Effect of Process Parameters on Machining Characteristics in Electrical Discharge Machining of Al7075/SiC/Al_2O_3 Hybrid MMC

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Abstract— High hardness and high strength materials are very difficult to machine with the help of traditional machining processes like turning, milling, drilling and so on. Machining of such hard materials can be done by a non-conventional machining technique called Electrical discharge machining. This paper presents the results of experiment done to find the effect of discharge current, pulse on time, pulse off time on the machining characteristics which are work piece erosion rate and electrode erosion rate in electrical discharge machining of 7075Al+4Wt%Sic+4Wt%Al2O3 using Copper Tungsten electrode. ANOVA was performed using Minitab16. Pulse on time had the highest significance on WER. Discharge current had more effect on EER. Interactive effect of discharge current and pulse on time was also found to have greater effect than interactive effect of other parameters.

Keywords: EDM, 7075Al, WER, EER, CuW Response Surface Methodology, Box Behnken Design

Abbreviations: EDM-electric discharge machining, WER-work piece electrode rate, EER- electrode erosion rate, CuW-copper-tungsten, RSM- Response Surface Methodology, BBD- Box Behnken Design

I. Introduction

In recent years, use of Metal Matrix Composites has been in wide applications for engineering purpose. These are composites, which use metal as base and are reinforced with ceramics or organic compounds to enhance certain properties. Aluminium matrix composites (AMCs) and Hybrid aluminium matrix composites (HAMCs) have the most widespread use in automobile, aerospace and electronics industries. These composites are in demand due to their suitable properties with low cost availability. AMCs and HAMCs use aluminium or aluminium alloy as the base metal. Non-metals can be added as reinforcements in weight percentage or volume percentage. In HAMCs, more than one reinforcement can be added. HAMCs have very high strength to weight ratio, superior wear resistance and high stiffness due to which machining of such elements become difficult using the conventional machining techniques.

When traditional machining methods reach their limit, electric discharge machining can be the answer. Electrical discharge machining, or EDM, is a non-traditional method in which material is removed from a work piece using current energy. EDM does not need mechanical force in the removal process like the other conventional machining process. In tool and mould making, EDM is very popular due to its applicability particularly for hard materials like titanium and MMCs or for mostly complex shapes that are hard to achieve with traditional machining. EDM process allows for high accuracy and is applicable for any conductive material. EDM involves the direction of high-frequency electrical spark discharges from soft metal tool, which serves as an electrode, to disintegrate electrically conductive materials such as hardened steel or carbide. Fig. 1 shows schematic representation of Die-sink type EDM machine.

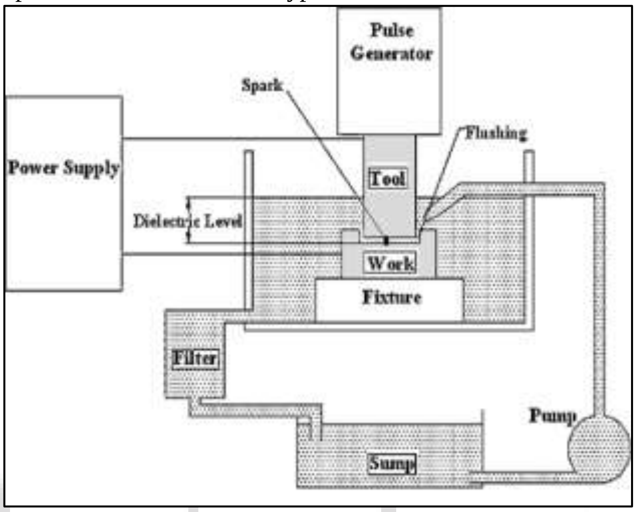

Fig. 1: Schematic representation of Die Sinking EDM Process

A discharge occurs in the small gap between work piece and electrode that removes material through melting. The electrode and the work piece need to be submerged into a dielectric fluid. The dielectric fluid used can be kerosene, EDM oil or deionized water. The tool becomes the cathode and work piece becomes anode. There is no contact between the tool and the work piece. Discharge of current occurs over 100000 times in a second. Discharge causes small amounts of metal to melt and erode along with the flow of dielectric fluid.

