Multi Objective Optimization of Material Removal Rate and Tool Wear Rate in EDM Machining of Metal Matrix Composite using Firefly Algorithm

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Abstract - **Aluminium is ductile, cheapest and light material but when alloyed with silicon carbide using centrifugal casting has wide applications in aerospace and automobile industry due to increase in hardness. In order to make dies, Electric Discharge Machine (EDM) is a proven non-conventional method of machining. In this paper, AlSiC is taken as work piece and pure copper as electrode and experiments are conducted for various combinations of selected input variables. The objective of this work is to find optimum combination of these input variables in order to have optimum values of material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). Control parameters used are discharge voltage (*V*), discharge current (*Ip*), Pulse on time (*Ton*) and Pulse duty factor (*Tau*). Taguchi (L16b orthogonal array) design of experiments is used for data collection and firefly algorithm (FFA) is used for optimization. The MRR, SR and TWR obtained after optimization are presented.**

Index Terms - **Design of Experiments, electric discharge machine, firefly Algorithm, metal matrix composites and multi-objective optimization.**

I INTRODUCTION

Powder metallurgy method and centrifugal casting method are popularly used for combining Aluminium (Al) and silicon carbide (SiC) in order to make a metal matrix composite. Alloying Al and SiC makes the composite hard whereas powder metallurgy route makes it relatively brittle. In this paper, centrifugal casting has been used. However, it is important to select proper proportion of these two constituents in order to obtain desired results. Presence of silicon makes the material cheaper and harder whereas presence of aluminium makes it ductile. As the silicon constituent is increased in the composite, the product becomes harder but then, the machinability of the product becomes more and more difficult. Thus, the best possible combination of these two should be selected in order to make the composite with desired properties. At the same time, it should have good machinability properties on EDM. Hence, study of the machinability by testing various combinations of constituents of Al and SiC on EDM is an important to start with for any researcher. This work has been taken up by earlier researchers for various machining operations such as, lathe, milling machine, drilling machine etc.

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It is important to study the results for electric discharge machining (EDM) where the method of machining is different and electrical conductivity is one of the requirements for the work piece material.

Unlike, conventional machining processes, Electric Discharge Machining (EDM) is non-conventional machining process where controlled thermal spark generated by electrical energy between tool electrode and work piece in the presence of dielectric fluid is used to remove the material on the work piece. There is no physical contact between the work piece and the tool material and hence there is no tool force. The space between electrode and tool is filled with dielectric fluid in order to control the spark emanating from the tool material and propagating towards the work piece. For this case, use of Aluminum silicon carbide as work material is challenging as Aluminum is electrically conductive where as silicon is not. Hence the surface roughness becomes a major constraint if we increase the silicon carbide content in the composite.

Many researchers have worked in the area of machining of composites. Fabriziacaiazzo et al [1] tested two tool materials, such as, graphite (Poco EDM-3) and copper infiltrated graphite (Poco EDM-C3) on EDM to process nickel based super alloys. Surface roughness, tool wear ratio and material removal rate were considered for discussion on effect of discharge current, discharge voltage, reversion of polarity and duty cycle. It was suggested to use tool as anode while machining Rene 108 DS to reduce wear ratio. Using graphite as a tool with higher discharge current and voltage, tool wear ratio was less. Better surface finish was obtained from extended spark-on time which results in reduced duty cycle. Karthikeyan et al [2] developed a mathematical model to optimize the EDM characteristics such as tool wear rate (TWR), material removal rate (MRR) and surface roughness (SR). From experimental data, it was found that surface roughness, material removal rate and tool wear rate were greatly influenced by volume percentage of SiC present in Metal Matrix Composites, pulse duration, and Input current. With increase in percentage volume of SiC, material removal rate decreases, where as with increase in volume percentage of SiC, tool wear rate and surface roughness will increase.

