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Some investigations into the sinker type EDM of hybrid alsic MMC using RSM approach.

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ABSTRACT

The present study deals with preparation of metal matrix composites(MMC), Aluminium (Al 6061) used as base material is reinforced with 3wt. % silicon carbide and 3wt. % Aluminium oxide (3wt. %SiC+3wt. %Al2O3) by stir casting method. The objective of this project is to investigate the effect of process parameters such as current (I), pulse on time (Pon) and pulse off time (Poff) on material removal rate (MRR) and tool wear rate (TWR) during electrical discharge machining (EDM) process. The tool used here is copper-tungsten. In this paper mathematical models are prepared by response surface methodology (RSM) and central composite design (CCD) for different combinations of process parameters. Analysis of variance (ANOVA) is used to check the significance of the model.

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Introduction:

Composite material is a combination of two or more than two distinct materials which have recognizable interface between them.[1] MMC are one of the recent advanced materials having properties of light weight, high strength, good wear resistance and so on [2] .These composites are mainly used in aerospace, structural and automotive industries.

Aluminium 6061 is the base matrix material used in this case study with SiC and Al_2O_3 reinforced in it. As these reinforced materials provide hardness and high strength to the composites it is difficult to machine such composites by conventional machining process, hence non-conventional machining technique is used [3].

Electrical discharge machining (EDM) is one of the most often used non-conventional technique. This process is most suitable for such kind of machining. As the percentage of SiC is increased in the MMC there is decrease in material removal rate (MRR) and increase in tool wear rate (TWR) [4].

Experimental details:

During this study, a series of experiments were conducted on hybrid AlSiC using electrical discharge machine with a model of PRIDE-Z manufactured by ELECTRONICA MAKE EDM to examine the effect of input process parameters such as current, pulse on time, pulse off time, on the machining rate of tool and work piece. In this test, the responses i.e. output variables, namely Material removal rate and tool wear rate were measured using different techniques [5].

Work piece material:

In this experimentation, Al6061 is used as base material reinforced with 3wt. % of SiC and 3wt. % of Al_2O_3 by Stir casting method. After casting the metal matrix composite is cut into pieces of dimensions 50x50x5, all dimensions are in mm. chemical composition and properties are given in Table.1and 2.

Table: 1. Chemical composition of Al6061 by wt. percent

Chemical composition	Al6061
Si	0.62
Fe	0.23
Cu	0.22
Mn	0.03
Mg	0.84
Cr	0.22
Zn	0.10
Ti	0.1
Al	Bal

Table: 2. Properties of Al6061

Properties	Al6061	SiC	Al_2O_3
Elastic modulus(Gpa)	70-80	410	300
Density (g/cc)	2.7	3.1	3.69
Poisons ratio	0.33	0.14	0.21
Hardness (HB500)	30	800	1175
Tensile strength (T) / Compressive strength(C) (Mpa)	115 (T)	3900 (^{0}C)	2100 (^{0}C)

Tool material

The tool used is a copper-tungsten which is made by powder metallurgy technique. This prepared tool is then machined on the lathe machine to get the desired diameter. After turning process the facing is done and hence the tool is ready for machining process. Properties of copper tungsten are shown in Table.3.

Table: 3. Properties of copper tungsten [5]

Properties	Copper Tungsten
Composition	75% tungsten, 25% copper
Density(g/cm^3)	15.2
Melting point(^{0}C)	3500
Electrical resistivity(μΩ cm)	5.5
Hardness	HB200

Experimental setup and procedure:

The experimental setup of electrical discharge machining (EDM) is as shown in Fig.1

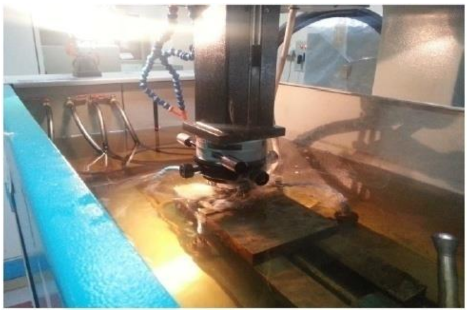

Fig.1: Experimental setup of EDM

The work piece is initially weighed on digital weighing machine. The work piece is then rigidly hold on the fixture. The tool electrode is clamped in the quill. Parameter settings were done based on the design matrix of central composite design. The work piece selected for the experimental work having the dimension of 50 x 50 x6 mm. The copper–Tungsten (Cu-W) tool electrode used of diameter 8mm.Impulse flushing is adopted and is applied between tool and work-piece gap. The dielectric fluid used is commercial EDM120 oil. The experiments were conducted in the submerged condition. for 3minutes.The work-piece and the tool is taken out from the fixture then cleaned and weighted on the digital weighing machine for 40 run numbers as per central composite design.

