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Optimization of Silicon Carbide (SiC) Nano Powdered EDM Process of Inconel 625

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***Abstract*: Electric discharge machining (EDM) is commonly used process for machining of Inconel 625. To enhance the performance of EDM process researchers are using various methods. Among them addition of Nano powders to the dielectric medium is used for enhancing the performance of EDM. There are several types of Nano powders namely aluminum, graphite, copper and silicon carbide (SiC). SiC is commonly used Nano powder in the dielectric medium to enhance the performance of EDM because of its high thermal conductivity. In this dissertation work, various concentrations of Nano powders in dielectric medium of EDM process is carried out on Inconel 625. In addition to Sic, parameters like peak current, pulse on time and pulse off time also varied. Material removal rate (MRR) and surface roughness (Ra) are considered as performance measures. Using grey relational analysis selected parameters are optimized for maximum MRR and minimum surface roughness. Optimum values of these parameters are found to be powder concentration = 3g/6liters, peak current = 15 A, pulse on time = 5 µm and pulse off time = 4 µm. At these values there is improvement of MRR = 143 % compared to EDM process without Nano powder in dielectric medium. ANOVA is also carried out to find out the influence of each parameter on MRR and surface roughness. It is observed that powder concentration and peak current are significant parameters compared to pulse on time and pulse off time on MRR and surface roughness.**

***Keywords*: Analysis of variance (ANOVA), Electric discharge machining, Grey relation analysis, Inconel 625 alloy, Material removal rate, Silicon carbide Nano powder, Surface roughness.**

1. Introduction

Electric discharge machining (EDM) process is commonly used process for Inconel alloy 625. In any typical EDM process material is removed from work piece by spark erosion. The working system is illustrated in below Fig. 1. The work piece and tool (anode and cathode respectively) are two electrodes connected by D.C pulse generator.Built-up of a suitable voltage across tool and work-piece causes cold emission of electrons from the cathode. A spark generates due to avalanche of electrons. Very high temperature is developed which induces melting and evaporation of both the electrode and work piece. Copper rod acts as electrode and dielectric medium as water or oil. To improve the performance of EDM process, in particularly material removal rate and surface finish, Nano powders namely graphite, aluminum, copper and silicon carbide (SiC) are commonly added to the dielectric medium.

Among them SiC is widely used Nano powder because of its high thermal conductivity. Sic Nano powder with average particle size 50-200 nm, as claimed by NANO WINGS PRIVATE LIMITED, was utilized in the current work.

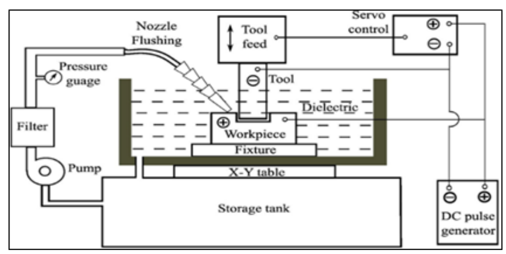

Fig. 1. A typical EDM set up

2. Experimental details

A. Development of experimental set up

Experiments are performed on Electronica make smart ZNC EDM machine. The working tank of ZNC machine has the dimensions of 800 mm x 500 mm x 350 mm. It needs a more amount of Nano powder for mixing in such a large tank. Also clogging takes place when Nano powder in dielectric is filtered with the existing filtering system. To overcome these difficulties, a new tank, having volume of 8 liters has been chosen for conducting experiments. For the proper blending of powder with dielectric fluid and circulating the same in the spark gap, a submerged electric pump is placed in the new tank. Stirring system is employed in this tank to achieve a homogeneous dispersion of powder in the dielectric fluid. A permanent magnet is used in machining tank to separate the

Table 1
Chemical composition of Inconel alloy 625

	Cr	Mo	Co	Nb+Ta	Al	Ti	C	Fe	Mn	Si	P	S	Ni
Min	20	8	--	3.15	--	--	--	--	--	--	--	--	Balance
Max	23	10	1	4.15	0.4	0.4	0.1	5	0.5	0.5	0.015	0.015	Balance

debris from the dielectric fluid. The schematic representation of experimental setup as shown in Fig. 2. Inconel alloy 625 having the dimensions of 50 mm x 50 mm x5 mm is used for conducting the experiments. A hole of 8 mm diameter is machined on the work piece. The chemical composition of Inconel 625 is shown in Table 1.

