Study on the Effect of Process Parameters on Machinability Performance of AA7050/B4C Metal Matrix Composite on Wire Cut EDM

Arvind Kumar, Subhan Pandey, Virendra Singh, and Ram Naresh Rai

Abstract The present investigation has been initiated based on the wire electric discharge machining of Al7050/7.5 B4C stir cast metal matrix composite. Taguchi L9 orthogonal array has been used to analyses the concurrent effect pulse current (I_p), pulse-on time (T_{on}) and servo voltage (S_v) on material removal rate (MRR) and surface roughness. From Taguchi analysis, it is observed that the optimal setting of process parameters for maximum MRR is $I_p3T_{on}3S_v3$, whereas for minimum surface roughness, the optimal configuration of process parameters is $I_p3T_{on}2S_v1$. The error estimated between predicted MRR and surface roughness with experimental MRR and Surface roughness at the optimal setting of process parameters is within ±5%. Analysis of variance shows that I_p contributes maximum towards MRR and T_{on} contributes maximum towards surface roughness.

Keywords AA7050/7.5% (wt.) B4Cp composite · WEDM · Stir casting · Taguchi · Analysis of variance

1 Introduction

Metal matrix composite is a new engineered material which possesses the inherent properties of matrix and reinforcements [1]. Metal matrix composites have high specific strength most suitable for aerospace and automobile components [2]. Therefore, machining of those components with close tolerance and in desired shape is the major industrial concern especially through the conventional machining process [3, 4]. Wire cut EDM serves this purpose up to some extent. Some of the previous findings on wire cut EDM are as follows: Velmurugan et al. [5] investigated on nickel-titanium shape memory alloy machining in WEDM. They used servo voltage, pulse-on time, pulse-off time, current and wire-speed as an input parameter. Servo voltage is the major influencing factor for MRR and surface roughness. Choudhuri

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et al. [6] investigated on surface quality of WEDM machined stainless steel 316. T_{on}, T_{off}, I_p, S_v, WT were the input parameters for machining 25 sets of experiment. From ANOVA result, Ton found to be the most controlling factor for roughness as well as recast layer. Jain et al. [7] have used ANN for the evaluation machining performances with the simultaneous effect of T_{on}, T_{off}, I_p and bed speed on surface roughness and AE signals. The result shows that better R values obtained when network trained with 70% of the data compared to 50 and 60% of data. Nain et al. [8] have evaluation of surface roughness and waviness of the WEDM of aeronautic superalloy with the various process parameters. The results concluded that apart from T_{on} T_{off} and S_v wire tension has significant effect on surface roughness. Also, the machining performance of aeronautics superalloy can be efficiently evaluated by BP-ANN model as compared to fuzzy logic method. Devarasiddappa et al. [9] have predicted the surface roughness of Inconel 825 aerospace alloy machined through WEDM through ANN model. The parametric study shows that the lower SR can be obtained at low levels of T_{on} and S_v. ANN model accuracy recorded as 93.62% and average predicted error recorded as 6.38% at ANN architecture 4-16-1. This ANN architecture found optimum, which were statistically validated by conducting hypothesis tests. ANOVA showed that T_{on} is the most affecting factor for SR with 76.12% contribution, followed by S_v and T_{off}, respectively, with 7.18 and 5.3% contributions. Das et al. [10] have used Taguchi L16 OA to conduct WEDM experiment on Al6061/0.5% SiC/0.5%B4C hybrid nano-composite to evaluate the effect of I_p, S_v, T_{on} and T_{off} on surface roughness. The experimental data have 96.32% accuracy with predicted values from RSM modelling. Also from the ANOVA Ton is the most influential factor for surface roughness. Garg et al. [11] have machined the $ZrSiO_4$/6063 aluminium MMC using CNC WEDM. In this study, the author has developed the quadratic model for dimensional deviation to evaluate the contemporaneous effect of machining parameters, namely I_p, S_v, T_{on} and T_{off}. Experimental results show that the dimensional deviation (DD) is directly proportional to the pulse-on time and peak current. The objective of the present study is to synthesis AA7050/B4C composite through stir casting method and performs machining through CNC wire cut EDM.