II. Literature review

This section presents the work done previously by various researchers in the field of electric discharge machining. Several studies are done on the effect of numerous process parameters of EDM and their effects on the machining characteristics. Farman Khan et al., conducted experiments on electrical discharge machining of Al/SiC MMC [1]. The effect of rotation of electrode with 100 rpm on MRR and TWR was observed. From the experimental results and comparison of both rotating and non-rotating electrode it was concluded that MRR was increased in rotating electrode by 61.67% as compared to non-rotating electrode. But there was also an increase in TWR by 11.79%. From taguchi method it was noted that peak current and pulse one time were more significant parameters impacting MRR. S. Gopalakannan and T Senthilvelan accomplished EDM of Al/SiC metal matrix nano composite by applying response surface methodology [2]. The matrix material was 7075 Al and nano particles of 0.5%SiC were reinforced into the matrix using stir casting method. From the readings it was seen that the MRR and

TWR increased with increase in pulse current and pulse on time. Voltage was an insignificant parameter. S. Gowthaman et al., performed experiments on monel alloy to discover the effects of current, pulse on time, pulse off time, and voltage gap [3]. Grey relation analysis and regression analysis was incorporated to optimize the results obtained. Pulse current was observed to have the highest influence (82%), followed by pulse off time (12%) and pulse on time (4%) on the dependent variables which included MRR and surface roughness. Gap voltage had significantly less effect. Anupama N. Kallol et al., by applying central composite design of response surface methodology discovered that discharge current, pulse on time, pulse off time and diameter of tool electrode (brass) are all significant factors affecting the MRR and TWR of C-40 steel [4]. Out of the four parameters, discharge current and pulse on time were found to have high significant effect on the machining characteristics while the other two had less significant effect. Rajeev Kumar et al., by adopting taguchi methodology of L9 orthogonal array and ANOVA deduced that pulse on time had the highest influence on the MRR as compared to current and electrode diameter in EDM of EN44 tool steel using copper electrode [5]. Ramanuj Kumar et al., investigated the machining characteristics of Ti-6Al-4V ELI titanium alloy by EDM [6]. Technique of grey relation analysis and L9 orthogonal array was used for design of experiments and analysis of data. From main effect graph it was seen that higher current diminishes the surface roughness. High MRR was found when there was a combination of high discharge current, moderate pulse on time and lowest voltage. MRR increased with increase in discharge current. Soraya Plaza, et al., from here comparative study of using CuW and graphie electrode in machining titanium alloy discussed that for high aspect ratios, wear rates of CuW were extensively lesser than graphite [7]. It was also observed that small pulse on time leads to reduced wear for same depth of hole. B. Singaravel, et al., stated that vegetable oils are having similar dielectric properties as conventional dielectrics [8]. However surface finish achieved using vegetable oil as dielectric is comparatively less than that achieved by usual dielectric. Rajesh Purohit and Pramod Sahu presented the effect of pulse-on time, pulse current, and gap voltage on metal removal rate, tool wear rate and radial over cut during machining of Al-alloy- 20 wt. % SiCp composites using 20 mm diameter copper electrode [9]. Three level 3 factor full factorial design of experiment technique was used for the analysis. The MRR was found to increase with increase in current and pulse duration. TWR was also found to increase with increase in current. However the TWR was found to first decrease and then increase with pulse duration and gap voltage. L. Feray Guleryuza et al., investigated the effect of current, electrode type, pulse-on-time, particle reinforcement weight ratio and voltage on the surface roughness for machining of Al/SiCp metal matrix composites produced with the powder metallurgy [10]. Results of experiments showed that pulse-on-time (34%) and current (31.26%) were the most influencing parameters. The electrode type has the lowest effect (1.63%) on the surface roughness.

