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Design and Optimization of EDM using Metal Matrix Composite by Genetic algorithm and Jaya Algorithm

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Abstract*: Aluminum Boron carbide (Al-B4C) is a form of metal matrix composite (MMC) belongs to advanced category of material which is gaining popularity now-a-days because of its excellent mechanical and physical properties. Unconventional machining processes (UMPs) are now day's best options to machine such kinds of modern materials. Electro discharge machining (EDM) process now days the best UMP whichever utilizes thermic energy power of spark for material removal. In present research the EDM has been carried out in Al-B4C MMC by varying different EDM parameters to evaluate material removal rate (MRR) and tool wear rate (TWR). The response surface model (RSM) has been developed for both the MRR and TWR. The developed RSM has been utilized during optimization. Optimizations of responses the MRR and or TWR have been done by using genetic algorithm and jaya algorithm. Finally both the algorithms have been compared with respect to current manufacturing paradigm.

Keywords: **Electric discharge machining, Genetic Algorithm, Jaya Algorithm, Metal matrix composite.**

I. INTRODUCTION

AMMCs are known as aluminium –metal- matrix -composites which are comparatively newer category of materials these composites are most extensively used in the many advanced engineering industries applications. Al-SiC, Al-Al2O3, Al-B4C, Al-graphite, Titanium-SiC, Iron-Copper-Graphite are examples of few popular MMCs. Because of their excellent mechanical properties, the conventional processes of machining have confirmed ineffective for machining such advanced AMMCs. Many unconventional machining processes (UMPs) have been evolved in the past to machine such types of materials (Shrivastava and Dubey, 2014). Some of the most preferred UMPs now days are ECM, EDM, LBM, ultrasonic machining, plasma arc and AJM.

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Furthermore EDM is thermo power/energy based UMPs which has economizes the heat power of generated sparks between tool and work piece. Because of fusion and vaporization of work piece with the localized intense heat removal of material takes place (Jain, 2015). The EDM on AlB4C MMC have been performed by few researchers. Surekha et al. (2018) depicted electric discharge machining on the Al- red- mud MMC by deviating pulse- on time, open circuit voltage and peak current and evaluated TWR , MRR and radial overcut. The central composite DOE was selected for performing the experiments. They found that the current and on-time are more expressive input control factors. Kumar et al. (2014) considered Al-B4C-SiC MMCs for their scientifically designed EDM experimentation by deviating different EDM parameters to study TWR, SR & power consumption. They concluded that the more suggestive control factor is the peak current affecting all the response characteristics. Furthermore SEM was used to analyzed the surface and observed that surface is full of recast layer, waviness and bubbles. Yadav et al. (2017) did grinding-EDM hybrid machining on hybrid aluminum MMC. Electrical EDM parameters, abrasive grit size, wheel speed and table speed were advised as control input factor while output parameters were surface integrity and MRR. They have been concluded that high values of parameters boost high MRR at certain value of pulse-off time. Correspondingly, abrasive grit size plays significant influence on SR and MRR. Yadav et al. (2016) used the erosion and abrasion based compounded wheel to perform electric discharge grinding on hybrid Al-SiC-B4C MMC. They acknowledged that the high wheel speed effects in the more MRR and best surface quality. Correspondingly, high grit number of abrasive results in the better surface finishes but poor MRR. Kandpal et al. (2018) conducted EDM of Al-Al2O3 MMC to figure out the most important process output parameter that is MRR. They have been selected duty factor, pulse-on time and gap current as input control parameters. They find the optimal values of input control factors. Kumar and Parkash (2016) studied the effect of EDM parameters and electrode material on MRR, TWR and SR during EDM of Al- B4C MMC. They used three different electrodes; EN-19, graphite and copper to evaluate the process performance. Taguchi based L9 orthogonal array DOE was assumed to perform the experiments. Analysis of variance (ANOVA) revealed that peak current is more contributing factor for respsoses.

Further, they optimized the process with an objectives to maximizes the MRR and minimize the TWR & SR. Kumar et al. (2015) identified the optimum control factors for both the qualities by applying combined approach of grey relational analysis and Taguchi method. Rajkumar et al. (2014) selected hybrid Al/B4C/Graphite MMCs to evaluate MRR and TWR during EDM. Dubey and Singh (2018) fabricated Al-B4C MMC by stir casting and performed EDM varying different parameters. They developed RSM for MRR and concluded that peak current and pulse-on time are most important parameters for MRR. Sankar et al. (2014) also did considerable work on Al-B4C MMC to study different process behavior.

