OPEN ACCESS

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Parametric Optimization of EDM Process for Hybrid Metal Matrix using GRA Method

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Abstract**:** ***Metal matrix composites (MMC's) have evolved an extreme attention in current era for their superior applications in aerospace, defence and automobile industries. Metal matrix composites are found as current materials, possessing the characteristics of light in weight, greater wear resistance & superior specific strength. Due to presents of high hardened reinforcement strength, composite materials are very difficult to do machining by traditional techniques. Therefore unconventional machining like Electrical Discharge Machining becomes feasible method to these kinds of composite materials. EDM process does not require any mechanical energy because there is no direct contact between tool and workpiece. So there no influence of superior material properties like hardness, strength, toughness etc in machining hybrid metal matrix composite.***

In the present paper , an analysis is carried out to evaluate the influence of input parameters such as peak current (I), tool lift (TL), pulse off time (T off) and pulse on time (Ton) on the machining of 90%-Al(6061)-3 weight % silicon carbide (SiC)-7 weight % boron carbide (B_4C) hybrid metal matrix composite through electrical discharge machining. The individual parameters were analyzed with an objective to minimize tool wear ratio (TWR) and to maximize the material removal rate (MRR). The grey relation grade (GRG) for Electric discharge machining is obtained by using taghuchi based grey relation analysis (GRA) method with multiple response parameters like MRR and TWR. The ANOVA based GRA method is employed to find the significance of process parameters like Peak Current, Pulse on time, and Pulse off time and Tool lift.

Keywords: MRR, EWR, MMC, GRA, EDM.

I. INTRODUCTION

EDM uses electric energy, the dielectric breakdown with straight polarity between the tool and workpiece creates discharges between negative tool electrode and positive work piece which are submerged in dielectric fluid, the distance between tool and workpiece are maintained by a servo mechanism. As tool electrode approaches to a work piece, the electric filed between tool and work piece increases larger and larger and then it comes to a point where a spark occurs. This is known as the fluid-ionization point and it is based on the dielectric strength of the fluid. EDM to cause erosion process the electrode and work should be electrically conducting material. The discrete electrical discharges between tool and work piece will cause melting and evaporation of the material and produces a small cavitations on both tool and work piece. As there is no physical contact between tool and work piece so mechanical stresses, chatter and vibration problems are avoided. The flushing pressure of dielectric fluid will remove the debris's from tool and electrode

II. LITERATURE REVIEW

Garg et al (2010) investigated on MMC's which are recent advanced materials having outstanding mechanical properties used in aerospace, structural and automobiles industries. Aluminium alloy 6061 reinforced with B_4C ceramic particulate is difficult to machine in Traditional machining process due to possession of high hardened reinforcement in the composite. Hence, EDM process is the precise technique to machine these kinds of MMC's [1]. Akhil Sharma et al (2007) had observed the experimental study on machining of cast Al-MMC with 10% SiCp and outlined the effect of machining parameters like peak current (I), Arc on-time (P on), flushing pressure (P) on metal removal rate (MRR), tool wear rate (TWR), radial overcut (ROC) and surface roughness (Ra) in EDM process. The authors have considered L27 orthogonal array for experimentation. The relationship between machining parameters and response parameters has been indicated with a second order and non-linear mathematical model and also an ANOVA technique is employed to confirm the fit and satisfactoriness of the obtained mathematical models [2]. Mohan et al (2002) have studied the effect of EDM input parameters like peak current, tool material, polarity, pulse on time & electrode rotation on MRR, TWR & SR during machining on Al-SiC with 20-25% of SiC composite. The MRR was increased with increased discharge current and also concluded that higher speed of rotation electrode resulted in positive effect with TWR, MRR and good surface finish[3]. Narendar Singh et al (2004) had analyzed about the effect of machining parameters like peak current , duration of pulse & flushing pressure on TWR, MRR, ROC and SR of machining of Al-10% SiCp reinforced MMC with EDM.

Manuscript published on 30 September 2019
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Taghuchi L27 orthogonal array was used for experimentation. ANOVA was applied and the most favorable levels for maximizing the output parameters were established. Primarily current then pulse on time are influencing parameters on MRR. The TWR was found to be higher value than MRR at higher current value [4]. Suhant et al (2007) have examined the influence of peak current, voltage gap and pulse duration on MRR, ROC & TWR by EDM machining of a Al-4Cu-6Si alloy-10 wt% SiCp composites.