Gopalakannan et al [3] conducted experiments by choosing EDM process parameters such as pulse on time, gap voltage, peak current, and pulse off time. For obtaining grey relational grade for Electric Discharge Machining (EDM) with multiple characteristics like tool wear rate, material removal rate, and surface roughness, Taguchi based gray relational analysis was used. Based on ANOVA and Taguchi method, it was found that peak current has about 55% contribution whereas voltage and pulse on time have

15% and 18% respectively. Gap voltage, peak current and pulse on time are primary factors which affect the machining quality of Aluminum Metal Matrix Composites and pulse off time as secondary factor. Using gray relation analysis, EDM quality enhanced from 0.5746 to 7949 and by 27.71%. Chen et al [4] utilized the Taguchi method to optimize the EDM process parameters of A6061-T6 aluminum alloy. Parameters considered for the experimental trial are peak current, duty cycle, pulse on time, and machining duration. The optimized parameters and their effect on the surface roughness were determined by using experimental data for analysis of variance (ANOVA) and analysis of means (ANOM). From results, it was revealed that, for surface roughness, duty cycle and peak current were found to be primary factors. Using same optimal parameters when CuZn40 brass alloy was machined, it was found to be having lower surface roughness than the specimen chosen earlier i.e. A6061-T6 Aluminum alloy. S. Suresh et al [5] experimentally optimized the EDM parameters of Al 6351 alloy (AMMC) reinforced with 10 wt. % boron carbide and 5 wt. % silicon carbide fabricated using stir casting. Using GRA method, multi response optimization technique with an aim to minimize the response parameters, such as, tool wear rate (TWR), power consumption, and surface roughness was used. Optimal combination of control parameters were identified which have significant impact on response parameters. Analysis of Variance (ANOVA) was used to calculate the contributions of each machining parameter. From results, it was revealed that pulse current has significant effect (83.94%) followed by spark on time (10.99%), pulse duty factor (2.22%) and voltage (2.07%).

II EXPERIMENTAL PROCEDURES

The experimental procedure starts with mixing proper proportion of aluminium alloy with silicon to make composite material using stir casting method. It is important to fix the percentage of silicon in order to have desired properties of the resultant material. The second step is to conduct experiments on EDM for different values of selected input variables and measurement of output variables. The third step includes development of prediction models for selected response variables, such as MRR, SR and TWR. Finally, the prediction models are optimized for response variables for best results. Each of the stages is explained in the following sub-sections.

The experimental study was carried out using dielectric fluid as EDM oil on Electric discharge Machine, (Make: Electronica, Pune, India, Table: 550x350 sq mm X: 300mm, Y: 200mm, Z: 250mm, MOFSET pulse generator). The work piece material used was aluminium silicon carbide composite in the form of a 55×55×22 mm³ block. Stir casting method was used for the preparation of Al-SiC composite material. Various combinations of aluminium and silicon have been tried before selecting 85% aluminium alloy and 15% silicon carbide which has desired mechanical properties, the component after machining is shown in Figure-1.

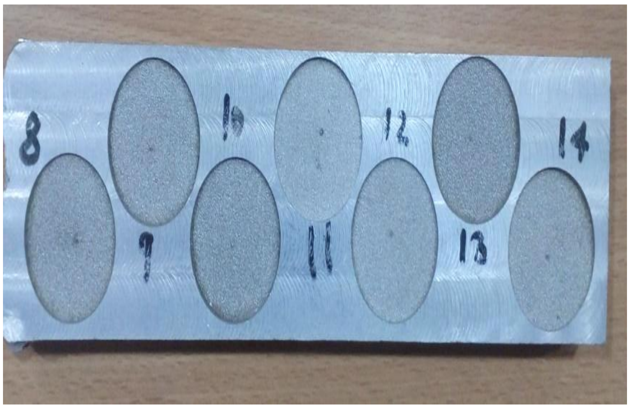

Fig.1: Work Piece AlSiC (15%SIC) after machining on EDM

A. Selection of input parameters

It is important to select input parameters that are proved to have significant effect on the selected response parameters from the literature. In this work, in addition to three parameters that have been tried by earlier researchers, duty factor has also been selected as input variable. The definitions of these variables are as follows:

- Pulse on time (spark on time or Ton): The duration of time for which current is flowing through the spark gap per cycle is known as pulse on time. It is measured in microseconds (µs).