2 Experimental Setup

Procedure for the synthesis of AA7050-B4C (7.5% by weight) is explained in my previous paper [12]. A rectangular plate of thickness 7 mm was cut from the developed composite block and used as workpiece materials for CNC wire EDM machining. The pictorial representation with specifications CNC wire cut EDM is shown in Fig. 1 and Table 1.

Fig. 1 Wire cut CNC EDM

Table 1 Specification of wire cut CNC EDM

Description	Unit	Specification
Main axis transverse (*X*, *Y*)	mm	400 × 300
Aux, axis transverse (*u*, *v*)	mm	100 × 100
Worktable size	mm	680 × 500
Max. taper angle	mm	35°/50°
Max. workpiece height	mm	300
Max. workpiece weight	kg	500
Max. machine current	Ampere	25
Resolution	mm	0.0005 mm
Max. wire spool capacity	8 kg (16–45 kg optional with de collar)	
Wire electrode diameter	0.25 mm (standard) 0.1, 0.15, 0.2, 0.3 (optional)	
Wire spool size	DIN 125, DIN 160, P-3-R, P-5-R	
Connected load	13 KVA	
Die electric fluid	Deionized water	
Dielectric capacity	850 L	

2.1 Design of Experiments

Orthogonal array (OA) designed by Dr. Genichi Taguchi, the primary purpose was to reduce the number of the experiment by considering whole domain of process parameters [13]. For the present study, three process parameters are selected which varies at three-level each, so as per the full factorial experimental design 27 experiments proposed which is not only time taking rather costly as well. Nine tests can also make a similar study. Therefore, Taguchi L9 orthogonal array experimental design has used as shown in Tables 2 and 3.

The material removal rate (MRR) has been calculated using Eq. (1). Machining time has been noted using stopwatch with least count of 1 s. The volume of material removed is calculated by (length of machining × thickness of machining × average kerf width).

$$\text{MRR} = (\text{Volume of material removed})/(\text{Machining time}) \quad (1)$$

Length and thickness of machining for the present study considered as 5 mm and 7 mm, respectively, and Kerf widths were obtained from the optical microscope for entire machining length of 5 mm, with optical magnification at 5×. Taylor Hobson Profilometer was used to measure surface roughness of the machined surface. Surface roughness has been measured considering the value of average surface roughness (R_a) of the machined surface.

Table 2 Design of experiments

Parameters	Notations	Unit	Factors		
			1	2	3
Pulse current	I_p	A	80	160	230
Pulse-on time	T_{on}	µs	106	108	110
Servo volt	S_v	V	20	30	40

Table 3 Experimental arrangement as per Taguchi L9 orthogonal array

Run order	Factor 1	Factor 2	Factor 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3 Results and Discussions

The experimental results in terms of MRR and surface roughness obtained with different sets of process parameters are listed in Table 4.

3.1 Taguchi Methods

In Taguchi method, signal-to-noise ratio (S/N) is a measure of the deviation of the experimental values from the desired benefits. In the term, signal-to-noise ratio signal means the desired benefits, whereas the noise stands for undesired values. There is three definite way to express S/N ratio, namely higher-the-better (HB), lower-the-better (LB), nominal-the-better (NB) [14]. In the present study, both response parameters are of different perspectives. The prime motive of the study was to obtain maximum material removal rate (MRR) with least surface finish. Therefore, MRR was considered as HB, whereas surface roughness considered as LB. The *S*/*N* ratios were calculated as per Eqs. (2) and (3), respectively, for MRR and surface roughness [14].

$$\text{SN ratio for Higher the better} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (2)$$

$$\text{SN ratio for smaller the better} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \quad (3)$$

where n and y_i are the total number of experiments and values of MRR or surface roughness for ith experiments. The S/N ratio of each response parameters listed in

