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Multi Response Optimization of Electric Discharge Machining (EDM) Parameters for Machining Hybrid Aluminum Metal Matrix Composite using Grey Relation Analysis (GRA)

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ABSTRACT

EDM is a non-traditional machining process which is used to machine very hard, difficult to machine materials. It possess the ability to create complex internal shapes and deep holes by using precisely controlled sparks that occur between an electrode and work piece in the presence of dielectric fluid. The study is focused on EDM of hybrid Aluminum metal matrix composite fabricated by stir casting method, having diverse engineering applications in the field of machining. The effect of machining parameters namely pulse-on time, pulse-off time, gap voltage and peak current on three responses viz. Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) is investigated by carrying out scientifically designed experiments planned by L18 array. Grey relation analysis (GRA) is employed to optimize the multi-optimal characteristics and to find out the optimum combination of process parameters for optimal values of MRR, TWR and SR.

Keywords EDM (electric discharge machining); Al MMC (Aluminum metal matrix composite); GRA (Grey Relation Analysis); MRR (Material Removal Rate); TWR (Tool Wear Rate); SR (Surface Roughness)

1. INTRODUCTION

Convectional monolithic materials have some limitation such as low strength, stiffness, toughness and density. To overcome these limitations and fulfill the demands of modern industry for high strength, power to weight ratio and high toughness, composites are the most promising materials. Metal matrix composites (MMC) have proven to be possess of improved properties such as high specific strength, good damping capacity and wear resistance and high specific modulus as compared to unreinforced alloys. In the present work a particulate reinforced hybrid aluminum metal matrix composite is developed by using Silicon Carbide particles (SiCp) and Graphite particles (Grp) as reinforcement into conventional Al6061 alloy. This hybrid composite is prepared by stir casting method. The developed sample, because of high hardness and brittleness of SiCp is difficult to machine by traditional machining methods. Hence, the nontraditional machining methods are employed to machine the materials.

EDM is used in many manufacturing industries due to its ability to machine any electric conductive material. In EDM, the electric spark is generated to erode the metal from the work piece. In EDM process, it is necessary that both work piece material and electrode material must be conductors of electricity. Complex shape dies and molds can be easily produced within faster time and lower costs by EDM. The aim of this study is to investigate the effect on EDM responses, MRR, TWR and SR as a function of already stated process parameters and to find the significant parameters affecting the EDM responses. This experimental work is carried out by two different electrode materials i.e. copper and brass of Ø12.5 mm each. Grey relation analysis (GRA) is employed to find the optimal combination of the process parameters.

2. PAST WORK

Many researchers have carried out their theoretical and experimental studies on the EDM of advance materials. Literature also proved that EDM is an effective technique for machining the MMC.

Kumar et al. [2012] explained that a composite material mainly consisting two distinct phases and a composite has a superior characteristics more than individual materials. Aluminum based MMC has gained lot of popularity in all the engineering fields due to their improved properties. James et al. [2014] prepared a hybrid aluminum-based metal matrix composite by stir casting technique and examined its mechanical properties. The hardness test and the tensile test revealed that the addition of reinforcement SiC and TiB2 directly affected the hardness and strength respectively. Adnan [2012] investigated both conventional and non-conventional machining process to machine Al 6061 MMC. He resolved that the surface roughness and material removal rate are directly affected by the process of machining. Wen Li et al. [2015] concluded that EDM is an energy efficiency manufacturing process. He investigated that the empirical approach is a well establish technique to characterize the energy efficiency of EDM process and predict the energy consumption of EDM processes with an accuracy of more than 90 % by combined empirical models. Tiwari et al. [2014] performed an experimental work on EDM to find out the optimum combination of process parameters with GRA approach. The standard L9 orthogonal array was used to perform the experiments. By varying the EDM process parameters authors achieved the optimal value of MRR and TWR. Garg et al. [2014] investigate optimization of WEDM parameters by ANOVA and F-Test. Talla et al. [2014] investigate the multi-response optimization in powder mixed EDM of Al MMC. The effect of process parameters was measured in terms of MRR and SR. Grey relation analysis (GRA) approach was used for multi-response optimization. Sabur et al. [2014] performed an experimental work on EDM to examine the material removal characteristics of non-conductive ZrO2 ceramic. Due to the high hardness and brittleness of ZrO2, it was difficult to machine by traditional methods so they used EDM for material removal. Singh [2012] applied the GRA approach to optimize the process parameters during the EDM of Al MMC. The final design matrix was conducted by L18 orthogonal array approach. ANOVA is also implemented with GRA for analysis the performance.