Response variables evaluations:

The evaluation of response variables are done to study the effect of MRR and TWR on Al6061 + 3wt. %SiC_p + 3wt. %Al_2O_3 metal matrix composite with the following formula. [2, 6, 7]

Material removal rate (MRR): is measured by dividing the difference of initial and final wt of work-piece by the time taken to machine.

$$MRR = \frac{W1 - W2}{T} \quad \text{in gms/min}$$

Where,

'W1' is the initial wt of the work-piece before machining in grams

'W2' is the final wt of the work-piece after machining in grams

'T' is the time taken for machining in mins

Tool wear rate (TWR): is measured by dividing the difference of initial and final wt of the tool electrode by the time taken to machine.

$$TWR = \frac{E1 - E2}{T} \quad \text{in gms/min}$$

Where,

'E1' is the initial wt of the tool before machining in grams

'E2' is the final wt of the tool after machining in grams

'T' is the machining time in min

Design of experiments (DOE):

In this study the experiments are conducted based on the influence of three input process parameters like current (I), pulse on time (P_{on}) in microsecond (μS) and pulse off time (P_{off}) in microsecond (μS) proposed by central composite design (CCD) method to run 40 experiments. The process parameter and their levels chosen and available range on the machine are shown in Table.4. [3, 8]

Table.4 Input process parameters, their levels chosen and the ranges available on machine [2][7]

Table: 4. Machining parameters, their levels chosen and the ranges available on machine

Machining parameters	Un coded value	Coded value	Levels			Ranges
			Low (-1)	Mid (0)	High (1)	
Current	**I**	X_1	2	5	8	1 to 20A
Pulse on time	P_{on}	X_2	25	45	65	0 to 99μs
Pulse off time	P_{off}	X_3	3	5	7	0 to 9μs

Results and Discussions

Mathematical models for MRR and TWR [9]

The empirical mathematical models of the response parameters are defined in terms of input parameters. In this case it is quadratic in nature.

Suppose (X_1), (X_2) and (X_3) are the process parameters and 'Y_i' is the maximum yield of the process then the yield is a function of coded values (X_1), (X_2) and (X_3)

$$Y_i = f(X_1, X_2, X_3) \ [2]$$

Where

Y_i represents the responses

X_1 represents current

X_2 represents pulse on time

X_3 represents pulse off time

Mathematical model for MRR (Y1) and TWR (Y2) when Al6061+3wt. %SiC+3wt. %Al_2O_3 work-piece and copper-tungsten electrode is used are given below: [3, 2, 6, 10]

$$Y1 = -0.118804 - 0.021152X1 + 0.005359X2 + 0.001937X_1^2 - 0.000052X_2^2 + 0.000264X_1X_2 + 0.002045X_1X_3 - 0.000282X_2X_3$$

$$Y2 = -0.040222 - 0.007695X_1 + 0.008609X_3 - 0.000096X_1X_2 + 0.000377X_1X_3 - 0.000123X_2X_3$$

Table: 5. Estimated Regression Coefficients for MRR in gms/min

Term	Coef	SE Coef	T	P
Constant	-0.118804	0.053047	-2.240	0.033*
Current	-0.021152	0.010031	-2.109	0.043*
Pulse on time	0.005359	0.001871	2.864	0.008*
Pulse off time	0.018654	0.020361	0.916	0.367
Current*Current	0.001937	0.000856	2.265	0.031*
Pulse on Time* Pulse on Time	-0.000052	0.000019	-2.702	0.011*
Pulse off Time* Pulse off Time	-0.000879	0.001925	-0.456	0.651
Current* Pulse on Time	0.000264	0.000075	3.515	0.001*
Current* Pulse off Time	0.002045	0.000752	2.718	0.011*
Pulse on Time* Pulse off Time	-0.000282	0.000113	-2.502	0.018*