Table 4 Experimental results with corresponding SN ratio

Run order	I_p	T_{on}	S_v	MRR	SR	*S*/*N* ratio for MRR	*S*/*N* ratio for SR
1	80	106	20	17.48335	2.643518	24.8525	−8.44365
2	80	108	30	18.95153	2.494273	25.5529	−7.93888
3	80	110	40	21.76882	2.925209	26.7567	−9.32314
4	160	106	30	27.39492	2.967209	28.7534	−9.44696
5	160	108	40	29.46445	2.456518	29.386	−7.8064
6	160	110	20	28.92993	2.731273	29.2269	−8.7273
7	230	106	40	29.11173	2.777273	29.2814	−8.87237
8	230	108	20	27.62882	2.181209	28.8272	−6.77395
9	230	110	30	29.29785	2.802518	29.3367	−8.95097

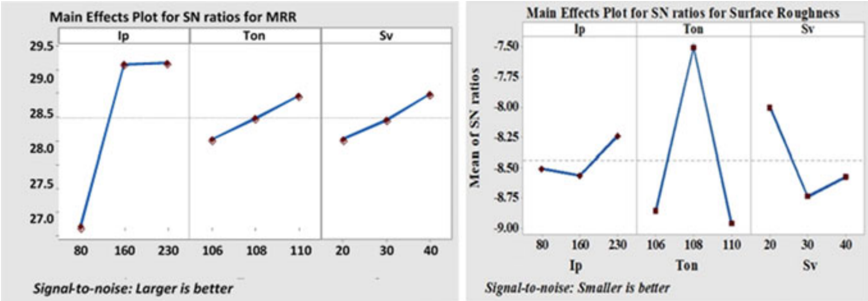

Fig. 2 Main effect plot for mean SN ratio of MRR and surface roughness

Table 4. In order to get maximum MRR, the S/N ratio plot is shown in Fig. 2. The similar graph has obtained from mean effect plot Fig. 3.

Minimum MRR has derived from lower I_p T_{on} and S_v. Since MRR in EDM process is a function of spark energy and the spark energy is a function of I_p T_{on} and S_v as shown in Eq. (4).

$$E = \int I_p T\text{on} S\text{v} \tag{4}$$

Therefore, MRR is minimum at the lowest process parameters; it goes on increasing as spark energy rises [15]. But the on higher spark energy, there will be favourable energy loss which reduces the metal removal rate. Figures 2 and 3 show the S/N ratio plot and mean plot for surface roughness.

The main effect plot for mean MRR shows that for maximum MRR the optimised input parameters obtained from Taguchi analysis is $I_p3T_{on}3S_v3$, whereas for minimum surface roughness, the optimal combination of process parameters is $I_p3T_{on}2S_v1$. In the present study, the purpose of analysis of variance (ANOVA) is to verify the consistency of control variables in the experimental result. ANOVA

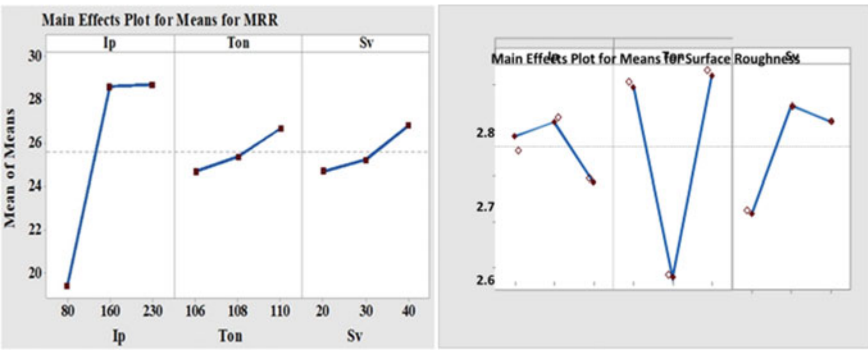

Fig. 3 Main effect plot for the mean of MRR and surface roughness

Table 5 ANOVA for MMR

Source	DF	Adj. SS	Adj. MS	F-value	P-value	Remarks	% Contribution
I_p	2	170.64	85.3221	1710.01	0.001	Significant	92
T_{on}	2	6.213	3.1066	62.26	0.016	Significant	3.37
S_v	2	7.154	3.5772	71.69	0.014	Significant	3.88
Error	2	0.1	0.049				
Total	8	184.11					

