Analysis of Machining Characteristics of Al7075 Hybrid Metal Matrix Composite Using EDM

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Abstract: **The composite materials are extensively used globally in major industries. It is very difficult to machine the metal matrix composite materials impeded with reinforcement by conventional machining methods [1]. Hence non conventional machining techniques are employed to overcome these difficulties. The influence of process parameters of Electrical discharge machining such as current, pulse on- time and pulse -off time on Metal Removal Rate (MRR) and Surface Roughness (SR) were analysed for Al7075 hybrid metal matrix composite reinforced with Silicon carbide (SiC) and Titanium carbide (TiC) in this paper. The hybrid metal matrix composite was fabricated using stir casting process and machining was performed by EDM using copper tool with the machining parameters and the run order obtained from design expert software [3]. The machining characteristics for different set of experiments were analysed. The optimum parameters were identified with the help of design expert software and the optimum values were verified. It has been observed that the metal removal rate decreases when the weight fraction of reinforcement increases and surface roughness increases.**

Index Terms - **Al7075, HMMC, EDM, SiC, TiC, Surface Roughness and Material Removal Rate.**

I. INTRODUCTION

A composite material can be defined as a combination of a matrix and a reinforcement which when combined gives properties superior to the properties of the individual components [2]. The primary reason composite materials are chosen for component is because of weight saving for its relative stiffness and strength. Al7075 is considered as it is light weight and it has a high stiffness value compared to many steels. The primary material in the Al7075 is Zinc which also processes good fatigue strength. This alloy is mainly used in aviation industry such as air plane wings, rudders, high performance aircrafts and supersonic aircrafts due to its high strength to density ratio. The aluminium hybrid metal matrix composite is fabricated using stir casting process reinforced with silicon carbide (SiC) and titanium carbide (TiC).

Design expert is a statistical software package from Stat-Ease Inc. that is specifically dedicated to performing design of experiments. Design Expert offers comparative tests, screening, characterization, optimization, robust parameter design, and mixture design and combined designs. Three input parameters considered during the machining of the composite material in EDM were current, pulse on time and Pulse off time. There can be other parameters that can be considered but it is evident from the literature review that these three parameters have a notable impact on both metal removal rate and surface roughness.

II. MATERIAL PREPARATION

Al7075 is the alloy considered for the analysis and the reinforcements were silicon carbide and titanium carbide. Stir casting (Fig. 1) is the casting technology used in the preparation of the composite material. The addition of the silicon carbide to the aluminium alloy improves the brittleness and the wear resistance of the material [5] and the addition of the titanium carbide improves the fracture toughness and exhibit high hardness [6].

Figure 1 Stir Casting Machine

The aluminium alloy was melted in the graphic crucible which is placed in the electric induction furnace. The temperature maintained in the crucible was in the region of 800°C [3]. The reinforcements for the composite material are 12.5% SiC and 12.5% TiC. The cast of the composite was obtained by stirring the molten alloy and the reinforcements mechanically for a period of 20 minutes at a rate of 750 rpm.

Metal matrix composite material is when two or more different materials are combined together to create a superior and unique material [9]. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics. Metal matrix composites (MMCs) are made of a continuous metallic matrix and one or more discontinuous reinforcing phase [11].

A composite material is a system composed of a mixture or combination of two or more macro constituent of different form or materials composition and that are essentially protects them chemically and thermally [8]. The normal view is that the properties of the matrix are improved on incorporating another constituent to produce a composite. The second constituent referred as reinforcing phase or reinforcement, as it enhances or reinforces the mechanical properties of the matrix. Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practised commercially. Its advantages lie in its simplicity, edibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the economical cost of the product [4]. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production, and allows very large sized components to be fabricated.

III. MACHINING OF COMPOSITE BY EDM

After completing the casting process the composite metal casting is machined by the Electric Discharge Machining (EDM) Figure (2), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Electric discharge machining provides an effective manufacturing technique that enables the production of parts made of special materials with complicated geometry which is difficult to produce by conventional machining processes [7]. Controlling the process parameters to achieve the required dimensional accuracy and finish placed this machining operation in a prominent position. For that reason, electric discharge machining has found broad applications in industry.

The input parameters of the electrical discharge machine are current, pulse on time and pulse off time are obtained for each experiments from the design expert software. After the completion of the machining process two machining characteristics material removal rate and surface roughness are calculated and analysed. After calculating the values they are entered in the software and the mathematical model for MRR and surface roughness are generated. The optimum values for the machining are obtained with the help of mathematical model. The input parameters and the machining characteristics were plotted to obtain the clear view about the influence of the parameters on the characteristics.

