Optimization of Process Parameters to Reduce Surface Roughness of Alumina Reinforced Aluminium Composite on EDM with Silicon and Kerosene Di-Electric Medium

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Abstract

The objective of this research study is to investigate the optimal Process parameters of Electric Discharge Machining on Alumina reinforced Aluminium composite work piece with copper as a tool electrode. The effect of various process parameters on machining performance is investigated in this study. The input parameters considered are impulse current, Pulse on time, Duty cycle and voltage gap are used for experimental work and their effect on Surface Roughness. The Response Surface method is used to formulate the experimental layout. ANOVA method is used to analysis the effect of input process Parameters on the machining characteristics and finds the optimal process parameters of Electric Discharge Machining. The results of the Present work reveal that proper selection of input parameters will play a significant role in Electric Discharge Machining.

Keywords: EDM, Surface Roughness, Alumina Reinforced Aluminium Composite.

1. Introduction

Electric discharge machining (EDM) is one of the most popular non-traditional material removal processes and has became a basic machining method for the manufacturing industries of aerospace, automotive, nuclear, medical and die-mold production [1]. The theory of the process was established by two Soviet scientists B.R. and N.I. Lazarenko in the middle of 1940s. They invented the relaxation circuit and a simple servo controller tool that helped to maintain the gap width between the tool and the work piece. This reduced arcing and made EDM machining more profitable and produced first EDM machine in 1950s. Major development of EDM was observed when computer numerical control systems were applied for the machine tool industry. Thus, the EDM process became automatic and unattended machining method. The process uses thermal energy to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium [3]. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. However, the melted material is flushed away incompletely and the remaining material resolidifies to form discharge craters. As a result, machined surface has micro cracks and pores caused by high temperature gradient which reduces surface finish quality. There have been many published

studies considering surface finish of machined materials by EDM. It was noticed that various machining parameters influenced surface roughness and setting possible combination of these parameters was difficult to produce optimum surface quality [2, 3 and 4].

The microstructure of MMC's indicates the homogenous mixture of the alumina in the composite. Surface roughness increases with the process variables except the speed, speed made adverse effect on surface roughness [5]. The performance of EDM on Alumina reinforced Aluminium composites are governed by a large number of interactive variables. The variables can be classified as electrical parameters, non-electrical parameters, electrode based parameters and work piece material based parameters. Review of literature revealed that among all the factors, discharge parameters such as discharge current, pulse-on time, and duty cycle and gap voltage have most significant influence on the EDM performance [6]. Therefore, it has been decided that these four factors be chosen for the present study.

In our experiment alumina particles reinforced metal matrix composites were casted in which 30% by weight alumina and remaining aluminium and could able to mix 8% by weight alumina in the final cast product. The dimension of workpiece was 30 mm x 30 mm x 10 mm.

Due to its structural integrity, Copper can produce very fine surface finishes, even without special polishing circuits. This same structural integrity also makes Copper electrodes highly resistant to DC arcing in poor flushing situations. Copper is frequently used to make female electrodes on a Wire EDM for subsequent use in reverse burning punches and cores in the Sinker EDM. The addition of 1-3% Tellurium to Copper improves its machine-ability to a level similar to brass, eliminating the "gummy" properties normally exhibited by Copper when it is machined.

Our study examined copper tool electrode and provided useful information the effects of machining parameters on surface roughness [8].

ANOVA is a computational technique that enables the estimation of the relative contribution of each of the control factor that makes to the overall measured responses and expresses it as a percentage. ANOVA uses a mathematical technique known as sum of squares to quantitatively examine the deviation of the control factor response average from the overall experimental mean responses, which is referred to as the variation between the control factors. The significance of the individual and interaction effects is quantified by comparing the variance between the control factors effects against the variance in the experiment data due to random experimental error. The variation of the data due to random experimental variability and interaction is referred to as the variation within the control factors that make up the experiment. This ratio is referred to as *F*-ratio and can be formed between the control factors effect variance (the mean square due to experimental error). The ANOVA process permits to gain insight into which factors have main effects, interaction effects, less significant and noise. This helps in deciding the factors that are most relevant for performing the desired analysis thereby enhancing product robustness. Based on the mean responses, response equations for all the target parameters are developed.