They have established the relationship between machining parameters and output parameters by a second order and non-linear mathematical model. ANOVA has been used to confirm the fit & satisfactoriness of developed models [5]. Rajesh & Dev Anand (2012) derived the multiple regression and modified genetic algorithm models in order to verify the optimal machining parameters in EDM. The effect of current, oil pressure, spark gap, voltage, pulse off time and pulse on time on MRR and SR have been examined. The empirical model for MRR and surface finish has been developed by conducting a design of experiment based on the grey relational analysis (GRA). Genetic algorithm has been used to attain the maximum MRR & minimum surface roughness [6]. K Raj kumar et al in 2014 studied the effect of EDM parameters on microwave heat treated Al-B4C-Graphite composites. EDM process parameters optimization was carried out using Taguchi design with input parameter such as peak current, pulse duration and pulse off for the MRR and TWR as response parameters. Microwave heat treated composite exhibited higher hardness than the conventionally heat treated composites. Arc off time and Arc duration time was a non-linear function for the MRR of the composite and the most influential parameters for the MRR were determined [7].

III. Experimental Work

The experimentations were conducted with various combinations to establish optimum parametric combinations that can be adopted by manufacturing industries. The electrode material is pure electrolytic copper (99.987%) of diameter 10 mm and density of 8.93 g/cm3. Dielectric fluid as commercial EDM oil (Rustlick grade 30) is used and it is circulated by jet flushing. The Electrode and work piece surfaces are polished to obtain the surface finish of approximately 1 µm using emery papers of very fine grade before conducting the experiments. The specifications of EDM are presented in table 1. Al 6061 alloy reinforced with 7 % of B4C and 3 % of SiC hybrid metal matrix composite was considered as a work piece. The straight polarity i.e., workpiece is connected to (+ve) positive polarity and tool is connected to (–ve) negative polarity is used for machining on EDM. In present investigation, experiments were designed and performed on the basis of Taghuchi L27 orthogonal array and are tabulated in table II.

Table I Specifications of EDM

Limit of -Table Loading	200 Kg
Work Tank –Dimension	600 x 390 x 275 mm
Table Dimension	350 x 250 mm
Dielectric Fluid	EDM 30 grade oil
Spark gap	0.025mm
Tool Material	Copper
Normal Current	25 Amp
Materials which can be machined	All conducting alloys and metals.
Limitations	Non conducting materials can't be machined

Table II Taghuchi design L27 orthogonal array

I	P On	P Off	T L	MRR (mg/min)	TWR (mg/min)
9	20	50	1.5	0.106	0.023
9	20	100	3	0.103	0.030
9	20	200	4.5	0.092	0.023
9	50	50	3	0.108	0.034
9	50	100	4.5	0.094	0.032
9	50	200	1.5	0.098	0.034
9	100	50	4.5	0.093	0.020
9	100	100	1.5	0.078	0.030
9	100	200	3	0.096	0.031
12	20	50	3	0.121	0.030
12	20	100	4.5	0.112	0.030
12	20	200	1.5	0.12	0.030
12	50	50	4.5	0.126	0.030
12	50	100	1.5	0.120	0.04
12	50	200	3	0.125	0.042
12	100	50	1.5	0.108	0.03
12	100	100	3	0.098	0.028
12	100	200	4.5	0.108	0.03
15	20	50	4.5	0.148	0.042
15	20	100	1.5	0.140	0.042
15	20	200	3	0.154	0.05
15	50	50	1.5	0.163	0.051
15	50	100	3	0.157	0.052
15	50	200	4.5	0.156	0.05
15	100	50	3	0.14	0.038
15	100	100	4.5	0.128	0.04
15	100	200	1.5	0.132	0.04

Retrieval Number: C5353098319/2019©BEIESP
DOI:10.35940/ijrte.C5353.098319
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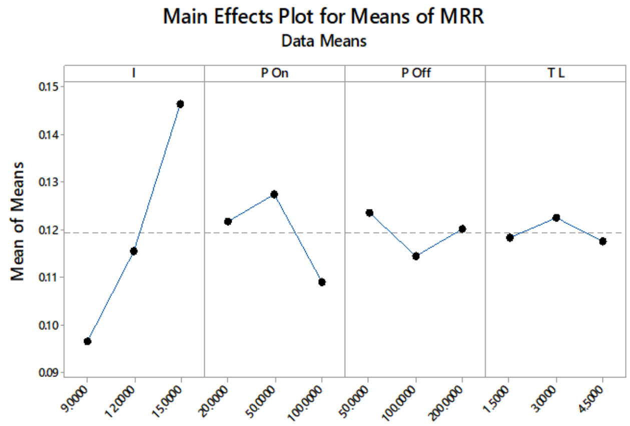