Figure 2 Electric Discharge Machine.

IV. RESPONSE VARIABLES AND MACHINING PARAMETERS

The following are the three input parameters considered for the machining of the Hybrid Metal Matrix Composite (HMMC).

Pulse on Time

Pulse on time is defined as the time during which the machine is performed. The machining process become faster after increasing the pulse on time the metal removal rate increase and poor surface finish on the material surface also given in the pulse on time process.

Pulse off Time

Pulse off time process is the time during which re-ionization of the dielectric takes place. An insufficient off time can leads to erratic cycling and retraction of the advancing servo thereby slowing down the operation cycle. The main reason for choosing the above pulse on/off time is to fixing the time for the time interval of time period. This is the main reason for choosing the pulse ON/OFF time.

Current

This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. In each on-time probe the current increase until it reaches a present level, which is expressed as the peak current. Higher value of current leads to rough surface finish operations and wider creators on work material. Its higher value improves MRR, but at the cost of surface finish and tool wear. Hence it is more important EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of materials.

The following Table (1) shows the input process parameters range considered for the machining of the Al7075 hybrid metal matrix composite.

Table 1 Input Process Parameters

Input Parameters	**Current (Amps)**	**Pulse On Time (µS)**	**Pulse Off Time (µS)**
RANGE	10-20	40-60	7-9

The following Figure (3) shows the composites machined using copper tool by EDM. All the seventeen experiments are carried out as per the conditions obtained from the design expert software.

Figure 3 Machined Composites

Metal Removal Rate (MRR)

The metal removal rate is generally described as the volume of metal removed per unit time. Metal removal rate depends upon current density and it increases with current. But high removal rates produce poor finish. Therefore the usual practice in EDM is a roughing cut with a heavy current followed by a finishing cut with less current. Metal removal rate of up to 80 mm^3/s can be achieved on higher currents and surface finish of 0.25 µm can be obtained at very low cutting rates.

$$MRR = \frac{W_i - W_f}{T}$$

W_i - Weight of the work piece (g) before trial.
W_f - Weight of the work piece (g) after trial.
T - Period of time taken (s).

Surface Roughness (SR)

Often shortened to roughness, a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If this deviations are large the surface is rough if they are small the surface is smooth. Roughness is typically considered to be the high frequency short wave length. Surface Roughness is a measure of the finely spaced surface irregularities. In engineering, this is what is usually meant by surface finish. The surface finish of the finished work piece is measured using instruments now a days. Mitutoyo Talysurf tester (Fig 4) is the instrument used to measure the surface finish of the machined composite. The centre line average of surface roughness in micron for each experiment is obtained.

Figure 4 Surface Roughness Tester

V. Design Expert

Design expert is a statistical software package from Stat-Ease Inc. that is specifically dedicated to performing design of experiments. Design Expert offers comparative tests, screening, characterization, optimization, robust parameter design, and mixture design and combined designs. Design Expert provides test matrices for screening up to 50 factors. Statistical significance of these factors is established with analysis of variance (ANOVA). Graphical tools help identify the impact of each factor on the desired outcomes and reveal abnormalities in the data.

Feature of design expert

Design-expert offers test matrices for screening up to 50 factors. A power calculator helps establish the number of test runs needed. ANOVA is provided to establish statistical significance. Based on the validated predictive models, a numerical optimizer helps the user determine the ideal values for each of the factors in the experiment.

Response Surface Model (RSM)

Design-expert provides graphs in addition to text output to analyse the residual. A response surface model (RSM) can be used to map out a design space using a relatively small number of experiments. RSM provide an estimate for the value of response for every possible combination of the factors in parallel, making it possible to comprehend a multi-dimensional surface with non-linear shapes. The optimization feature can be used to calculate the optimum operating parameter for a process.

Box – Behnken approach

A method for developing mathematical model used to find combinations of factors that yield optimal business performance. Box- Behnken design are a type of response surface method which provides detailed information about solutions. Allowing researchers to better understand the forces affecting the output of the model.

VI. Experimental values:

The following Table (2) shows the values obtained for the experiments carried out in EDM in the order prescribed by the design expert software.