3. EXPERIMENTAL DETAIL

3.1 Fabrication of Al (SiC_p + Gr_p) MMC

Literature reports metal mainly three processing techniques; 1) solid, 2) liquid and 3) powder processing techniques. In this study hybrid aluminum-based metal matrix composite is developed by using stir-casting method, one of the liquid metal processing techniques. Silicon carbide and Graphite particles with average particle size of 74µm (200 mesh) in weight percentage of 12% and 4% reinforced into Al6061 to develop the work piece. The fabricated sample is shown in figure.1. First of all the Aluminum 6061 was melted in graphite crucible placed in a vertical muffle furnace by increasing its temperature up to 720°C. The reinforcements (Silicon carbide and graphite) were preheated to 700°C into another muffle furnace for one hour to remove the moisture.

Figure.1 Prepared sample of hybrid Al MMC

The preheated reinforcements were then added into melted aluminum with constant stirring using motorized stirrer. Stirring was continued for a period of 30 min. After the proper mixing of materials the molten metal was poured into preheated cast iron mould. The solidification of molten metal took place by placing the mould at room temperature.

3.2 Machining of Al (SiC_p + Gr_p) MMC

All the experiments were performed on Oscar Max EDM machine (Taiwan made) shown in Figure.2. EDM oil is used as the dielectric fluid (specific gravity – 0.763). Both work piece and tool remain immersed in dielectric and it also sprinkled between the gap of work piece Al (SiCp + Grp) and tool (Cu & Brass), shown in figure.3. The fabricated Al (SiCp + Grp) samples and commercial brass and copper of Ø12.5 each was used as a work piece and electrode materials respectively. The chosen process parameters, Pulse-on time (T-on), pulse-off time (T-off), Gap voltage (V) and Peak current (Ip) are varied according to the plan of experiments suggested by Taguchi Orthogonal array L18 result of analysis are analyzed by using Minitab 17 software. The machine process parameters and their levels are given in table.1.

Figure.2 EDM machine

Figure.3 W/p and tool setup

Table.1 Process parameters and their levels

Parameter	Symbol/unit	Levels		
		Level 1	Level 2	Level 3
Tool	T	0 (brass)	1 (copper)	-
Pulse-on time	T-on/mu	30	60	90
Pulse-off time	T-off/mu	30	60	90
Gap voltage	V/V	6	7	8
Peak current	I_p/amp	10	12	14

3.3 Measurement of responses

By varying the levels of selected process parameters as per plan of L18 array, the performance of the process is analyzed in the form of three responses; 1) MRR, 2) TWR and 3) SR. To determine the MRR and TWR, the weight difference of work piece and tool electrode, before and after the machining was calculated respectively using high precision weighing machine (model PGB 200), shown in figure.4. The machining time of each trial was continuously displayed by machine control unit automatically. The equation.1 and equation 2 are used to calculate the MRR and TWR respectively.

$MRR = \frac{(Wb - Wa)}{T}$ …………… (1)

Where W_{am} – work piece weight after machining, W_{bm} – work piece weight before machining and T_m – machining time.

$TWR = \frac{(Tb - Ta)}{T}$ …………… (2)

Where T_{am} – tool/electrode weight after machining, T_{bm} – tool/electrode weight before machining and T_m – machining time.

Roughness is measurement of vertical deviations of a machined surface. If the calculated deviation is high, then the surface is rough; if low, then the surface is smooth. An Insize surface roughness tester model ISR-S400 shown in figure.5 was used to determine the surface roughness of every machined hole. The result of experiments conducted as per plan of Taguchi L18 array are presented in table.2.

