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Optimization of EDM Parameter of Al/TiC Composite Using Taguchi Methodology

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Abstract: Metal-matrix composites (MMCs) are newly advanced materials having the properties of light weight, high specific strength, good wear resistance and a low thermal expansion coefficient. These materials are extensively used in industry. Machining of hard materials such as metal matrix composites (Al/TiC) to a high degree of accuracy and surface finish is difficult. The use of traditional machinery to machine hard composite materials causes serious tool wear due to abrasive nature of reinforcement. These materials can be machined by many non-traditional methods like water jet and laser cutting but these processes are limited to linear cutting only. Electrical discharge machining (EDM) shows higher capability for cutting complex shapes with high precision for these materials. The objective of this work is to investigate the effect of current (C), pulse on-time (POT) and flushing pressure (P) on Metal removal Rate (MRR), Tool Wear Rate (TRR) during electrical discharge machining of as sintered Al-TiC MMC (5% reinforcement) is prepared by in-situ technique by synthesis route using stir casting furnace. The use of kerosene as dielectric fluid was employed in the present investigation. An L9 orthogonal array was formed to examine both metal removal rate and tool wear rate. Analysis of variance (ANOVA) was performed to find the validity of the experimental plan followed in the present work.

Key words: Electrical discharge machining · Wear · TiC · ANOVA · Taguchi Methodology

INTRODUCTION

Aluminum (Al) alloys are an important vital engineering material for tribological and mechanical applications due to its low density, high thermal conductivity and improved machinability for automobile, aerospace, marine and mineral processing industries. Due to its high wear loss nature it will not be applicable for many tribological applications [1]. The incorporation of a hard ceramic phase like SiC, Al_2O_3, B_4C, TiC, TiB_2, MgO, TiO_2 and BN into a relatively soft matrix alloy improves the strength and wear resistance of the alloy [2].

Generally the hardness of the Al is increased by the reinforcement of Titanium Carbide (TiC) and by increase in different volume fraction of TiC, will increase ultimate strength also [3]. Many techniques were developed for producing particulate reinforced Aluminium Metal Matrix Composites (AMCs), such as powder metallurgy [4], in situ [5] and squeeze casting [6]. From all the above three methods, stir casting technique is the simplest and the most economical process for fabricating particulate reinforced MMCs [7].

For these improved hard and high strength composites materials like AMC with TiC are becoming complex to machine through traditional methods [8]. To overcome this situation, the most advanced non-traditional methods are employed in modern manufacturing environment. Among the non traditional methods of machining processes, Electrical Discharge Machine (EDM) has drawn a great deal for researchers' attention because of its broad industrial applications. EDM is widely used in machining high strength steel,

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tungsten carbide and thermal conductivity [9]. But the processing parameters of EDM for machining the hard composites need to be optimized.

Experimental investigation was carried out in the past to evaluate the effect of current, pulse on time and flushing pressure on Metal Removal Rate (MRR), Tool Wear Rate (TWR) for MMCs through EDM [10]. This raises the objective of this research article to analyse and optimise the processing parameters of EDM for Al-TiC.

Radhika *et al*. [11] found Taguchi technique as a valuable technique to deal with responses influenced by multi-variables. It is formulated for process optimization and detection of optimal combination of the parameters for a given response. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments.

The most important benefit of this technique is to find out the possible interaction between the factors. Investigation of the experimental outcomes uses signal to noise ratio to support the determination of the finest process design. This method is effectively used to analysis of wear behaviour of composites materials [12]. In this work, the "smaller the best" quality characteristics were taken to find the wear ratio between TWR to MRR under various EDM process parameters.

MATERIALS AND METHODS

The Aluminum 6061 alloy (Table 1) was selected as matrix material and it was heated in a resistant heat furnace containing a stirrer. The castings were done in a batch of 600g. For 5% of TiC reinforcement, it was introduced into the alloy by the reaction between the molten alloy and the mixture of 5% K_2TiF_6 and 6g of graphite powders. The salt and graphite powders were mixed in the molar ratio of 1:1.3 [13]. The melt temperature was kept as 900°C. This molten mix was held for about 30 minutes before removing the slag and subsequently poured into a mild steel mould of cylindrical cross section with 30mm diameter. The melt was stirred at regular intervals for distribution of reinforcement in the base metal.