B. Plan of experiments

The methodology of Taguchi for four factors at three levels is used for the implementation of the plan of experiments. Taguchi L9 orthogonal array is used to define the 9 trail conditions. The process parameters powder concentration (Cp), peak current (I), pulse on time (Ton), and pulse off time (Toff) are selected at 3 levels. These values are shown in the below Table 2. Each set of the nine experiments are performed two times and the average values are used for analysis. Table 3 shows the experimental layout and corresponding average results.

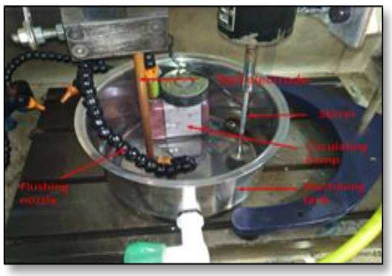

Fig. 2. Real picture of experimental setup

3. Determination of Optimum Machining Parameters

A. Grey relation analysis (GRA)

In many cases, process parameters cannot be set only for one response, as the objective would be to minimize some responses and maximize some responses simultaneously. Here there is a need for a multi response optimization. The multi response optimization first converts multiple objectives into a single response and optimizes it. In present work, GRA is used for the multi response optimization of powder mixed electric discharge machining (PMEDM) process.

B. Normalization of different responses:

'Higher the better (HTB)' or 'Lower the better (LBT)' condition is chosen for each response based on the desired objective. For this experiment HBT and LBT were chosen for MRR and SR respectively. For HTB, For LTB the equation of normalization is

$$y_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad y_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)}$$

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

C. Grey relation coefficient (GRC)

Grey relation coefficient ξ_i (k) is calculated by using the following equation

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta_i \Delta_{\max}}{\Delta_i(k) + \zeta_i \Delta_{\max}}$$

Where Δ_{min} and Δ_{max} are the global minimum and maximum values of normalized values respectively of the k^{th} response. ξ_i is the distinguished factor whose values lies between 0 and 1. Its purpose is to expand or compress the range of grey relation coefficient. In this experiment it is taken as 0.5.

D. Grey relation grade (GRG):

Performance of the multi response is evaluated by GRG. It is the weighted summation of all the GRC'S and it is calculated by the following expression.

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} \zeta_i(k)$$

Table 2
Process parameters and their levels

S.No.	Parameters	Symbols	Level -1	Level-2	Level-3	Units
1	Powder concentration	Cp	0	2	3	Gram/6 liters
2	Peak current	I_p	9	12	15	A
3	Pulse on time	T_{on}	4	5	6	μs
4	Pulse off time	T_{off}	4	5	6	μs

Table 3
Experimental layout using an L9 orthogonal array and corresponding results

S. No.	Cp (g/6 liters)	Peak current (A)	Pulse on time (μs)	Pulse off time (μs)	MRR (mm^3/sec)	Ra (μm)
1	0	9	4	4	0.255	7.4
2	0	12	5	5	0.430	10.2
3	0	15	6	6	0.474	12.7
4	2	9	5	6	0.268	6.2
5	2	12	6	4	0.540	8.3
6	2	15	4	5	0.535	9.4
7	3	9	4	5	0.334	5.8
8	3	12	6	6	0.565	9.7
9	3	15	5	4	0.621	8.1

Table 4
Evaluation of grey relational coefficient and grade values

	Normalized values		Grey relation coefficient ξi(k)		Grey relation Grade (GRG)
S. No.	MRR yi(k)	Ra yi(k)	MRR	Ra	
1	0.000	0.768	0.333	0.683	0.508
2	0.478	0.362	0.489	0.439	0.464
3	0.598	0.000	0.555	0.333	0.444
4	0.036	0.942	0.341	0.896	0.619
5	0.779	0.638	0.693	0.580	0.637
6	0.765	0.478	0.680	0.489	0.585
7	0.216	1.000	0.389	1.000	0.695
8	0.847	0.435	0.766	0.469	0.618
9	1.000	0.667	1.000	0.600	0.800
Mean value of GRG Υ_m = 0.596					

Table 5
Average response of Grey Relational Grade

	Average Grey relational grade					
S.no	Process parameters	Level 1	Level 2	Level 3	Max-Min	Rank
1	Powder concentration	0.472	0.613	0.704*	0.232	1
2	Peak current	0.607	0.573	0.609*	0.036	4
3	Pulse on time	0.596	0.627*	0.566	0.061	3
4	Pulse off time	0.648*	0.581	0.560	0.088	2

Table 6
Performance measures using initial and optimal machining parameters

		Initial machining parameters	Optimal machining parameters	
			Estimation	Experiment
S. No.	Setting level	$A_1B_1C_1D_1$	$A_3B_3C_2D_1$	$A_3B_3C_2D_1$
1	Surface roughness (R_a)	7.4	8.078	8.1
2	Material removal rate (MRR)	0.255	0.622	0.621
3	Grey relational grade	0.508	0.8	

n = number of response parameters, $\xi_i(k)$ is Grey relation coefficient, ϒ is the grey relation grade.