Fig. 1. Main effects plot for MRR

The main effects plot for MRR and TWR are shown in Figure 1 and figure 2.The Pareto Chart is shown in figure 3which describes the significant factors which influences the MRR

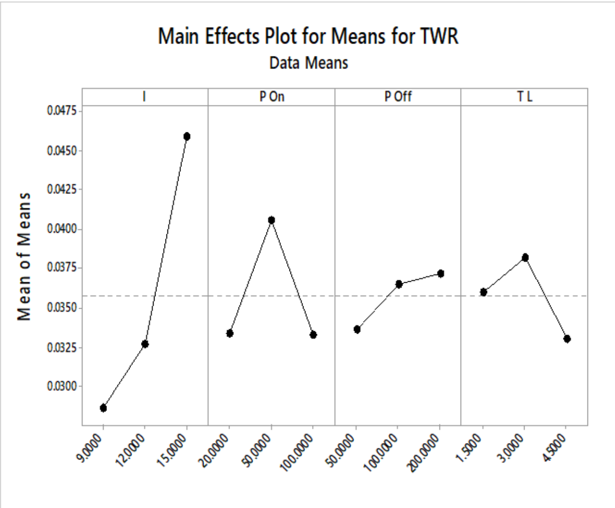

Fig. 2. Main effects plot for TWR

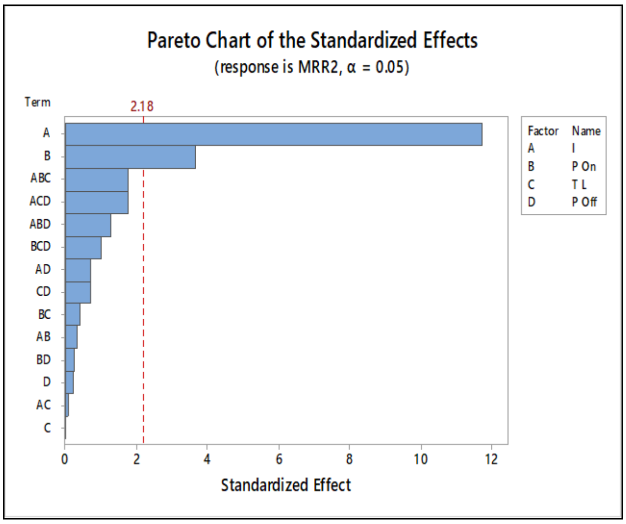

Fig. 3. Pareto Chart for MRR

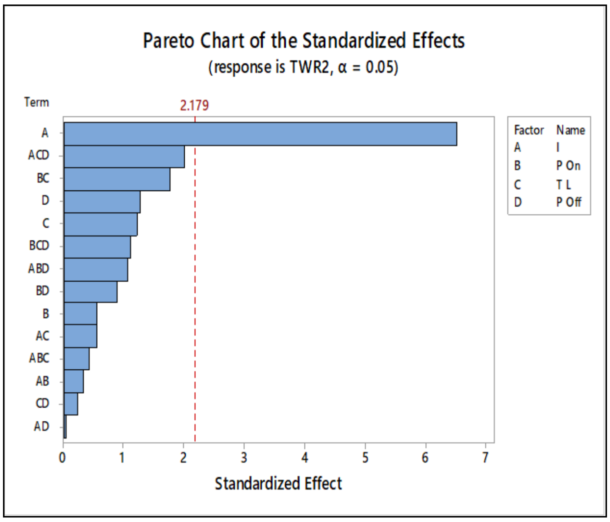

Fig. 4. Pareto Chart for TWR

IV. OPTIMIZATION BY GREY RELATION ANALYSIS

Grey relation analysis GRA is useful method in which analysis is being conducted among the ordered units requires that all the units should satisfy comparability conditions.