Following reaction (1-3) took place before the formation of Al-TiC.

$$3K_2TiF_6 + 4\,Al \rightarrow 3Ti + 3KAlF_4 + K_3AlF_6 \quad (1)$$

$$Ti + 3Al \rightarrow Al_3Ti \quad (2)$$

Table 1: Chemical composition of Al 6061

Element	Al	Cr	Cu	Fe	Si	Mn	Mg	Zn	Ti
Wt. %	96.5	0.375	0.275	0.7	0.6	0.15	1	0.25	0.15

Table 2: Parameters and levels assigned.

		Levels		
Machining Parameter	Units	Level 1	Level 2	Level 3
Discharge current	A	5	10	15
Pulse on time	µs	50	200	600
Flushing Pressure	Kgf/cm^2	3	6	9

$$Al_3Ti + C \rightarrow TiC + 3Al \quad (3)$$

The work piece used in this experiment was Al-TiC composites with 5% reinforcement. A die sinking EDM machine was used for the machining work. The specimens were cut for the thickness of 3 mm by EDM with the fine surface finishing. Copper hollow tubes of 3mm diameter are used as electrode. The machining parameters assigned for the process is given in the Table 2.

Material removal rate is expressed as the ratio of the difference of weight of the work piece before and after the machining to the machining time (equation 4).

$$MRR = (W_{jb} - W_{ja}) / t \quad (4)$$

Tool wear rate is expressed as the ratio of the difference of weight of the tool before and after the machining to the machining time (equation 5). And the wear ratio (WR) is expressed as the ratio between TWR and MRR.

$$TWR = (W_{tb} - W_{ta}) / t \quad (5)$$

RESULTS AND DISCUSSION

The optimization process involves the studying the response based on the combinations, estimating the coefficients, fitting the experimental data, predicting the response and checking the adequacy of the fitted model. Discharge current, Pulse on Time and Flushing Pressure were chosen as the independent variables and wear ratio was selected as response variable for the composite. The first independent variable (Discharge current) was varied over the low and high levels 5 and 15A. While the second independent variable (Pulse On Time) was varied over the low and high levels of 50 and 600µs and the third independent variable (Flushing Pressure) was varied over the low and high levels of 3 and 9Kgf/cm^2 as shown in Table 3.

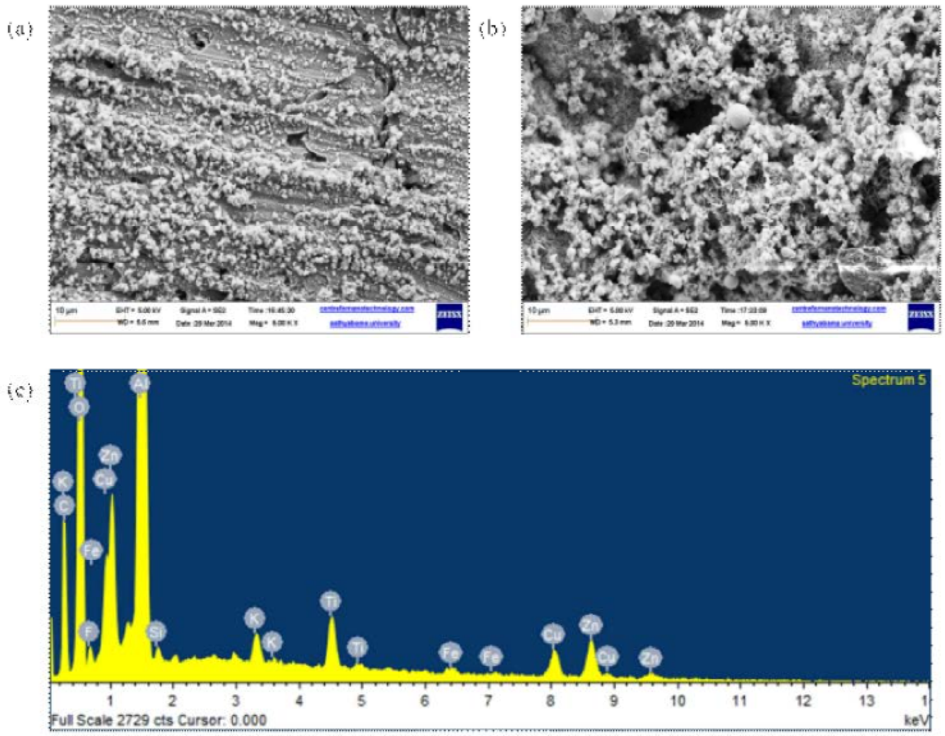

Fig. 1: (a) SEM of tool wear; (b) SEM of work piece; (c) EDAX of work piece.

Table 3: Independent variables and the levels.