Required number of experiments was decided based on concept of response methodology. In addition to that, ANOVA for all response has also been conducted. Suresh et al [9] conducted experiments on the machining of MMCs using EDM. Multi response optimization was used to find the optimal set of parameters to speed up the machining of high strength aluminium metal matrix composite.

In the present paper examines the effects of pulsed current, pulse time, Duty cycle and Gap voltage on surface roughness in the Alumina reinforced Aluminium composite. The influence of the process parameters has been studied by conducting ANOVA. Further, the mathematical models developed have also been validated with the help of experimental tests cases.

2. Experimental Details

2.1 Material Used:

The Al_2O_3 reinforced Al composite was used, The range of particle size of alumina is 16-30 µm and average particle size is 25µm.The general properties of aluminium are non toxic, impervious, non magnetic, non sparking, easily machined, low density, corrosion resistant, electricity conductor, non-magnetic and malleable. The properties of 8% reinforcement of alumina composite material are as follows:

S.No.	Property	Range
1.	Hardness	113-115 HRB
2.	Tensile strength	110-117 MPa

Table 2.1:- Mechanical properties of 8% reinforcement of alumina composite material

2.1 Selection of process parameters

It is necessary to choose a reasonable set of factors to be varied in the experiment. The performance of EDM of Alumina reinforced Aluminium composites are governed by a large number of interactive variables. The variables can be classified as electrical parameters, non-electrical parameters, electrode based parameters and work piece material based parameters. Review of literature revealed that among all the factors, discharge parameters such as discharge current, pulse-on time, and duty cycle and gap voltage have most significant influence on the EDM performance. Therefore, it has been decided that these four factors be chosen for the present study.

The experiments have been conducted keeping the four factors at various levels. The range of each factor has been selected based on the review of past literature and preliminary experiments conducted by using one variable at a time approach. The range of the discharge current, pulse-on time, duty cycle and gap voltage have been selected as 3 to 7 A, 100 to 500 µs, 0.60 to 0.84 and 50 to 70 V respectively. When the current was kept below 3A, it was observed that MRR was insignificant and when current more than 7A was selected, it resulted in very rough surface necessitating the selection of the values at an intermediate. The range selected for the pulse-on time is commonly used in EDM process. The range selected for the duty cycle covers a wide range of duty cycle. Whereas the range of gap voltage selected is in accordance to that available on the machine used for the experimentation.

FACTORS	**RANGE**	**UNITS**
Discharge Current (I_P)	3, 4, 5, 6, 7	A
Pulse On Time (T_{on})	100, 200, 300, 400, 500	µs
Duty Cycle (DC)	0.60, 0.66, 0.72, 0.78, 0.84	DC
Gap Voltage (V_g)	50, 55, 60, 65, 70	V

Table 2.2:- The process parameters with ranges

The first order model is acceptable over a narrow range of variables, therefore the experiments are conducted to obtain second order model. In this RS method the design parameter are selected on the following method.

$DC=T_{ON}/(T_{ON}+T_{OFF})$.

For the designing this parameter is necessary to fulfill the following equation.

$DC\ (T_{ON}+_{OFF})$ =Ton .the all the designing parameter must fulfill this equation.