Table III Computing of GRC, GRG and Rank

Normalization		Grey relation coefficient		Grey relation grade (GRG)		avg GRG	Rank
MRR	TWR	MRR	TWR	MRR	TWR		
0.671	0.915	0.671	0.085	0.427	0.854	0.641	3
0.699	0.691	0.699	0.309	0.417	0.618	0.517	18
0.835	0.915	0.835	0.085	0.374	0.854	0.614	4
0.647	0.568	0.647	0.432	0.436	0.536	0.486	22
0.812	0.631	0.812	0.369	0.381	0.575	0.478	23
0.765	0.568	0.765	0.432	0.395	0.536	0.466	27
0.824	1.000	0.824	0.000	0.378	1.000	0.689	1
1.000	0.694	1.000	0.306	0.333	0.620	0.477	24
0.787	0.656	0.787	0.344	0.388	0.593	0.491	21
0.494	0.694	0.494	0.306	0.503	0.620	0.562	10
0.600	0.694	0.600	0.306	0.455	0.620	0.537	13
0.506	0.694	0.506	0.306	0.497	0.620	0.559	12
0.435	0.694	0.435	0.306	0.535	0.620	0.577	9
0.503	0.379	0.503	0.621	0.499	0.446	0.472	26
0.447	0.315	0.447	0.685	0.528	0.422	0.475	25

0.647	0.694	0.647	0.306	0.436	0.620	0.528	16
0.765	0.757	0.765	0.243	0.395	0.673	0.534	15
0.647	0.694	0.647	0.306	0.436	0.620	0.528	16
0.176	0.315	0.176	0.685	0.739	0.422	0.581	8
0.271	0.315	0.271	0.685	0.649	0.422	0.535	14
0.106	0.063	0.106	0.937	0.825	0.348	0.587	7
0.000	0.032	0.000	0.968	1.000	0.340	0.670	2
0.071	0.000	0.071	1.000	0.876	0.333	0.605	5
0.082	0.063	0.082	0.937	0.859	0.348	0.603	6
0.271	0.442	0.271	0.558	0.649	0.472	0.561	11
0.412	0.379	0.412	0.621	0.548	0.446	0.497	20
0.365	0.379	0.365	0.621	0.578	0.446	0.512	19

The first step in GRA is finding the normalized values for all the experimental data between the ranges of 0 to 1

For the MRR response characteristic of "larger the better" criteria the following normalization equation 1 is used:

$$xi^*(j) = \frac{xi(j) - \min xi(j)}{\max xi - \min xi(j)} \quad (1)$$

For TWR response characteristic "lower the better" criteria the following normalized equation 2 is used:

$$xi^*(j) = \frac{\max xi(j) - xi(j)}{\max xi - \min xi(j)} \quad (2)$$

Where xi*(j) and xi (j) are the normalized data and experimental data for i^{th} experiment using j^{th} response.

After normalizing the response characteristics, the next step is to find the grey relation coefficient (GRC). GRC is denoted by for j^{th} response and it can be determined by the equation 3.

$$\zeta i(j) = \frac{\Delta \min + \zeta \Delta \max}{\Delta i(j) + \zeta \Delta \max} \quad (3)$$

Where Δi(j) is the absolute value of difference between the $xi^0(j)$ and xi*(j) and $\Delta i(k) = |xi^*(j) - xi^{\circ}(j)|$. Δ max & Δ min are the global maximum and minimum values in different data units respectively. The distinctive coefficient lies in between the range of 0 and 1, which is to expand or compress the range of GRC, in general ζ=0.5 is considered.

For MRR Response characteristic of "larger the better" criteria is used and values after normalization by using equation, are tabulated in table III.

TWR response characteristic of 'lower-the-better' principle is selected. Therefore, the output values after normalization by using Eq. (2) are tabulated in table III.

GRCs Grey Relation Coefficients for each and individual responses are calculated by using Eq. (3) and they are tabulated in table III. Table III shows the normalized data and grey relational coefficients GRC, grey relation grade GRG and rank to each experiment run.

To identify the performance of a group of parameters ANOVA is generally used. The interpretations of experimental outcomes were carried out by using a standard statistical ANOVA technique. ANOVA Table is shown in table IV to analyze the influence of parameters whose combination of levels to total variations is significant.

Table IV ANOVA table

Source	DF	Seq SS	Adj SS	Adj Ms	F	P
I	2	0.008758	0.00875	0.004379	1.47	8.8%
P On	2	0.007062	0.00706	0.003531	1.19	7.1%
P Off	2	0.02439	0.02439	0.012195	4.11	24.6%
TL	2	0.0053	0.0053	0.00265	0.89	0.427
Residual	18	0.05347	0.05347	0.002971		
Total	26	0.098981				

The ANOVA analysis in Table IV and % contribution of each term which influences the grey relational grade indicates that the Pulse off time shows a significant on multiple performance due to more time of pulse off the debris or removed material form tool and workpiece can be flushed sufficiently by dielectric fluid then after Peak current and Pulse duration time have prominent effect on multiple performance characteristics. Based on the above discussion, the optimal process parameters in EDM are Pulse current (15Amps) at level 3, Pulse on time (50 µs) at level 1, Pulse Off time (50 µs) at level 1 and Tool lift at (4.5 µs) at level 3.