Machining Parameter	Lower Level	Upper Level
Discharge current	5	15
Pulse on time	50	600
Flushing Pressure	3	9

Table 4: Analyse of TWR and MRR.

S.No	Current	Pulse on Time	Flushing Pressure	MRR	TWR	WR
1.	5	50	3	0.025	0.017	0.672
2.	5	200	6	0.027	0.019	0.692
3.	5	600	9	0.023	0.032	1.410
4.	10	50	6	0.093	0.032	0.345
5.	10	200	9	0.053	0.039	0.734
6.	10	600	3	0.047	0.086	1.833
7.	15	50	9	0.069	0.068	0.977
8.	15	200	3	0.073	0.140	1.907
9.	15	600	6	0.041	0.178	4.367

In order to the combined effects of the independent variables on the responses, a face centred central composite response surface design with 20 sets of experiment with five repetitions were carried out. The observed responses were fitted to a second order polynomial model shown in equation (6).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1^2 + \beta_{12} X_1 X_2 \quad (6)$$

Where, Y is the observed response; X_1 and X_2 are the independent process parameters; β_0 is the constant; β_1 and β_2 are the linear coefficients; β_{11} is the quadratic coefficients; β_{12}, is the interaction coefficients.

For the above described model, the wear ratio was experimentally found out from the Al-TiC machining process in EDM and it is tabulated in Table 4.

From the table, it was evidenced that the lower WR is noticed at 10A, 50µs POT, with 6Kgf/cm^2 Flushing Pressure. The EDAX and SEM analysis at this level was shown in Fig. 1.

The Fig.1 (a) evidences the minimum wear occurred in the tool compared to work piece wear (Fig. 1(b)). The EDAX analysis (Fig. 1(c)) confirms the transfer of Cu during the EDM process on the work piece from the Cu wire. And also it visualize the Fe transfer from the Al, which confirms the EDM process and protective layer formed on the Al/TiC surface to resist wear [14].

Taguchi Analysis: The minimal WR was noticed but the major influencing parameter was not evidenced from the experimental analysis. The Taguchi analysis helps to find

Table 5: Analyze of TWR and MRR.

Current	Pulse on Time	Flushing Pressure	SN Ratio	SD	MEAN
5	50	3	33.5167	0.005742	0.0207
5	200	6	32.6843	0.005883	0.02284
5	600	9	31.0962	0.006616	0.027478
10	50	6	23.1334	0.04319	0.06267
10	200	9	26.7047	0.0099	0.04568
10	600	3	23.147	0.027759	0.066782
15	50	9	23.3013	0.001125	0.068377
15	200	3	19.0323	0.047073	0.106715
15	600	6	17.7708	0.097149	0.109495

Table 6: Analyze of TWR and MRR.

	Signal to Noise Ratios			Means			Standard Deviations		
Level	C	POT	P	C	POT	P	C	POT	P
s1	32.43	26.65	25.23	0.02367	0.05058	0.06473	0.00608	0.016686	0.026858
2	24.33	26.14	24.53	0.05838	0.05841	0.065	0.026949	0.020952	0.048741
3	20.03	24	27.03	0.09486	0.06792	0.04718	0.048449	0.043841	0.00588
Delta	12.4	2.65	2.5	0.07119	0.01734	0.01782	0.042369	0.027155	0.042861
Rank	1	2	3	1	3	2	2	3	1

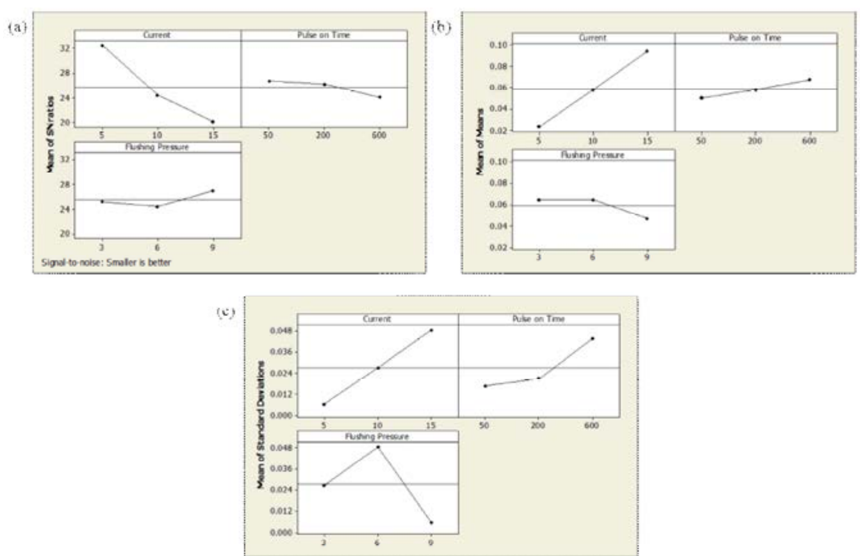

Fig. 2: Effect plots of (a) SN ratios; (b) Means; (c) SD.