Exp. No.	Discharge current (A) (X_1)	Pulse-on time (µs) (X_2)	Duty cycle (X_3)	Gap voltage (V) (X_4)
1	1	1	1	-1
2	-1	1	1	1
3	-1	-1	-1	1
4	-1	-1	1	-1
5	0	0	0	0
6	1	-1	1	-1
7	0	0	0	-2
8	1	1	1	1
9	1	-1	1	1
10	0	0	0	0
11	-1	-1	-1	-1
12	0	0	2	0
13	0	0	0	0
14	-1	1	1	-1
15	0	2	0	0
16	-1	1	-1	1
17	1	-1	-1	1
18	-2	0	0	0
19	0	0	0	0
20	0	-2	0	0
21	-1	-1	1	1
22	1	1	-1	1

23	0	0	0	0
24	0	0	0	0
25	1	1	-1	-1
26	1	-1	-1	-1
27	-1	1	-1	-1
28	0	0	0	2
29	0	0	-2	0
30	0	0	0	0
31	2	0	0	0

Table 2.3:- Central composite design for experimentation

Central composite design (CCD) is the most popular class of second order designs suggested by Box and Wilson. A design is rotatable if the variance of the response is constant for all variables at a given distance from the design Centre. The rotatable central composite design would be nearly orthogonal if the number of center points is about five. Central composite rotatable design (CCRD) is capable of predicting independent, quadratic and interaction effects of different parameters on the responses. Total 31 experiments (16 factorial runs, 8 axial runs, 7 central points) have been carried out at five levels.

Factors	**Units**	**Levels**				
		-2	**-1**	**0**	**1**	2
Discharge current	A	3	4	5	6	7
Pulse-on time	(µs)	100	200	300	400	500
Duty cycle		0.60	0.66	0.72	0.78	0.88
Gap voltage	(V)	50	55	60	65	70

Table 2.4:- The process parameters with levels.



Fig. 2.1:-Die Sinking EDM Experimental set up

3. Result and discussion

3.1 Experimentation on EDM with Kerosene as Di-Electric Medium

In all the experiments, Kerosene oil has been used as dielectric medium. Total 31 experiments have been performed using CCRD with independent variables at 5 different levels. Machining time for each work piece in the experiments has been kept 60 minutes.
After EDM, Alumina reinforced aluminium composites (8%) samples have been cleaned with acetone. A high precision electronic weighing balance with least count 0.01 mg has been used to measure the weight loss of work piece and electrodes after each experiment. After EDM, Alumina reinforced aluminium composites (8%) samples have been cleaned with acetone. A high precision electronic weighing balance with least count 0.01 mg has been used to measure the weight loss of work piece and electrodes after each experiment. The surface finish after machining was measured using Talysurf 6 (Rank Taylor Hobson, England). A traverse length of 3 mm with a cut-off evaluation length of 2 mm was used. The Centre line average value of the surface roughness (SR) is the most widely used surface roughness parameter in industry, was selected in this study. Each sample was measured three times and the average was taken as the response.

A statistical model for the SR was developed, by correlating the input parameters namely discharge current, pulse on time, duty cycle and gap voltage, based on analysis of the data presented in table, and is given below as equation after eliminating all the insignificant parameters. This equation has been generated with the help of MINITAB 16 with respect to all linear, square and interactive parameter.

$$\mathbf{Ra = -8.9 + (1.54 \times I_p) - (0.0171 \times T_{on}) + (5.96 \times DC) + (0.0874 \times V_g) - (0.139 \times I^2_p) + (6 \times 10^{-6} \times T_{on}) - (5.71 \times DC^2) - (0.000307 \times T_{on} \times V_g) \ldots\ldots\ldots\ldots\ldots}$$

ANOVA has been used to check the adequacy of the developed model. The F-ratio of the predictive model was calculated and compared with the standard tabulated value of the F-ratio for a specific confidence interval. The ANOVA of model indicates that the model is significant as 2*R* statistics is 94.2 % which shows that regression model provides strong correlation between

independent variables and the response (SR) and gives good explanation of the relationship between the independent variables and the response (SR). The calculated *F* value for the model is 35.49. The computed *F* value is greater than the value of $F_{0.01,14,16}$which is 3.45 for a significance level of α=0.01. It indicates that the model is adequate for 99% confidence level.