- Duty Factor: Duty Factor may be defined as the percentage on-time with respect to the total cycle time. Mathematically it is expressed as given in equation – 1.

$$Duty\ Factor = \frac{T_{on}}{T_{on}+T_{off}}\ X\ 100 \qquad \text{--- (1)}$$

- Supply/ Servo Voltage: It is the voltage which is supplied between the tool electrode and work piece during the supply of DC power in circuit. It is measured in Volts and is denoted by *V*. It affects MRR, TWR and SR.

- Discharge Current (Peak Current or Ip): It is defined as the amount of power used in the EDM. Discharge current has significant impact on MRR, TWR and SR. It is measured in terms of Ampere (*A*).

B. Selection of output parameters

The output parameters selected in this study are material removal rate, tool wear rate and surface roughness. The objectives of this study are to maximize the MRR, minimize the TWR and SR. The methods used for measurement of these output variables are given as follows:

- Material Removal Rate (MRR)

Material removal rate is defined as rate of material removal per unit time. Material removal rate is directly proportional to pulse-on time, discharge current, and supply voltage. It is inversely proportional to spark-off time. MRR is calculated using equation-2.

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$$MRR(gm/min) = \frac{Initial\ weight\ of\ workpiece - Final\ weight\ of\ workpiece}{Timing\ of\ Machining\ X\ Density\ of\ Workpiece}$$ -----------(2)

- Tool Wear Rate (TWR)

TWR is defined as rate of removal of tool material per unit time. TWR is directly proportional to pulse-on time, discharge current, and supply voltage. It is inversely proportional to spark-off time. TWR is calculated using equation – 3.

$$TWR(gm/\min) = \frac{Initial\ weight\ of\ tool - Final\ weight\ of\ tool}{Timing\ of\ machining \times Density\ of\ tool}$$ ---------(3)

- Surface Roughness Measurement

A portable Surtronic 3+ was used to measure the surface roughness (SR) in terms of R_a. In order to cover the entire region of machining, it is important to take three to four readings and take average of them. Hence, four readings have been taken in the traverse direction and the average value is recorded.

C. Conduction of planned experiments

Electric Discharge Machine (EDM) is used for experimentation as explained earlier. The tool material used is pure cylindrical copper electrode of 30mm diameter. The input parameters are varied at four levels and it is possible to have 256 combinations with this arrangement. However, it is time consuming and not economical to conduct these many experiments. The same results can be obtained by using statistical approach which is used in Taguchi design of experimentation using L16 array. The levels of input variables are shown in Table-I. The lower and higher range values are selected based on the availability of these values in the machine.

TABLE-I
SELECTED INPUT PROCESS PARAMETERS AND THEIR LEVELS

Selected Input Parameter	Level-1	Level-2	Level-3	Level-4
Discharge Current, I_p (A)	5	10	12	15
Voltage, V	40	45	50	55
Pulse on Time μ_s	100	150	200	250
Duty Factor	20	25	27	30

D. Development of prediction model for the selected output parameters

In order to predict the values of the selected response variables, prediction models for MRR, TWR and SR have been developed using linear regression with the help of MINITAB 17 software. The response variables have been taken as dependent variables and input process variables (pulse-on time, supply voltage, current, and duty factor) are taken as independent variables. It is important to test the significance of relations using F-test and t-test. These values can also be obtained from the software.

E. Optimization of predictive model

The multi objective optimization of the three response variables is done using firefly algorithm. This helps in finding the best values of the three responses and the corresponding input variables. The programme code for firefly algorithm is prepared in MATLAB 2012. By using this algorithm, it is also possible to find optimum values in any range of input variables other than the values used in this study. Hence this algorithm gives wider scope for optimization of response variables simultaneously.

III RESULTS AND DISCUSSIONS

In this paper, linear relationship was established between selected input parameters and response variables. Firefly algorithm is used for optimization. The experimental data has been shown in Table-II.