the parameters effect on WR. Using the MINITAB 16 environment, the Design of Experiment (DOE) was done on wear ratio through Taguchi design. The wear ratio was analyzed in terms of Signal to Noise Ratios (SN) ratio, standard deviation (SD) and mean plots. It is tabulated in Table 5.

The minimal WR was noticed but the major influencing parameter was not evidenced from the experimental analysis. The Taguchi analysis helps to find the parameters effect on WR. Using the MINITAB 16 environment, the Design of Experiment (DOE) was done on wear ratio through Taguchi design. The wear ratio was analyzed in terms of Signal to Noise Ratios (SN) ratio, standard deviation (SD) and mean plots. It is tabulated in Table 5.

The Table 6 shows the taguchi analysis of Signal to Noise Ratios (SN) ratio, standard deviation (SD) and mean plots for Discharge current, Pulse on Time and Flushing Pressure. The influence of input parameter are varied on varies levels, it is evidenced from the variation of results of SN ratios, Means and SD plots shown in Fig.2.

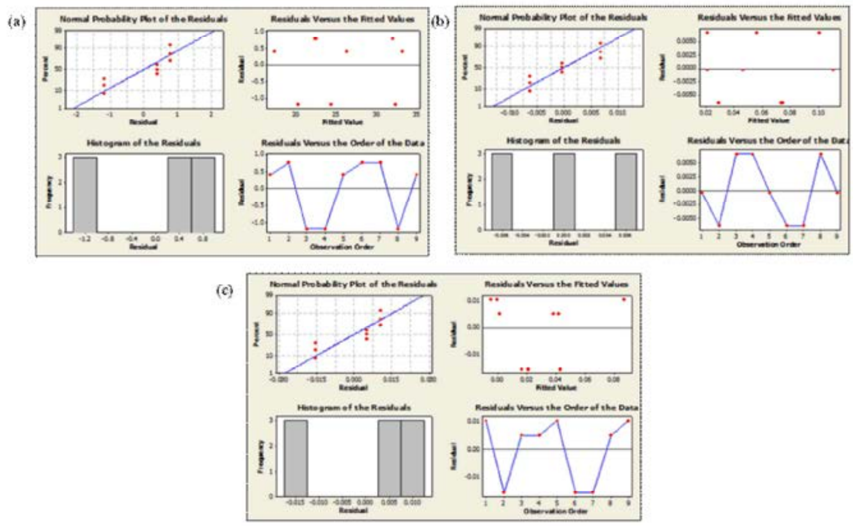

Fig. 3: Residual plots of (a) SN ratios; (b) Means; (c) SD.

Table 7: Estimated Model Coefficients.

Term	Estimated Model Coefficients SN ratios	Means	SD
Constant	25.5985	0.058971	0.007934
Current 5	6.8339	-0.0353	0.011221
Current 10	-1.2701	-0.00059	0.011221
Pulse on 50	1.0519	-0.00839	0.011221
Pulse on 200	0.5419	-0.00056	0.011221
Flushing 3	-0.3665	0.005761	0.011221
Flushing 6	-1.069	0.006031	0.011221

Table 8: Estimated Model Coefficients.

Term	Estimated Model Coefficients SN ratios	Means	SD
S	1.797	0.01123	0.02380
R-Sq	97.6%	97.2%	85.6%
R-Sq(adj)	90.30%	88.70%	42.30%

Table 9: Analysis of Variance for SN ratios.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current	2	237.811	237.811	118.906	36.81	0.026
Pulse on Time	2	11.822	11.822	5.911	1.83	0.353
Flushing Pressure	2	10.014	10.014	5.007	1.55	0.392
Residual Error	2	6.46	6.46	3.23		
Total	8	266.107				

The results are not concluded from the Taguchi analysis so the variance has been analyzed for Signal to Noise Ratios (SN) ratio, standard deviation (SD) and mean.

The Table 7 shows the estimated model coefficients of SN ratio, Means and SD. From this the plots are generated for the input and results values. And the model of residual plots is shown in Fig. 3.