From the literature survey it was concluded that pulse on time, pulse off time, and discharge current have significant impact on the work piece erosion rate and electrode erosion rate in electric discharge machining of several materials. Present work focuses on finding the significance of these three input parameters on the responses viz. WER and EER.

III. MATERIALS AND METHODS

A. *Work piece and Electrode Material*

Al7075+4Wt %Sic+4Wt %Al2O3 Hybrid MMC was used as the work piece. Aluminum (Al 7075) was used as the base matrix alloy. The aluminium matrix was reinforced with 4Wt% of silicon carbide and 4Wt% of Al2O3 using stir casting method. Chemical composition of Al7075 is given in Table I. A square block of dimensions 50 mm * 50 mm * 5 mm was chosen for the experimentation. Fig. 2 shows two machined blocks of the work piece.

Elements	Wt%
Si	0.2
Fe	0.22
Cu	2.0 max
Mn	0.1
Mg	2.1-2.9
Zn	5.1-6.1
Ti	0.1 max
Cr	0.2
Al	Bal.

Table 1: Chemical Composition of Al7075

Tool material chosen was Copper-Tungsten. Tool was made of cylindrical shape having diameter of 6 millimeter. Percentage of Cu was 90% and tungsten was 10%. CuW electrode used for experimentation is shown in Fig. 5.

Fig. 2: Machined Work piece

Fig. 3: Copper-Tungsten Electrode

B. *Plan of Investigation*

The investigation of machining characteristics was executed according to the following steps.

1) Identification of the important process parameters.

2) Using the Box Behnken Design, to develop the design matrix.
3) Conduction of experiment according to set design matrix and documenting of data after every run.
4) Develop the mathematical models for WER and EER.
5) Performing ANOVA to examine the data.

IV. INVESTIGATION

A. *Parameters with their Levels and Ranges*

The process parameters which can be set on the EDM machine are given in the Table II with their levels used for the experimentation and the ranges available on the machine.

Machining Parameter	Symbol	Levels (in Amps)			Ranges
		Low (-1)	Mid (0)	High (+1)	
Discharge Current	I	5	7	9	1 to 20A
Pulse on time	T_{on}	20	30	40	0 to 99µs
Pulse off time	T_{off}	2	4	6	0 to 9µs

Table 2: Parameters with ranges and levels

Other than these parameters, there are some other controls which are available on the EDM machine like sensitivity, gap control, anti-arc, spark, lift and flushing pressure. All these were kept constant throughout the experimentation.

B. *Development of the Design Matrix and Experimentation*

The design matrix was established using MINITAB software. As per the methodology of the experimentation, the design matrix was developed by RSM with BBD. BBD uses the high (+1) and low (-1) levels of process parameters and generates the design matrix with addition of third level i.e., intermediate level (0). The design matrix with actual parameters and responses is given in Table III. Experiment was performed with two replications.

Run Order	Discharge current in A	Pulse on time in µs	Pulse off time in µs	WER in gm/min	EER in gm/min
1	7	30	4	0.1133	0.0194
2	7	20	2	0.0552	0.0162
3	5	30	6	0.0711	0.0142
4	7	20	6	0.1042	0.0216
5	9	30	2	0.0902	0.0158
6	9	30	2	0.0967	0.016
7	5	20	4	0.0585	0.0122
8	9	20	4	0.0532	0.0226
9	9	20	4	0.109	0.0257
10	5	30	2	0.036	0.0047
11	5	20	4	0.0502	0.0127
12	9	40	4	0.216	0.0306
13	7	30	4	0.1202	0.0196
14	5	30	6	0.0607	0.0084
15	7	40	6	0.1693	0.0263
16	9	40	4	0.201	0.0292
17	5	40	4	0.0873	0.0095
18	9	30	6	0.122	0.0253
19	5	30	2	0.0417	0.0046
20	7	30	4	0.1346	0.0199
21	7	20	6	0.1056	0.0213
22	7	40	2	0.1303	0.0138
23	5	40	4	0.0966	0.009
24	7	30	4	0.119	0.0197
25	7	40	2	0.1332	0.0161
26	7	40	6	0.1622	0.0204
27	7	30	4	0.117	0.0198
28	9	30	6	0.1222	0.024
29	7	20	2	0.047	0.0161
30	7	30	4	0.115	0.0199

Table 3: Experimental Response Table

Work piece erosion rate and electrode erosion rate was calculated by dividing the difference in each of their weights before and after each run by the time taken for each run. The duration of time for each reading was five minutes.