Figure.4 Weighing machine

Figure.5 Surface roughness tester

Table.2 Design matrix with responses

Expt.No	Tool	T-on	T-off	V	C	MRR	TWR	SR
1	0	30	30	6	10	1.87	0.12	3.59
2	0	30	60	7	12	1.39	0.1	3.58
3	0	30	90	8	14	1.33	0.16	3.73
4	0	60	30	6	12	1.96	0.14	3.71
5	0	60	60	7	14	1.21	0.04	3.21
6	0	60	90	8	10	1.47	0.1	3.35
7	0	90	30	7	10	2.16	0.14	4.56
8	0	90	60	8	12	2.24	0.12	3.78
9	0	90	90	6	14	1.66	0.12	3.96
10	1	30	30	8	14	2.83	0.12	4.29
11	1	30	60	6	10	1.38	0.06	3.45
12	1	30	90	7	12	1.24	0.06	3.98
13	1	60	30	7	14	1.94	0.09	5.03
14	1	60	60	8	10	1.58	0.096	4.74
15	1	60	90	6	12	1.29	0.06	4.61
16	1	90	30	8	12	2.77	0.03	4.05
17	1	90	60	6	14	1.84	0.03	4.44
18	1	90	90	7	10	1.48	0.05	4.49

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4. OPTIMIZATION USING GRA (GREY RELATION ANALYSIS)

Grey system theory (GST) invented by Deng in 1982. GST is a approach to solve the certain problem of systems which are complex and multivariate. Mainly there are three types of system 1) White, 2) Black and 3) Grey. A system which has complete relevant information is known as "white" system while a system which has uncompleted relevant information is known as "black" system and if any system between these limits that is "grey" system; its mean that a system has a poor and limited information. So the grey theory was developed in which small data sets are used for analysis of such system. GRA (grey relation analysis) is a traditional statistical method which is used to optimize the multiple quality/response characteristics. In many cases, machining parameters cannot be set only for one response, as the objective is to minimize some responses and maximize some responses simultaneously. In this present study, GRA is used for multi-response optimization of EDM process parameters.4.1.1 Grey relation normalization

"Larger the better" (LTB) or "Smaller the better" (STB) condition is chosen for each response based on desire objective. For this experiment "LTB" was chose for MRR and "STB" was chose for both TWR and SR.

4.1.1 LTB normalization equation:

$$Y\ (k) = \frac{X\ (k) - \mathrm{m}\quad X\ (k)}{\mathrm{m}\quad X\ (k) - \mathrm{m}\quad X\ (k)} \qquad \ldots\ldots\ldots\ldots.. (3)$$

STB normalization equation:

$$Y\ (k) = \frac{\mathrm{m}\quad X\ (k) - X\ (k)}{\mathrm{m}\quad X\ (k) - \mathrm{m}\quad X\ (k)} \qquad \ldots\ldots\ldots\ldots.. (4)$$

Where Y_i (k) is i^{th} normalized response value and X_i (k) is the observed for the i^{th} run of the k^{th} response.

4.1.2 Grey relation coefficient (GRC)

Grey relation coefficient is calculated to represent the relationship between the actual and normalized data. The grey relation coefficient $£_I$ (k) can be calculated as

$$£i(k) = \frac{\Delta\mathrm{m}\quad + \mu\,\Delta\,\mathrm{m}}{\Delta o\ \ (k) + \mu\,\Delta\,m} \qquad \ldots\ldots\ldots.. (5)$$

Where $\Delta_{min}$and Δ_{max} are the global minimum and maximum values of normalized values respectively of k^{th} response. Here μ is identification coefficient $0 \le \mu \le 1$ and its value is taken as 0.5.