The Table 8 shows the estimated coefficients of lower and upper levels of input parameters. The obtained S value is 1.797, R-Sq is 97.6% and the R-Sq(adj) is 90.30% from the SN ratios is the most significant.

The Table 9 is the ANOVA for SN ratio of WR. The P value obtained is less than 0.5 and also lesser than F value at all input levels. It confirms that the WR is significant and agrees with the results of SN ratio. From this analysis, the influencing parameters are sorted in the order of percentage of effect it causes on WR. This result is concluded by the SN ratios, i.e. discharge current, pulse on time and then flushing pressure.

Regression Analysis: As considering the WR, the most influencing parameter is inferred but considering TWR or MRR alone the most influencing parameter is to be inferred. The regression analysis for TWR and MRR are shown in equation 6 and 7 respectively.

$$TWR = - 0.0328 + 0.0106 *C + 0.000104 *POT - 0.00581 *P \quad (7)$$

$$MRR = 0.0265 + 0.00363 *C - 0.000044 *POT - 0.00004 *P \quad (8)$$

From this analysis, it is inferred that the most influencing parameter is discharge current and the second influencing parameter is POT for high wear and flushing pressure for low wear. This varying phenomenon leads the results of WR.

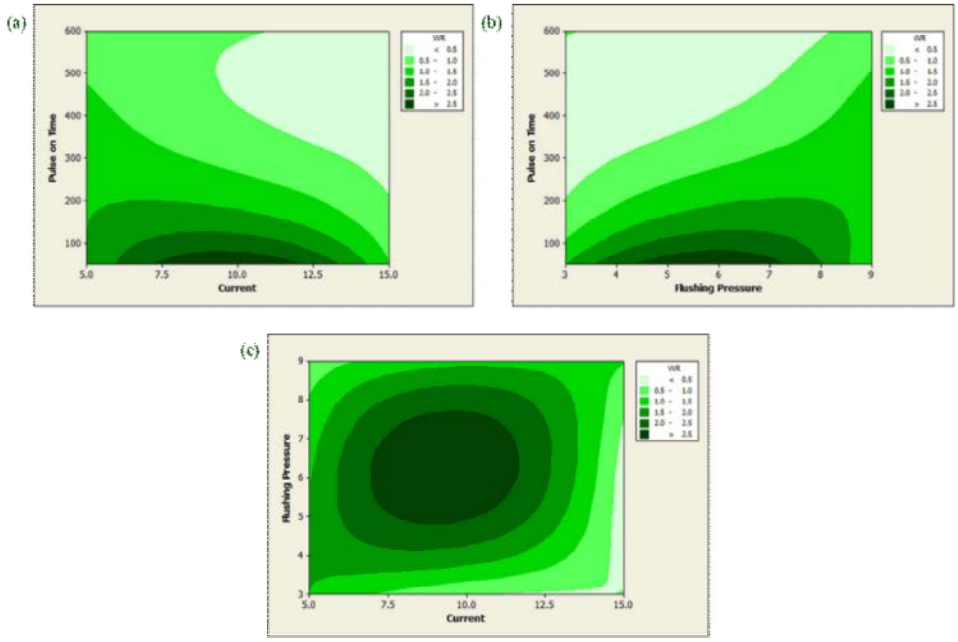

Fig. 4: Contour plots of WR (a) C Vs POT; (b) P Vs POT; (c) C Vs P.

Wear Analysis: From the experimental results the wear analysis was done. The contour plots are drawn by varying the influencing parameters. The Fig. 4 shows the Contour plots of WR (a) C Vs POT; (b) P Vs POT; (c) C Vs P. The Fig. 4(a) shows that the WR is less at high POT and C. the Fig. 4(b) shows that the WR is less at low P and high POT and the Fig.4 (c) shows the WR is less at high C and low P.

From these inferences, it was concluded that the WR is less at high C, POT and with low P. but the exact level of influence couldn't be inferred from it. The exact levels are inferred from the taguchi and regression analysis and it is confirmed significantly by ANOVA.

CONCLUSION

The hard AMC with 5% TiC was casted using liquid casting technique for the machining process. The non-traditional method called EDM was concluded as better for machining a hard AMC. The processing parameters of EDM like discharge current, pulse on time and flushing pressure were considered for analysing and optimization. The modern statistical tool called Taguchi from DOE was used to examine the significance and prediction. By this, the wear ratio of Al-TiC composite at various condition were significant and acceptable since the p-value is lesser. The optimal levels of EDM process were 10A current, 50µs pulse on time and flush pressure of 6 kgf/cm^2.

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