II. METHODOLOGY

A. Response surface model

In the response surface methods (RSMs), the fitness among the input control factors and output parameters is expresses as:

$$y = \emptyset(x1, x2, x3, \dots \dots \dots \dots . xp), (1)$$

The detailed discussion of RSMs has been presented somewhere (Phadke, 1989).

B. Genetic algorithm

As we know GA as a met heuristic which is assumed the natural selection based method. Generally GA is employed for solving optimization problems which were non linear where the conventional methods are very slower and or not give better outputs (Shrivastava and Dubey, 2016).

C. Jaya Algorithm

Jaya is evolutionary optimization algorithm has inherit certain advantages over other optimization methods. The Flow chart (Fig. 1) depicts the working of Jaya algorithm (Rao, 2016).

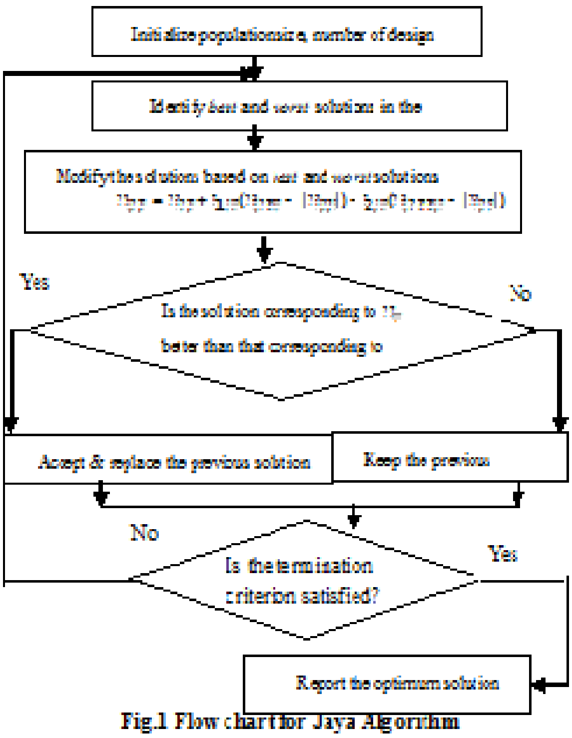

Fig.1 Flow chart for Jaya Algorithm

III. EXPERIMENTAL DETAILS

The experimentations were performed on ELEKTRA PLUS die sinking electrical discharge machine as shown in the Fig. 2. The input control factors selected were peak current, pulse on time and pulse off time. The different input control factors and their levels are given in Table I. The positive polarity has been used during the experimentation. The Al-B4C MMCs has been chosen as work piece material. The experimentations have been conducted using box-behnken DOE. Each experiment was performed for 45 minutes and responses MRR and TWR in every experimental run are acquired by computing the difference of mass of the work piece/tool measured before and after the experiment. To measure the mass of the samples the précised electronic digital weight balance with 0.1 mg resolution was used.

Fig. 2 EDM machine tool used for Experimentation

Table- I: Control Factors and Their Levels

Factors	Peak Current (A)X_1	Pulse-on time (μs)X_2	Pulse-off time(μs)X_3
Low (-1)	1	10	15
Central (0)	3	20	20
High (1)	5	30	25

Responses MRR and TWR in g/min mathematically were obtained by the following relation:

$$MRR/TWR = \frac{m_i - m_f}{t_p} \qquad (2)$$

In the above formula m_i and mf are first and last mass of the work piece/tool (after machining); respectively. Then observed values of the responses have display in the Table II. The machined samples of the work piece are shown in the Fig. 3.

Table- II: Experimental Observation

Ex. No	Control Factors			Responses	
	X_1	X_2	X_3	MRR (gm/min)	TWR (gm/min)
1	0	0	0	0.0072	0.0029
2	-1	-1	0	0.0025	0.0005
3	0	0	0	0.0069	0.0031
4	-1	1	0	0.0097	0.0007
5	0	1	-1	0.0293	0.0046
6	0	1	1	0.0285	0.0033
7	1	1	0	0.0551	0.0048

8	1	-1	0	0.0270	0.0034
9	1	0	-1	0.0474	0.0039
10	0	0	0	0.0079	0.0030
11	-1	0	1	0.0053	0.0004
12	0	-1	-1	0.0119	0.0012
13	-1	0	-1	0.0041	0.0008
14	1	0	1	0.0396	0.0036
15	0	-1	1	0.0092	0.0023