C. *Mathematical Model*

Mathematical models for WER (Y1) and EER (Y2) were established as follows:

$$Y1 = (-0.173716) + (0.059113\ X1) + (-0.009764\ X2) + (0.051069\ X3) + (-0.005522\ X1*X1) + (0.000112\ X2*X2) + (-0.004422\ X3*X3) + (0.001122\ X1*X2)$$

$$Y2 = (-0.009142) + (0.009529\ X1) + (-0.002119\ X2) + (0.005292\ X3) + (-0.000704\ X1*X1) + (0.000020\ X2*X2) + (-0.000694\ X3*X3) + (0.000112\ X1*X2)$$

X1, X2 and X3 represent the corresponding coded values for the discharge current, pulse on time and pulse off time respectively.

D. *Analysis of Experimental Data*

Analysis of variance (ANOVA) was applied to check the adequacy of the empirical response models for WER and EER. Data collected from the experiment was analysed using MINITAB software and regression coefficients for WER and EER were estimated. The significant terms were decided from the P-value. The P-value which is the probability value is defined as the smallest level of significance that would lead to rejection of null hypothesis. This P-value was set equal to or less than 0.10 for 90% confidence level. Table IV and Table V show the ANOVA statistics for WER and EER respectively.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.055981	0.055981	0.006220	43.57	0.000*
Linear	3	0.044775	0.006091	0.002030	14.22	0.000*
Discharge current	1	0.016142	0.001679	0.001679	11.76	0.003*
Pulse on time	1	0.023486	0.001368	0.001368	9.58	0.006*
Pulse off time	1	0.005148	0.002135	0.002135	14.96	0.001*
Square	3	0.006976	0.006976	0.002325	16.29	0.000*
Discharge current × Discharge current	1	0.003492	0.003603	0.003603	25.24	0.000*

Pulse on time × Pulse on time	1	0.001174	0.000928	0.000928	6.50	0.019*
Pulse off time × Pulse off time	1	0.002310	0.002310	0.002310	16.18	0.001*
Interaction	3	0.004229	0.004229	0.001410	9.88	0.000*
Discharge current × Pulse on time	1	0.004032	0.004032	0.004032	28.24	0.000*
Discharge current × Pulse off time	1	0.000001	0.000001	0.000001	0.01	0.926
Pulse on time × Pulse off time	1	0.000196	0.000196	0.000196	1.37	0.255
Residual Error	20	0.002855	0.002855	0.000143		
Lack-of-Fit	3	0.000660	0.000660	0.000220	1.70	0.204
Pure Error	17	0.002195	0.002195	0.000129		
Total	29	0.058836				

Table 4: ANOVA Table for WER

* Indicates the significant terms

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.001224	0.001224	0.000136	44.87	0.000*
Linear	3	0.001025	0.000165	0.000055	18.14	0.000*
Discharge current	1	0.000811	0.000044	0.000044	14.40	0.001*
Pulse on time	1	0.000003	0.000064	0.000064	21.26	0.000*
Pulse off time	1	0.000212	0.000023	0.000023	7.57	0.012*
Square	3	0.000151	0.000151	0.000050	16.66	0.000*
Discharge current × Discharge current	1	0.000057	0.000059	0.000059	19.30	0.000*
Pulse on time × Pulse on time	1	0.000038	0.000031	0.000031	10.10	0.005*
Pulse off time × Pulse off time	1	0.000057	0.000057	0.000057	18.79	0.000*
Interaction	3	0.000047	0.000047	0.000016	5.18	0.000*
Discharge current × Pulse on time	1	0.000040	0.000040	0.000040	13.22	0.002*
Discharge current × Pulse off time	1	0.000002	0.000002	0.000002	0.73	0.404
Pulse on time × Pulse off time	1	0.000005	0.000005	0.000005	1.59	0.222
Residual Error	20	0.000061	0.000061	0.000003		
Lack-of-Fit	3	0.000017	0.000017	0.000006	2.14	0.133
Pure Error	17	0.000044	0.000044	0.000003		
Total	29	0.001284				