4.1.3 Grey relation grade (GRG)

Grey relation grade is used to evaluate the performance of the multi response. It is the weighted summation of the entire grey relation coefficient (GRC), and it is calculated by using following equation

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} £i\ (k) \qquad \ldots\ldots\ldots\ldots\ldots (6)$$

5. EXPERIMENTAL RESULT AND DISCUSSION

Table.3 shows the normalized data of the MRR, TWRand SR. For MRR the value of min y_i (k) is 1.21 milg/sec and max y_i (k) is 2.83 milg/sec. For TWR the value of min y_i (k) is 0.03 milg/sec and max y_i (k) is 0.16 milg/sec and for SR the value of min y_i (k) is 3.21µm and max y_i (k) is 4.74 µm.

Table.3 Normalized data

Expt.No	Normalization		
	MRR	**TWR**	**SR**
1	0.407407	0.307692	0.810458
2	0.111111	0.461538	0.75817
3	0.074074	0	0.660131
4	0.462963	0.153846	0.673203
5	0	0.923077	1

6	0.160494	0.461538	0.908497
7	0.58642	0.153846	0.117647
8	0.635802	0.307692	0.627451
9	0.277778	0.307692	0.509804
10	1	0.307692	0.294118
11	0.104938	0.769231	0.843137
12	0.018519	0.769231	0.496732
13	0.450617	0.538462	-0.18954
14	0.228395	0.492308	0
15	0.049383	0.769231	0.084967
16	0.962963	1	0.189542
17	0.388889	1	0.196078
18	0.166667	0.846154	0.163399

Table.4 shows the grey relation coefficient (GRC) of each performance characteristics. For MRR, TWR and SR the value of Δ_{min} and Δ_{max} is 0 and 1 respectively.

Table.4 Grey relation coefficient (GRC) of each performance characteristics (μ = 0.5)

Expt.No	Grey relation coefficient (GRC)		
	MRR	**TWR**	**SR**
1	0.457627	0.419355	0.725118
2	0.36	0.481481	0.674009
3	0.350649	0.333333	0.595331
4	0.482143	0.371429	0.604743
5	0.333333	0.866667	1
6	0.373272	0.481481	0.845304
7	0.547297	0.371429	0.361702
8	0.578571	0.419355	0.573034
9	0.409091	0.419355	0.50495
10	1	0.419355	0.414634
11	0.358407	0.684211	0.761194
12	0.3375	0.684211	0.498371
13	0.476471	0.52	0.295938
14	0.393204	0.496183	0.333333
15	0.344681	0.684211	0.353349
16	0.931034	1	0.381546
17	0.45	1	0.383459
18	0.375	0.764706	0.374083

Table.5 shows the overall grey relation grade (GRG). There are three process responses MRR, TWR and SR so the value of n to be consider as 3 in this experiment.

Table.5 Overall grey relation grade (GRA)

Expt.no	Grey relation grade (GRG)	Rank
1	0.534033	7
2	0.505163	10
3	0.426438	17
4	0.486105	12
5	0.733333	2
6	0.566686	6
7	0.426809	16
8	0.523653	8
9	0.444465	14
10	0.61133	4
11	0.601271	3
12	0.506694	9
13	0.430803	15
14	0.407573	18
15	0.460747	13
16	0.77086	1
17	0.611153	5
18	0.504596	11

Table.5 clearly display that Expt.no -16 gives the highest value of overall grey relation grade (GRG). So the initial parameters setting based on highest value of GRG is T2, T-on3, T-off1, V3, & Ip2.

6. ANALYSIS OF RESULT

ANOVA (analysis of variance) is carried out to analyze the optimum combination of process parameters for multi response characteristics. ANOVA is given in following table.6. From the table it can be analyze that the model is significant.

Table.6 ANOVA for Means

Source	DF	Seq SS	Adj MS	F
tool	1	0.003708	0.003708	0.20
on	2	0.003211	0.001606	0.09
off	2	0.020052	0.010026	0.5552
v	2	0.003837	0.001918	0.11
c	2	0.005109	0.002555	0.14
Residual Error	8	0.145162	0.018145	
Total	17	0.181079		

Figure.6 shows the main effect plot for GRG. The maximum GRG values were observed at tool 1 (copper), T-on of 90µm, T-off of 60µm, Voltage of 8v and I_p of 12amp, the combination of these process parameters values give the optimum results for multi response characteristics.