Table V Response Table for Means of GRG

Level	1	2	3	Delta	Rank
I	0.5399	0.5302	0.5723*	0.0421	2
P On	0.5703*	0.5369	0.5352	0.0351	3
P Off	0.5883*	0.5169	0.5372	0.0714	1
TL	0.54	0.5353	0.5671*	0.0318	4
Mean GRG =0.5480					

Retrieval Number: C5353098319/2019©BEIESP
DOI:10.35940/ijrte.C5353.098319
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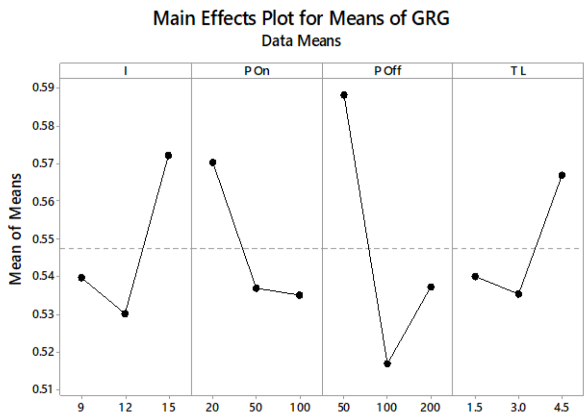

Fig. 5.Means for Grey Relation grade

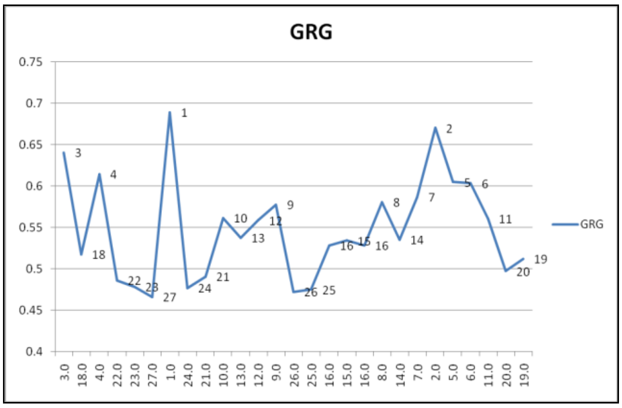

Fig. 6.Grey Relation grades for Multi-performance

Table VI Results of confirmatory experiment

Responses	**Optimal Machining parameters (A3B1C1D3) I=15Amp; P on=20µs; P off=50µs; TL=4.5µs**	
Setting Level	Predicted Value	Experimental Value
Metal Removal rate (MRR)	0.151070	0.148
Tool wear rate (TWR)	0.0386778	0.042
Grey relation grade (GRG)	0.655695	0.580681

The optimal EDM process parameter obtained from the Taguchi L 27 orthogonal array from the experiments wasA3B1C1D3 (Peak current at 15 Amps, Pulse on time at 50 µs, Pulse Off time at 50 µs and 5 Tool lift at 4.5 µs), which is utilized to predict the grey relation that represents the EDM of Al-MMC quality. The prediction of the grey relation αp predicted of the EDM parameters and it can be expressed as:

$$\alpha p = \alpha \cdot m + \sum_{i=1}^{q} (\alpha \cdot o - \alpha \cdot m) \quad (4)$$

Where

- α.m is mean of GRGs all experimental runs,
- α.o mean of GRG at the optimum level of i^{th} parameter
- q is the number of machining parameters that significantly affect GRG

V. CONCLUSION

In present work, Taghuchi Orthogonal L27 array with GRA was employed for multi-objective optimization of performance characteristics viz., material removal rate & tool wear rate. It is observed that the influence of each process parameter in sequence are Pulse off Time, due to more pulse off time will remove the debris or eroded material form tool and workpiece can be flushed sufficiently by dielectric fluid. Then peak current and then after pulse On Time is most significant factor which was found from response table V. The most favorable combination of input parameters was achieved by using GRA. Results were validated by conducting experiments at optimal process parametric settings. Further, the comparison was made between the predicted and achieved values and realized that predicted values are in good agreement with experimental results

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