Table 5: ANOVA Table for EER

* Indicates the significant terms

From the ANOVA table of WER, by observing the P-value it is evident that all the three parameters are significant as their P-value falls below the set P-value i.e. 0.10 with 90% confidence. Also the interactive effect of discharge current and pulse one time is highly significant.

From the ANOVA table of EER, it is seen that the P-values of all the three process parameters and of the interactive effect of discharge current and pulse on time is less than the set P-value which is 0.10.

Main effect plots of the individual effect of three parameters on WER and ERR are shown Fig. 4 and Fig. 5 respectively. Also interactive effect of discharge current and pulse on time WER and EER is depicted in Fig. 6 and Fig. 7 using surface plot.

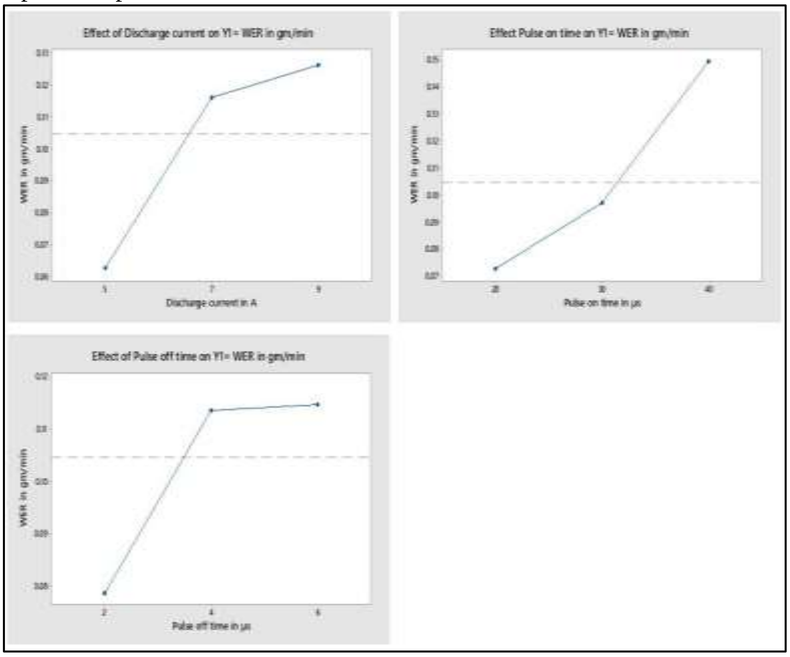

Fig. 4: Main Effect Plot of Influence of Process Parameters on WER

From the above plots and discussion it can be inferred that pulse on time has the highest significant effect on WER as compared to discharge current and pulse off time.