Source	SS	DF	MS	F value	P value	R_2	Remarks
Regression	3.46397	14	0.247427	35.49	< 0.0001	0.942	$F_{0.01,14,16} = 3.45$ $F > F_{0.01,14,16}$ Model is adequate
Linear	0.64716	4	0.161790				$F_{0.01,10,16} = 3.69$ $F < F_{0.01,10,16}$ Lack of fit is insignificant
Square	1.27782	4	0.319455				
Interactions	0.43366	6	0.072277				
Residual error	0.11156	16	0.006972				
lack-of-fit	0.08954	10	0.008954	2.44	0.144		
Pure error	0.02202	6	0.003670				
Total	3.57553						

Table 3.1:- ANOVA table for Surface Roughness on EDM

The *P*-value calculated for the lack of fit terms is more than 0.05. It means the lack of fit is insignificant.

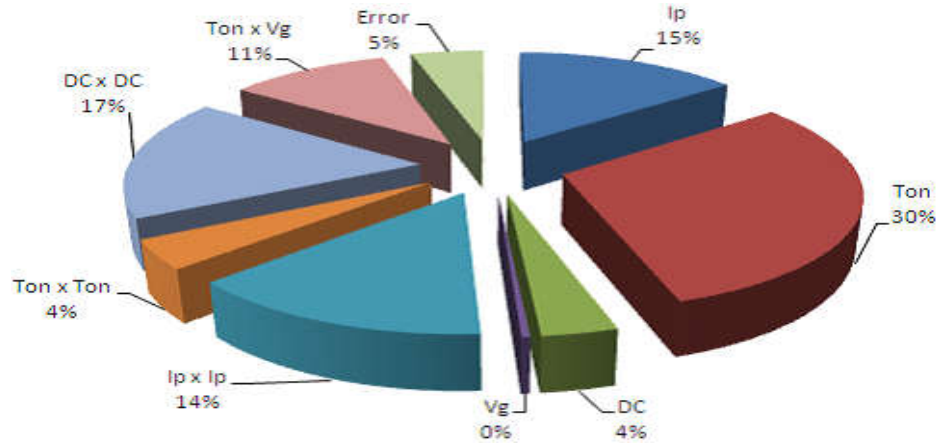

Fig. 3.1:- Percentage contribution of the factors on SR for EDM

Percentage contributions for each term of the model for SR are shown in figure 3.1. The figure shows that discharge current and pulse on time are the most influential parameters affecting SR. The pulse-on time is found to be the most significant factor influencing the SR with contribution of 30 % which is followed by discharge current with a contribution of 15%. Figure 3.2 shows the main effects plots for SR. It can be seen that SR increases with discharge current. It is also observed that SR increases with pulse on time. Further it can be seen that an increase in the duty

cycle leads to increase of the SR initially and then leads to decrease. It can be seen from figure 3.2 that the gap voltage does not influence the SR.