R-Sq = 90.52%, R-Sq (adj) = 87.67%

Table: 6. Estimated Regression Coefficients for TWR in gms/min

Term	Coef	SE Coef	T	P
Constant	-0.040222	0.012384	-3.248	0.003*
Current	0.007695	0.002342	3.286	0.003*
Pulse on Time	0.000419	0.000437	0.959	0.345
Pulse off Time	0.008609	0.004753	1.811	0.080*
Current* Current	-0.000124	0.000200	-0.621	0.539
Pulse on Time* Pulse on Time	0.000004	0.000004	0.978	0.336
Pulse off Time* Pulse off Time	-0.000352	0.000449	-0.784	0.439
Current* Pulse on Time	-0.000096	0.000018	-5.443	0.000*
Current* Pulse off Time	0.000377	0.000176	2.148	0.040*
Pulse on Time* Pulse off Time	-0.000123	0.000026	-4.655	0.000*

R-Sq = 89.89%, R-Sq (adj) = 86.86%

Effect of process parameters on MRR and TWR:

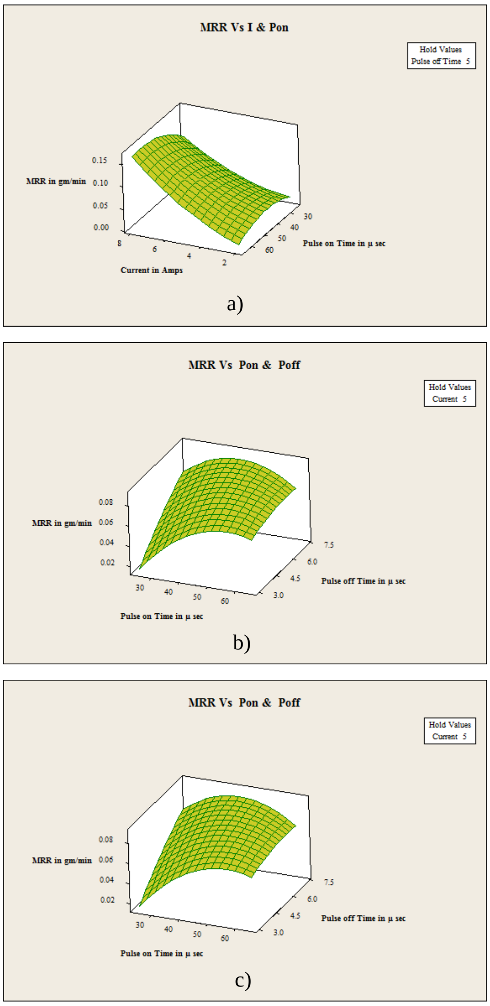

Fig.2: a, b, c shows estimated surface plot for MRR in relation to current, pulse on time and pulse off time.

Fig.2 shows the response surface plot for MRR in relation to input parameters. Graph (a) shows the response surface plot of MRR versus current and pulse on time. As the current increases MRR also increases linearly. For 2 Amps MRR is 0.02 gm/min, similarly for current 5 Amps MRR is 0.075 gm/min and for 8 amps MRR is0.14 gm/min.

As the pulse on time increases MRR increases and then starts deceasing slowly. For 25 µ sec MRR is 0.06 gm/min. For 45 and 65 µ sec the MRR remains constant. From the graph it is clear that MRR is high (0.186000 gm/min) for high current (8 Amp) and pulse on time (45µsec).

This is because discharge energy is increased with increase in current and pulse on time to facilitate the action of melting and vaporization and creating a large impulsive force in the spark gap, thereby increasing MRR. [3]

From graph (b) for surface plot it is relevant that the current and pulse off time combined is significant factor of MRR. As the current increases MRR also increases. Now for increase in pulse off time MRR increases till 5 µ sec and then starts decreasing. For 3 µ sec pulse of time MRR is 0.015 gm/min. For pulse off 5 µ sec it is around 0.04 gm/min and 0.021 gm/min for 7 µ sec pulse off time. MRR is high (0.168000 gm/min) for high current (8 Amp) and high pulse off time (5 µsec).