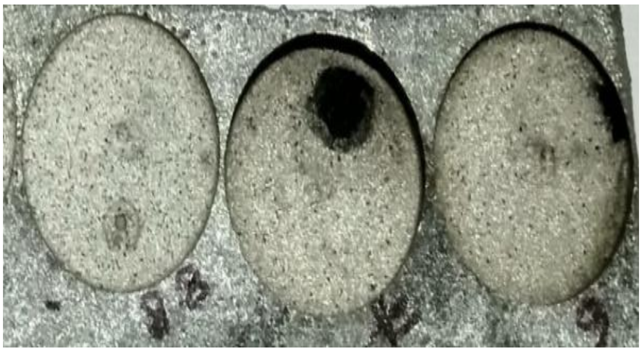

Fig. 3 Sample of machined surface

Total	14	0.00412			

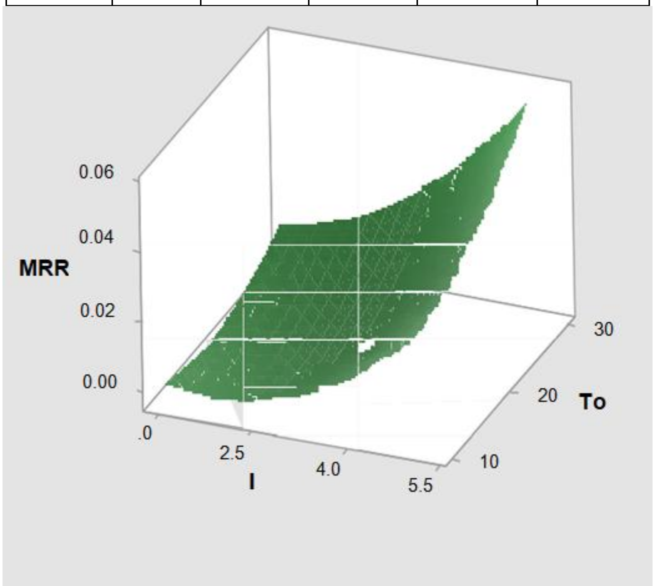

Fig. 4 Effect of peak current and pulse-on time on MRR

IV. MODELING AND OPTIMIZATION

Modeling

Response surface models (RSMs)

A. RSMs for MRR

In the Table III results of ANOVA for MRR have shown. Finally results shows that Peak current with a contribution of 79.7 % are viewed as more suggestive control factor followed by pulse-on time. Equation 5 represents the RSM for MRR. All the 15 data set as represented in Table 2 have been utilized to develop MRR RSM. The F-statistics for the model has been reported to be 299.30. The value of R^2 and adjusted R^2 has found to be 99.75% and 99.24%, respectively. The S value for the model is 0.0013, which is considerably negligible. All these statistical parameters show that developed RSM is reliable to predict the process output i.e. MRR.

$$MRR = 0.1192 - 0.00697X_1 - 0.002257X_2 - 0.00991X_3 + 0.002577{X_1}^2 + 0.000059{X_2}^2 + 0.000258{X_3}^2 + 0.000261X_1X_2 - 000255X_1X_3 \quad (3)$$

Fig. 4 elucidates the effect of peak current and pulse-on time on MRR. It is evident that as peak current and pulse-on time increases, the MRR also improves. The spark energy is proportional to the peak current and pulse-on time and hence as these two parameters increases, the more fusion and vaporization of work piece material takes place, which ultimately results in more MRR.

Table-III: Analysis of Variance for Material Removal Rate

Source	Degree of freedom	Sum of square	Mean square	F	Contribution (%)
Peak current	2	0.00311	0.00156	89.08	76.71
Pulse-on time	2	0.00078	0.00039	22.27	19.18
Pulse-off time	2	0.00017	0.00008	4.77	4.11
Error	8	0.00014	0.00002		

B. RSMs for Tool Wear Rate

ANOVA results for TWR model has shown in the Table IV. Peak current contributing of 82.77 % has been found as more suggestive control factor accompanied by pulse- on time. Pulse-off time has been setup as inconsiderable control factor for TWR. Equation 6 represents the RSM for TWR. All the 15 data set as represented in Table II have been utilized to develop TWR model.