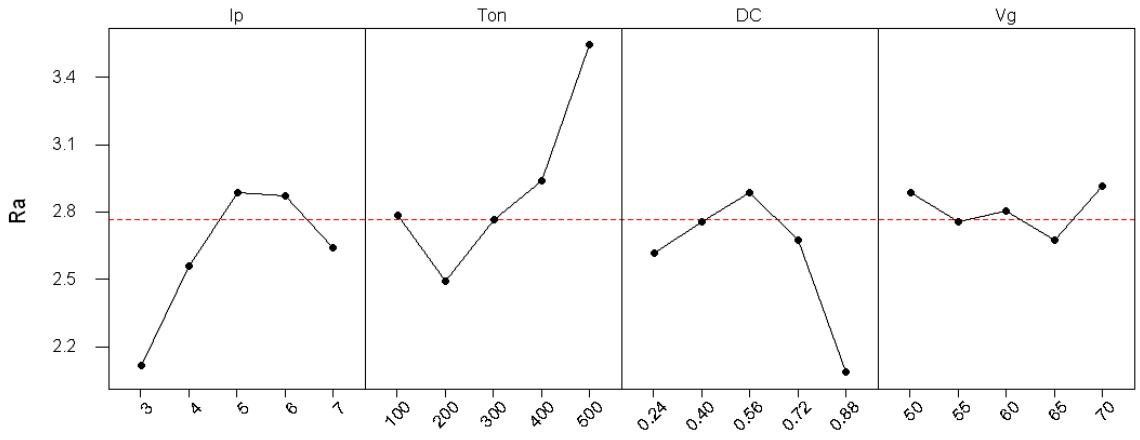

Fig. 3.2:- Main effects for SR

3.2 Experimentation on EDM with Silicon Oil as Di-Electric Medium

A statistical model for the SR was developed, by correlating the input parameters namely discharge current, pulse on time, duty cycle and gap voltage, based on analysis of the data presented in table, and is given below as equation after eliminating all the insignificant parameters.

Regression analysis:

SR = 128 - 3.70 Ip - 0.0299 Ton - 94.6 DC - 2.56 Vg + 0.216 IP^ - 0.000010 Ton^ + 25.9 DC^ + 0.0201 Vg^ + 0.00115 IP*Ton + 4.26 IP*DC - 0.0230 IP*Vg + 0.0386 Ton*DC + 0.338 DC*Vg……

ANOVA has been used to check the adequacy of the developed model. The F-ratio of the predictive model was calculated and compared with the standard tabulated value of the F-ratio for a specific confidence interval. The ANOVA of model indicates that the model is significant as R^2statistics is 94.8 % which shows that regression model provides strong correlation between independent variables and the response (SR) and gives good explanation of the relationship between the independent variables and the response (SR). The calculated F value for the model is 40.42. The computed F value is greater than the value of $F_{0.05,14,16}$ which is 2.3733 for a significance level of α=0.005. It indicates that the model is adequate for 97.25% confidence level.

The second order SR model. It is clearly evident from the plot that there are no obvious pattern and unusual structure. This means that model developed is adequate and can be used for analysis to determine effects of various parameters on the response

Source	S.S	D.F	M.S	F Value	P value	R^2	Remark
Regression	20.2210	14	1.44436	40.42	<0.005	0.948	$F_{0.05,14,16} = 2.3733$ $F > F_{0.05,14,16}$ Model is adequate
Linear	8.8824	4	2.22061				
Square	8.8446	4	2.21114				
Interaction	2.4940	6	0.41567				
Residual Error	0.5717	16	0.03573				
Lack of fit	0.3319	10	0.3319	0.83	0.622		$F_{0.05,10,16} = 2.4935$ $F < F_{0.05,10,16}$ Lack of fit is insignificant
Pure Error	0.02398	6	0.03996				
Total	20.7927						

Table 3.2:- ANOVA Table for SR of EDM (silicon oil).

4. Conclusion

In this work, EDM has been successfully performed on Alumina reinforced Aluminium composite work piece material. Statistical models have been developed for predicting SR in EDM by correlating the input parameters, namely, discharge current, pulse-on time, duty cycle, and gap voltage. In EDM process, significant parameters have been identified and ANOVA was used to establish the adequacy of the model. The second order model developed for SR is statistically significant. It has been observed that discharge current and pulse-on time are significant parameters affecting SR. It has been observed that SR increases with increase in discharge current. An increase in pulse-on time increases the SR. Confirmation experiments were conducted at various test conditions to show that the developed models for CEDM of kerosene and silicone process can predict SR values accurately within 94% confidence interval. Optimal process parameters have been identified for obtaining minimum SR.

The comparison of SR for conventional EDM process in silicon and kerosene di-electric medium and it is observed that the surface roughness of silicon oil is better than the kerosene oil in the silicon oil the SR is decreases has resulted in greater occurrence of recast layer formation which fills the micro cracks and holes, resulting in smoother surface of the work piece. It was observed that in EDM with silicon oil increase the SR 29%.as compression to kerosene oil so why the silicon oil is better than kerosene oil in the silicon oil SR has optimize value is 0.5324.it is better as any other conventional type's di-electric fluids so silicon is best.

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