TABLE-II
EXPERIMENTAL DATA OF EDM OPERATION ON ALSIC (15%)

Exp No	I_p Ampere	V Volts	Ton (μs)	Tau time (min)	MRR g/min	TWR (mm^3/min)	SR microns
1	5	40	100	20	38.39	0.0149	6.6
2	5	45	150	25	39.99	0.0154	7.6
3	5	50	200	27	40.19	0.0160	7.8
4	5	55	300	30	41.49	0.0180	8.2
5	10	40	150	27	71.97	0.0291	8.6
6	10	45	100	30	74.77	0.0286	8.4
7	10	50	300	20	64.97	0.0297	8.7
8	10	55	200	25	66.76	0.0299	8.9
9	12	40	200	30	86.74	0.0380	9.2
10	12	45	300	27	81.24	0.0450	9.2
11	12	50	100	25	78.05	0.0321	8.9
12	12	55	150	20	72.11	0.0344	9.1
13	15	40	300	25	111.35	0.0536	10.1
14	15	45	200	20	99.01	0.0461	9.7
15	15	50	150	30	96.22	0.0487	9.5
16	15	55	100	27	83.92	0.0429	9.3

A. Regression analysis

The regression equations obtained from linear regression analysis using MINITAB 17, are given below:

$MRR = 28.5 + 5.728\ Ip - 0.754\ V + 0.0325\ Ton + 0.502\ Tau$ -------- (4)

$TWR = -0.00301 + 0.003169\ Ip - 0.000199\ V + 0.000033\ Ton + 0.000217\ Tau$ -------- (5)

$SR = 4.451 + 0.2120\ Ip + 0.0145\ V + 0.003561\ Ton + 0.0273\ Tau$ ---(6)

TABLE III
ANALYSIS OF VARIANCE OF MRR

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	4	7385.18	1846.29	137.05	0.000
I_p	1	6955.6	6955.6	516.33	0.000
V	1	283.96	283.96	21.08	0.001
Ton	1	92.24	92.24	6.85	0.024
Tau	1	53.38	53.38	3.96	0.072
Error	11	148.18	13.47		
Total	15	7533.36			

As shown in Table-III, the t-values and *F*-values from analysis show that all the input variables have significant effect on the output variables and hence the equations can be used for prediction of output variables when AlSiC is machined under given environmental conditions. Normal probability plot indicates that the residuals are normally distributed as required for analysis.

B. Multi-objective optimization of MRR, TWR and SR

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Multi objective optimization means optimization of three responses at a time. For this, codes are developed for Firefly algorithm using MATLAB 12 and optimum values for maximum MRR, minimum TWR and minimum SR are obtained. Equation – 4 is used as the objective function and equations '5' and '6 are made constraints. With this, the best optimized values obtained, are listed in the Table-IV.

TABLE-IV
OPTIMIZED PARAMETERS AND RESPONSES OF AL 15% SIC USING FIREFLY ALGORITHM

S. No		Input Current (A)	Servo Voltage (V)	Ton μs	Pulse Duty Factor	MRR	TWR	SR
1	Optimum values	15	40	300	30	109.07	0.0529	10.12

C. Validation of results

For validation purposes, four separate experiments are conducted, and the data are recorded. The value of MRR is computed using prediction model. It is measured for four experiments. The predicted value and the measured value are compared. The percentage error is calculated. It is observed that the maximum percentage of error was 16% for TWR.

IV CONCLUSIONS

In this research, the microstructure of AlSiC composite is found to be stable after machining it, using Electric Discharge Machine (EDM). The selected proportion of silicon carbide used in this study is 15% and the hardness so obtained makes it suitable for die making. Experiments have been conducted for collection of data and linear regression analysis is done which helps in prediction of MRR, TWR, and SR. This is useful for the machine operators for selecting the optimum input parameters which optimizes MRR, TWR and SR simultaneously in any selected range. Further work may be done in this area by including various types of dielectric fluids.

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