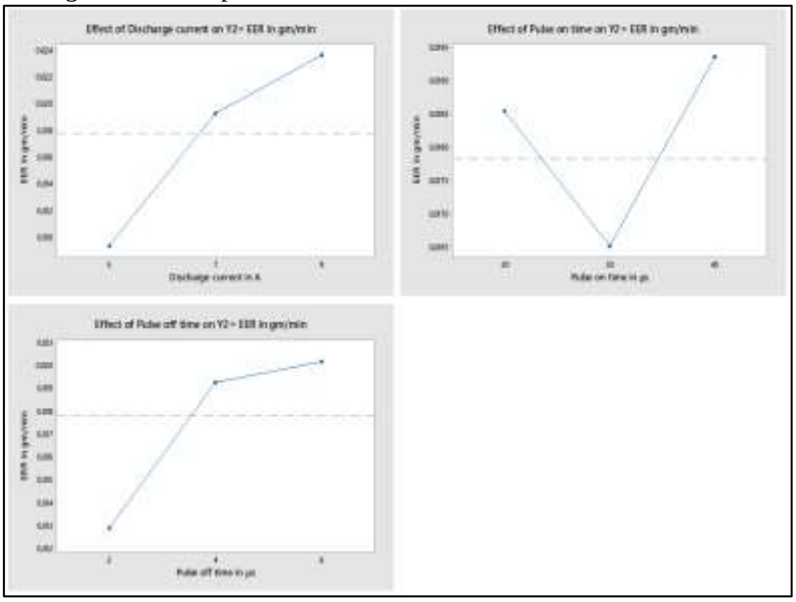

Fig. 5: Main Effect Plot of Influence of Process Parameters on EER

From the above plots it can be deduced that discharge current is the most significant parameter affecting EER as compared to pulse on time and pulse off time.

From the experimental data attained it was evident that discharge current and pulse on time had a highest level of effect on WER and EER. Hence an interactive effect of these parameters on WER and EER is show distinctly using surface plots.

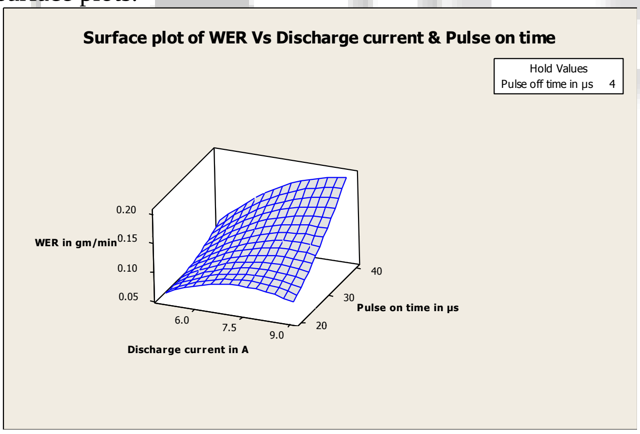

Fig. 6: Surface Plot for WER

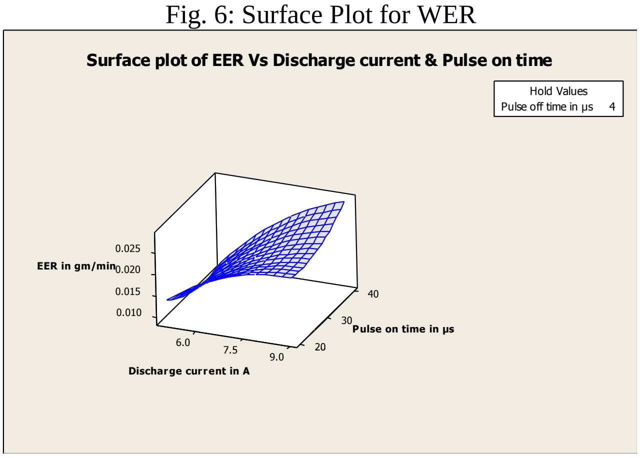

Fig. 7: Surface Plot of EER

V. CONCLUSION

In present study, investigation of the effect of most important parameters of EDM viz. discharge current, pulse on time and pulse off time on machining characteristics was successfully done. Effect of these variables on WER and EER in machining of Al7075/SiC/Al2O3 hybrid MMC using copper-tungsten electrode was effectively calculated by adopting the Box Behnken Design of Response Surface Methodology (RSM). Following conclusions were drawn from the results obtained from the experimentation.

- Discharge current, Pulse on time and Pulse off time are all significant parameters affecting WER and EER.
- Pulse on time is found to have the highest significant effect on WER.
- Discharge current is found to be the most significant factor influencing EER. As the discharge current increases, EER also increases.
- Interaction of Discharge current and Pulse on time has shown highest significant effect on WER and EER as compared to other interaction of input parameters.

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