The F-statistics for the model has been reported to be 34.43, the value of R^2 and adjusted R^2 has found to be 95.03% and 92.27%, respectively. The S value for the model is 0.0004, which is considerably negligible. All these statistical parameters show that developed RSM is reliable to predict the process output i.e. TWR.

$$TWR = -0.00690 + 0.001809X1 + 0.000315X2 + 0.000217X3 - 0.000163X2 - 0.000012X2X3 \quad (4)$$

Fig. 5 depicts the effect of peak current and pulse-on time on TWR. The TWR has increasing trend with the both of the input control factors. The more spark energy will results in more melting of the tool material, which will result in increased TWR.

Table-IV: Analysis of Variance for Tool Wear Rate

Source	Degree of freedom	Sum of square	Mean square	F	Contribution (%)
Peak current	2	0.00002	0.00001	127.9	82.77
Pulse-on time	2	0.00000	0.00000	26.05	12.41
Pulse-off time	2	0.00000	0.00000	0.59	0.38
Error	8	0.00000	0.00000		
Total	14	0.00002			

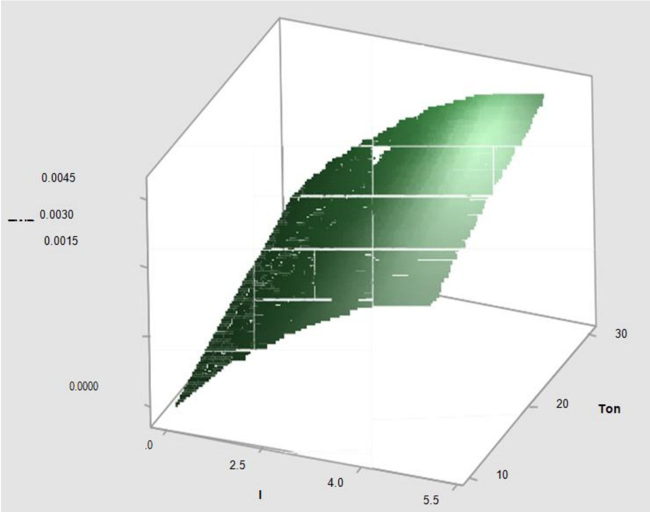

Fig. 5 Effect of peak current and pulse-on time on TWR

Optimization

The objective functions of optimizations problem can be expressed as below:

Find: X_1, X_2, and X_3

Maximize:

$$MRR = 0.1192 - 0.00697X_1 - 0.002257X_2 - 0.00991X_3 + 0.002577X_1^2 + 0.000059X_2^2 + 0.000258X_3^2 + 0.000261X_1X_2 - 0.000255X_1X_3 \quad (5)$$

And;

Minimize:

$$TWR = -0.00690 + 0.001809X1 + 0.000315X2 + 0.000217X3 - 0.000163X2 - 0.000012X2X3 \quad (6)$$

With the boundary conditions:

$1 \leq X_1 \leq 5$

$10 \leq X_2 \leq 30$

$15 \leq X_3 \leq 25$

A. Optimization of quality parameters using Genetic algorithm

The MATLAB 14.0 has used for optimization of MRR, 20 is the population size , 0.7 is the cross over rate , 0.01 is the mutation rate and 110 are the number of iterations ; were found optimum. Accordingly, they are considering here as the critical GA parameters. In Eq. (7) the objective function of the MRR as noted has been figured out by analyzing the non constraint optimizations problem. The plots of generation vs. fitness have been shown in the Fig.6. It was noted from the plots that after 8 generation the mean curve merges to the better curve. Analogous to that the values of input control factors peak current, pulse-on time and pulse-off time have been found to be 5 A, 30 µs and 15 µs; respectively. Analogous to these optimum values of the input control factors, the value of MRR has been acquired as 0.070 g/min.

Furthermore, for TWR 20 is the population size, 0.8 is the cross-over rate, 0.02 is mutation rate and 50 are the number of iterations; were found optimum. So in Eq. (8) the objective function of the TWR as mentioned has been solved by analyzing the non constraint optimizations problem. The plots of generation vs. fitness plots have been shown in the Fig.7. It was observed from the plots after 10 generation the mean curve converges to the best curve. Analogous to that the values of input control factors peak current, pulse-on time and pulse-off time have been found to be 1 A, 10 µs and 15 µs, respectively. Analogous to these optimum values of input control factors, the value of TWR has been acquired as -0.000649 g/min. So, practically optimum value of TWR is zero.