Mathematical Model for Material Removal Rate (MRR)

$$MRR = -1.08447 + 0.019807*A + 0.018719*B + 0.12735*C + 1.37500E\text{-}004*A*B - 1.27500E\text{-}003*A*C - 1.01500E\text{-}003*B*C - 5.34400E\text{-}004 *A^2 - 1.08350E\text{-}004*B^2 - 3.68500E\text{-}003*C^2$$

Mathematical Model for Surface Roughness

$$S.R = -5.38675 + 2.57685*A + 2.55600*B - 16.22325*C - 0.012600*A*B + 0.056500*A*C + 0.036000*B*C - 0.068870*A^2 - 0.026842*B + 0.84325*C^2$$

Where ,
A = Current in Amps.
B = Pulse on time in µs
C = Pulse off time in µs

Table 2 Experimental Values

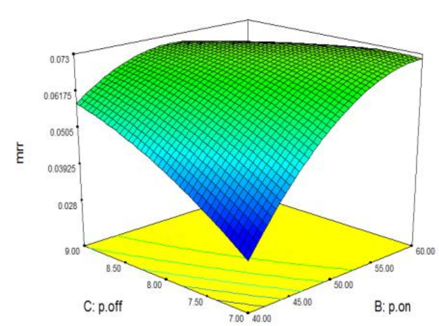
Std	Run order	Current *(Amps)*	Pulse on time *(µs)*	Pulse off time *(µs)*	MRR *(g/min)*	SR *(µm)*
1	1	15	50	8	0.0852	14.5
4	2	15	60	9	0.0872	11.43
8	3	20	40	8	0.0365	11.53
13	4	10	50	7	0.0612	10.59
3	5	10	40	8	0.0564	8.49
10	6	15	40	7	0.0325	14.36
11	7	10	60	8	0.0704	9.67
15	8	20	60	8	0.078	10.19
7	9	15	50	8	0.085	14.46
16	10	10	50	9	0.0586	11.53
9	11	15	60	7	0.0981	12.55
12	12	15	50	8	0.0842	14.54
6	13	20	50	7	0.0891	14.9
17	14	15	40	9	0.0622	11.8
2	15	15	50	8	0.0847	14.23
5	16	15	50	8	0.0835	14.15
14	17	20	50	9	0.061	16.97

VII. RESULTS

Effect of Pulse on time and Pulse off time on MRR:

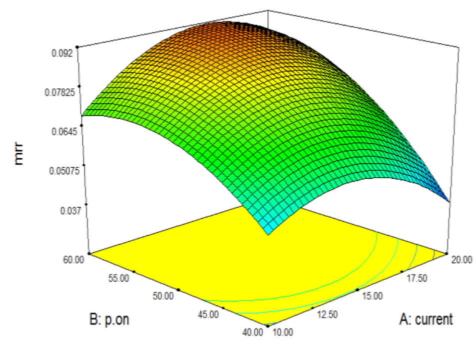
The following (Fig 5) shows the effect of pulse on and off time on material removal rate. It is evident from the graph that the increase in pulse on time increases the material removal rate but it has a greater effect on the MRR compared to Pulse off time.

Figure 5 Effect of Pulse on and off time on MRR



Effect of Pulse on time and current on MRR

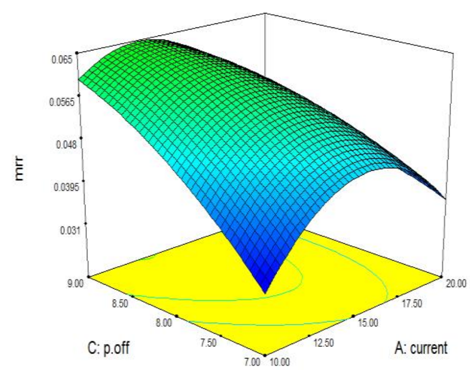
Figure (6) Effect of Pulse on time and Current on MRR



The above graph (Fig 6) shows the influence of pulse on time and current on MRR. When the pulse on time and current increases the MRR for the composite increases. Both Pulse on time and Current are important parameters to be considered while machining of the composite material.

Effect of Pulse off time and current on MRR

Figure 7 Effect of Pulse off time and Current on MRR

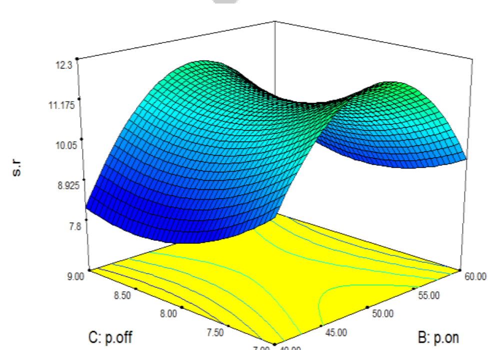


The above graph (Fig 7) implies that on increasing the current the MRR increases but the influence of Pulse on time on MRR is minimum compared to that of current.

