40	0.175	0.603	0.321192	0.384615	0.424157	0.448276
26	15	40	125	50	50	0.31	0.621	0.768212	0.298077	0.683258	0.416
27	15	40	125	50	60	0.38	0.598	1	0.408654	1	0.45815

4. CONFIRMATION TEST

Confirmation experiments were conducted with a new optimal parameter as shown in table.8. The combination level for Material Removal rate and surface Roughness is A3, B3, C2, D1, E3 and A1, B3, C3, D3, E1. The result of the confirmation experiment is obtained for Material removal rate in mm/min and for surface roughness in µm.

Table.8 confirmation result of MRR and R_a

Exp. No	Volume Fraction A	ReinSize B	Pulse On C	Pulse Off D	Wire feed E	Experimental Setup		Predicted value		Prediction Error	
						MRR	SR	MRR	SR	MRR	SR
Units	%	µm	µs	µs	mm/sec	mm/min	µm	mm/min	µm	mm/min	µm
1	15	40	125	50	60	0.380	0.598	0.376	0.600	1.05	0.33
2	5	40	127	60	40	0.087	0.671	0.096	0.661	9.38	1.49

5. CONCLUSION

The experiment has been done by choosing L_{27} orthogonal array in Taguchi experimental design. From the experimental result, ANOVA and S/N ratio for Material removal rate and Surface Roughness for optimum machining parameter has been discussed here,

1. Wire feed and Volume Fraction is the most affecting parameter which is important influencing the Material removal Rate (in rank order based on % contribution). The Reinforcement Size, Pulse On and Pulse Off time are the less influential parameter for Material Removal Rate.
2. According to our proposed level for maximum Material Removal Rate can be achieved by selecting the best combination level is **A3, B3, C2, D1, E3** (larger-is-better) i.e., volume fraction 15%, Size 40µm, Pulse On 125µs, Pulse Off 50µs and Wire feed 60mm/sec.
3. Pulse Off time and Reinforcement Size is the most affecting parameter which is important influencing the Surface Roughness (in rank order based on % contribution). The Volume Fraction, Pulse On and Wire feed are the less influential parameter for Surface Roughness
4. According to our proposed level for minimum Surface Roughness can be achieved by selecting the best combination level is **A1, B1, C1, D1, E1** (smaller-is-better) i.e., volume fraction 5%, size 10µm, pulse on 123µs, pulse off 50µs and wire feed 40mm/sec.
5. Confirmation experiments were conducted with a new optimal setting parameter for Material removal Rate and Surface Roughness with best combination parameter is **A3**, **B3, C2, D1, E3** and **A1, B3, C3, D3, E1** and having prediction error for **MRR** and $\mathbf{R_a}$ is **1.05** and **1.49.**

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