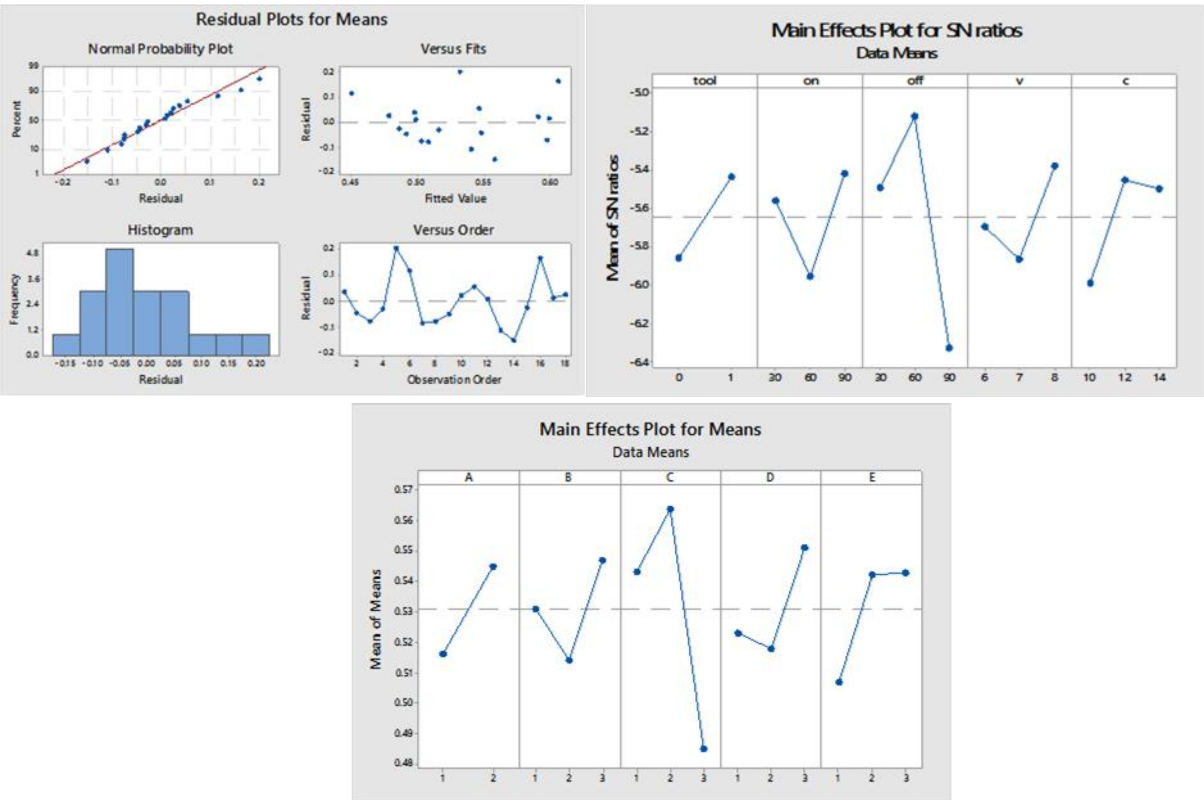

Figure.6 Main effect plot for GRG

7. CONCLUSION

In this experimental work the GRA approach, based on scientifically designed experiments planned by L18 arrayhas been proposed to investigate multi-response optimization. The GRA approach easily converts the optimization of multiple response characteristics into GRG. The GRG simplify the complicated analysis of multiple performance/response characteristics. Following are some of the conclusions were drawn.

1) It confirmed that “pulse-off time” (T-off) contributes more significantly towards MRR, TWR and SR, followed by peak current (Ip), pulse-on time (T-on), gap voltage (v) and tool.

2) This study shows that GRA approach could be successfullyapplied to other machiningoperations in which measurement ofperformance is determined by many process factors at multiple quality requests.

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