Effect of Pulse on time and Pulse off time on SR:

The following graph (Fig 8) shows the impact of Pulse on time and Pulse off time on SR. It can be inferred from the graph that the increase in pulse on time, surface Roughness is increases up to a certain limit, then decreases. But comparing to the pulse on time, pulse off time has less influence on the surface roughness.

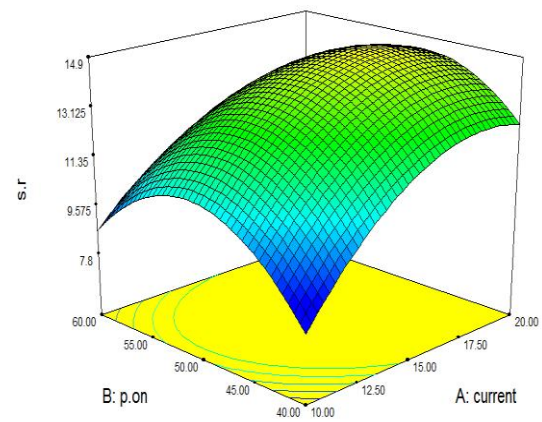
Figure 8 Effect of Pulse on time and Pulse off time on SR



Effect of Pulse on time and current on SR

The following graph (Fig 9) shows the influence of Pulse on time and current on the SR. The increase in pulse on time and current increases the surface Roughness. Surface roughness is minimum at pulse on time value is high and low. But in between that surface roughness is high.

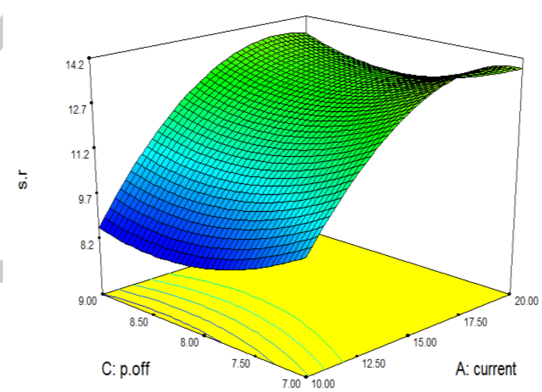
Figure 9 Effect of Pulse on time and current on SR



Effect of Pulse off time and current on SR

The following graph (Fig 10) shows that the increase in current, increases the surface Roughness. But comparing to the current, pulse off time has less influence on the surface roughness. So to achieve a better surface finish that is lower surface roughness current value has to be maintained on a lower level.

Figure 10 Effect of Pulse off time and Current on SR



VIII. DISCUSSION

Optimum Input Parameters

The optimum input parameters are obtained using Response Surface Methodology (RSM) for the machining of Al 7075 metal matrix composite reinforced with 12.5% SiC and 12.5% TiC are shown in the following table (3).

Table 3 Optimum values for copper tool

Current (Amps)	Pulse on time (µs)	Pulse off time (µs)	MRR (g/min)	SR (µm)
13	50	8	0.0839	10.5

Confirmatory Test

A confirmatory test was carried out for the above optimum input parameters such as current, pulse on time and pulse off time. The output values, MRR and SR are shown in the following table (4) using copper electrode in EDM.

Table 4 Confirmation test values

Current (Amps)	Pulse on time (µs)	Pulse off time (µs)	MRR (g/min)	SR (µm)
13	50	8	0.0829	10.2

The results obtained from the confirmatory test is nearly identical to the optimal results obtained from design expert. The deviation of the results are in the region of 1.2% for MRR and 2.85% for SR which are in the acceptable limit. Thus the confirmatory test results validates the experimental procedure and the optimisation by Response Surface Model (RSM).

IX. CONCLUSION

The following conclusions can be obtained for the Al7075 hybrid metal matrix composite reinforced with 12.5% SiC and 12.5% TiC.

- The material removal rate for the copper tool strongly depends on the current and then the pulse on time. Pulse off time has a relatively less influence on MRR.
- The surface roughness for copper tool depends more on the pulse on time and then the current. Similar to MRR the influence of pulse off time on SR is minimum compared to the other two input parameters.
- The optimum input parameters for the machining of the composite using a copper tool by EDM process are
    - ❖ Current – 13 amps
    - ❖ Pulse on time – 50 µs
    - ❖ Pulse off time – 8 µs

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