Graph © clearly depicts the effect of pulse on time and pulse off time on MRR. The combined effect of pulse on and pulse off is significant on MRR. MRR is high (0.085 gm/min) for low pulse on (25 µsec) and high pulse off time (7 µsec). This is because of correct flushing which removes the debris that make spark contamination leading to reduction in MRR.[11]

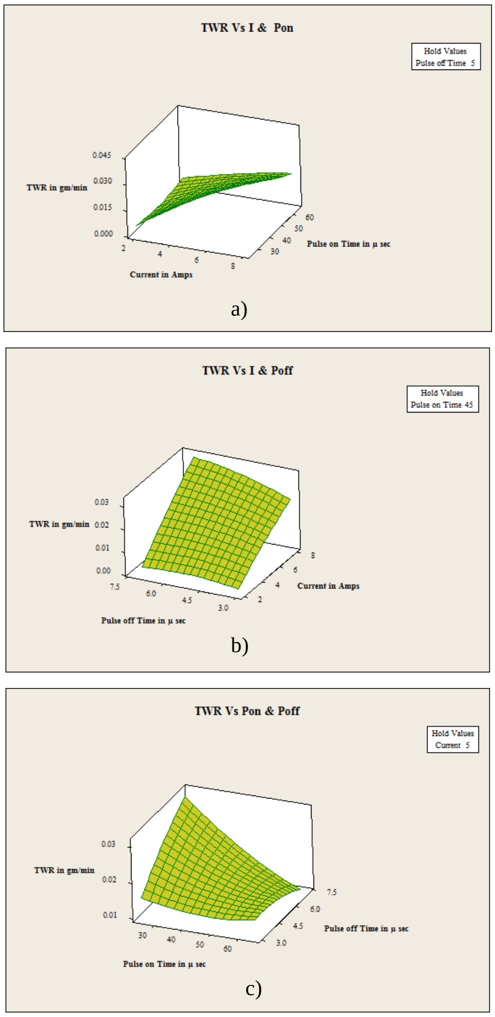

Fig. 3: a, b, c estimated surface plot for TWR in relation to current, pulse on time and pulse off time.

Fig.3 shows the response surface plot for MRR in relation to input parameters. Graph (a) represents the effect of current and pulse on time on TWR. As the current increases tool wear also increases but Decreases with increase in pulse on time. The combined effect of current and pulse on time is most significant on TWR. For current 2 Amps TWR is 0.002 gm/min, for 5

Ampere TWR is 0.0021gm/min and for 8 Amp tool wear is 0.029 gm/min. Hence tool wear goes on increasing with current. But TWR goes on decreasing with increasing pulse on time. For pulse on time 25, 45, 65 µ sec TWR is 0.024, 0.018, 0.016 gm/min. TWR is low (0.004 gm/min) for low current (2 Amp) and high value of pulse on time (45 µsec).

In graph (b) the TWR increases slightly with pulse off time and decreases at a mid value 5 micro seconds. The combined effect of current and pulse off time is significant on TWR. Pulse off time here is a significant factor for TWR. For 3, 5, 7 µ sec pulse off time TWR is 0.014, 0.019, 0.02 gm/min respectively. TWR is low (0.004) for low current (2 Amp) and mid pulse off time (5 µsec).

The combined effect of pulse on and pulse off is significant on TWR even though the pulse on time is insignificant on TWR as shown in graph ©. Tool wear is low (0.0020 gm/min) for high pulse off time (7 µsec) and high pulse on time (65 µsec). For longer pulse on duration, lower current and pulse off time tends to increase the carbon deposition on the tool surface that helps to minimize tool wear.[11]

Conclusions:

In the present work, the analytical and experimental study is carried on $AlSiC+Al_2O_3$ as work-piece material and copper-tungsten as tool material. The effect of the process parameters such as current, pulse on time, and pulse off time on MRR and TWR are studied with the help of RSM approach. [5, 11]

The following are the broad conclusions made:

Current and Pulse on time are the major significant factors that affect MRR. MRR increases with increase in the pulse on time in µ second and current in Amp, but decreases with the further increase in pulse on time [12]. Current and pulse off time are the major significant factors that affect TWR.TWR increases with increase in current and pulse off time. The predicted values of machining performance match with the experimental values, with R^2 of 90.52% and 89.89% for MRR and TWR respectively. The created mathematical models can be utilized to assess MRR and TWR with low percent Error. The first optimum parameter of a combination setting current is 8 Amps, pulse on time 65 micro seconds and pulse off time 7 micro seconds for maximizing MRR and minimizing the TWR. Second optimum parameter combination is current 8 Amps, 45 micro second pulse on time and 5 micro second pulse off time for high MRR and low TWR. The results obtained can be used to serve as technical database in aerospace, automotive industries. The mathematical model for MRR and TWR are well fitted for experimental values with 90 percent confidence level.

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