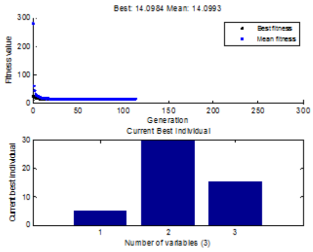

Fig. 6 Generation-fitness graphics for MRR using GA

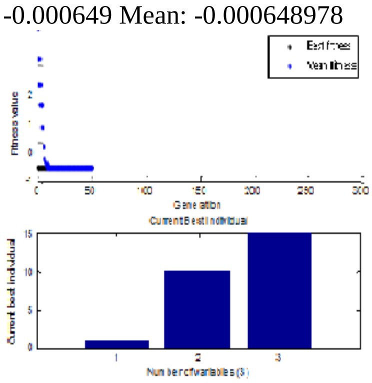

Fig. 7 Generation-fitness graphics for TWR using GA

B. Optimization of quality parameters using JAYA algorithm (6)

By using Jaya algorithm a MATLAB code has been written for optimization. This programme runs for 10000 iteration. Since Jaya does not have any algorithm specific parameters, it starts with the some initial random population, within working range and keeps on improving the solution. Fig. 8 shows the iteration versus MRR graph. It is evident that Jaya algorithm got optimum values at 11th iteration. The optimum values of control factors have been identified as peak current 5A, pulse-on time 30 µs and pulse-off time 15 µs. using these values of input control factors, the value of MRR acquired is 0.0658 g/min

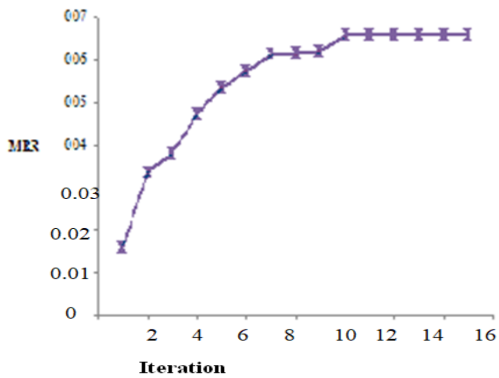

Fig. 8 Generation-fitness graphics for MRR using Jaya algorithm

Similarly, Fig. 9 shows the iteration versus TWR plot. It is evident that TWR got minimized at 17th iteration. The optimal values of the control factors have been identified as peak current 1A, pulse-on time 10 µs and pulse-off time 15 µs. Using these values of input control factors, the value of TWR acquired is -0.0006 g/min.

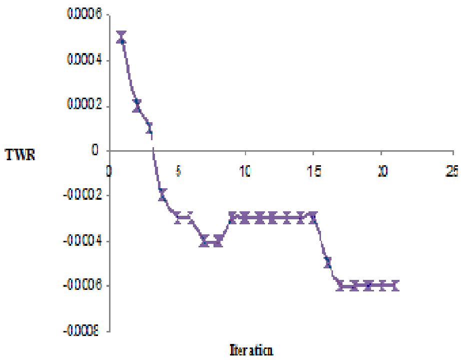

Fig. 9 Generation-fitness graphics for TWR using Jaya algorithm

Table V and Table VI compare the performance of GA and Jaya algorithm under present manufacturing paradigm. Comparison results shows that though Jaya requires more number of iterations to get optimum values of output parameters but there is insignificant difference in the optimization results acquired by GA and the algorithm Jaya. As Jaya does not contain any algorithm specific parameters (such as cross-over rate, mutation rate etc used in GA), it's working is very simple as compared to GA. So, Jaya algorithm can be effectively applicable for such type of optimizations problems where objective function is complex and non-linear.

Table- V: Comparisons of GA and JAYA algorithm for MRR

	GA	JAYA	% Deviation
Peak current (A)	**5**	**5**	-
Pulse-on time (µs)	30	30	-
Pulse-off time (µ)	15	15	-
MRR (g/min)	0.070	0.0658	6

Table- VI: Comparisons of GA and JAYA algorithm for TWR

	GA	JAYA	% Deviation
Peak current (A)	**1**	**1**	-
Pulse-on time (µs)	10	10	-
Pulse-off time (µ)	15	15	-
TWR (g/min)	-0.00064 9	-0.0006	7.5

V. CONCLUSIONS

The research findings are summarized as follows:

1. Response surface model has been developed for MRR and TWR and both the models have been found adequate to predict process output parameters.
2. Optimization result shows that there are significant improvements in both the MRR and TWR after optimization. With reference to maximum experimental values, there is enhancement of 21.3% and 100% in material removal rate and TWR.
3. The optimization results which are acquired by GA and Jaya algorithm are mostly identical. So, Jaya may me applied for such kind of optimization problem effectively.

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