E. Average response (GRG) at each level of parameter

Response of factor D (Pulse off time) at level1, m_{D1} = $(GRG_1+GRG_5+GRG_9)/3$, Response of factor D (Pulse off time) at level2, $m_{D2} = (GRG_2+GRG_6+GRG_7)/3$, Response of factor D (Pulse off time) at level3, m_{D3} = $(GRG_3+GRG_4+GRG8)/3$ .Similarly, we can find out the other factors average response (GRG) at each level. These Average GRG values are shown in below Table 5.

The optimal level of each factor can be selected from average response of GRG which has the highest value. From the Table 5 the optimal combinations of the process parameter levels are $A_3B_3C_2D_1$i.e. powder concentration (A) at level 3 = 3 g/ 6 liters, peak current (B) at level 3 = 15 amps, pulse on time (C) at level 2 = 5 µs and pulse off time at level 1 = 4 µs

F. Confirmation Experiment

Once the optimal level of machining parameters is selected, the last step is to predict and verify the improvement of the performance characteristics using the optimal level of machining parameters. The estimated grey relation grade Υ_e, the estimated surface roughness $(R_a)_e$, and the estimated MRR_e using the optimum level of the machining parameters can be calculated by $\Upsilon_e = \Upsilon_m + \sum_{i=1}^{q}(\Upsilon_j - \Upsilon_m)$, $(R_a)_e = (R_a)_m + \sum_{i=1}^{q}[(R_a)_j - (R_a)_m]$, $MRR_e = MRR_m + \sum_{i=1}^{q}(MRR_j - MRR_m)$ Where Υ_m is the total mean of the grey relation grade, Υ_j is the mean of the grey relation grade at the optimum level and q is the number of machining parameters that significantly affects the multiple performance characteristics.

4. Analysis of Variance (ANOVA)

ANOVA is carried out to study the influence of each parameter on selected performance measures MRR, and

Table 7
Analysis of variance (ANOVA) for MRR

S. No.	Source	DF	S_{eq} SS	Contribution	Adj MS	F-Value
1	Powder Concentration (gram/6litres)	2	0.021723	15.16%	0.010861	*
2	Peak current (amps)	2	0.118471	82.68%	0.059235	*
3	Pulse on time (micro seconds)	2	0.000243	0.17%	0.000121	*
4	Pulse off (micro seconds)	2	0.002848	1.99%	0.001424	*
5	Error	0	*	*	*	
6	Total	8	0.143285	100.00%		

Table 8
Analysis of variance (ANOVA) for R_a

S. No.	Source	DF	S_{eq} SS	Contribution	Adj MS	F-Value
1	Powder Concentration (gram/6litres)	2	9.549	26.10%	4.7744	*
2	Peak current (amps)	2	22.009	60.16%	11.0044	*
3	Pulse on time (micro seconds)	2	1.042	2.85%	0.5211	*
4	Pulse off (micro seconds)	2	3.982	10.89%	1.9911	*
5	Error	0	*	*	*	
6	Total	8	36.582	100.00%		

Surface Roughness. ANOVA for MRR and Surface roughness are generated by using MINITAB 18 and it is shown in Table 7 and Table 8.

5. Conclusion

It has been established that grey relational analysis is an effective optimization tool for machining of Inconel 625 in SiC Nano powder mixed in EDM. It has been also found that the optimal combinations of the process parameter levels are $A_3B_3C_2D_1$ i.e. powder concentration (A) at level 3 = 3 g/ 6 liters, peak current (B) at level 3 = 15 amps, pulse on time (C) at level 2 = 5 µs and pulse off time at level 1 = 4 µs. Further it has been observed that there is improvement of MRR = 143 % and at the same time surface roughness is decreased from 12.7µm to 8.1µm compared to EDM process without Nano powder in dielectric medium. Analysis of variance shows that powder concentration and peak current are the most significant parameters for multiple performance characteristics.

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