$R^2 = 99.95\%$

Table 6 Analysis of variance for surface roughness

Source	DF	Adj. SS	Adj. MS	F-value	P-value	Remarks	% Contribution
I_p	2	0.028323	0.014161	5.75	0.148	In significant	5.64
T_{on}	2	0.371501	0.371501	75.42	0.013	Significant	73.99
S_v	2	0.097322	0.048661	19.76	0.048	Significant	19.38
Error	2	0.004926	0.002463				
Total	8	0.50207					

$R^2 = 99.02\%$

Table 5 shows that although all the process parameters have significant contribution towards achieving maximum MRR pulses current have maximum contribution compare to other two parameters. For surface roughness evaluation, the pulse-on time and servo voltages are the highly significant factors than pulse current. The similar trend shows in Table 6.

3.2 *Confirmation Test and Prediction*

Taguchi method can be used to predict the *S*/*N* ratio, using the optimal level of the process parameters can be calculated as Eq. (5) [16].

$$\tilde{\chi} = \chi_m + \sum_{i}^{n} (\chi_i - \chi_m) \tag{5}$$

where $\tilde{\chi}$ is the mean of S/N ratio χ_{m} is the total mean of S/N ratio and n is the number of process parameters. Table 7 compared the predicted and experimental values of MRR and surface roughness at optimal setting of process parameters. For MRR, the optimal configuration of process parameters is $I_p3T_{on}3S_v3$ that is pulse current 230 A, pulse-on time 110 µs and servo voltage of 40 V. The predicted MRR estimated as 31.0086 mm^3/s, whereas the experimental value of MRR at optimal setting of process parameters evaluated as 30.1242 mm^3/s. The error calculated from predicted

Table 7 Confirmatory test

S. No.	Performance parameters	Optimum combination of process parameters	Predicted values	Measured experimentally	% Error
1	MRR	$I_p3T_{on}3S_v3$	31.0086	30.1242	2.85
2	Surface roughness	$I_p3T_{on}2S_v1$	2.15433	2.18129	1.24

Table 8 Results of confirmation at initial settings of process parameters

S. No.	Performance parameters	Initial combination of process parameters	Predicted values	Measured experimentally	% Error
1	MRR	$I_p2T_{on}2S_v2$	28.0414	29.0183	−3.4
2	Surface roughness	$I_p2T_{on}2S_v2$	2.52167	2.4025	4.7

and experimental MRR calculated as 2.85% which is within the acceptable range. Similarly, the optimal setting of process parameters for surface rough obtained from the Taguchi method is $I_p3T_{on}2S_v1$, i.e. pulse current 230 A, pulse-on time 108 μs and servo volt 20 V. The predicted surface roughness estimated as 2.1543 μm. Whereas the experimental values of surface roughness at optimal setting of process parameters evaluated as 2.18129 μm. The error calculated from predicted and experimental MRR calculated as 1.24% which is within the acceptable range.

To verify the consistency of the proposed Taguchi method, the predicted MRR and surface roughness obtained at the initial set of process parameters ($I_p2T_{on}2S_v2$) compared with experimental one. The errors estimated are within ±5%. Hence, the proposed Taguchi method is consistent (Table 8).

4 Conclusions

AA7050/7.5% B_4C composite fabricated successfully through stir casting method. Wire cut electro discharge machining performed on the composite with pulse current, pulse-on time and servo volt as process parameters to evaluate MRR and surface roughness of the machined surfaces. Following conclusions can be drawn from the results.

1. Analysis of variance for MRR shows that the pulse current is the major influential factor for obtaining maximum MRR followed by servo volt and pulse-on time. For surface roughness, pulse-on time is the major influential factor followed by servo volt and pulse current.

2. Optimal setting of process parameters obtained from the Taguchi analysis for MRR is $I_p3T_{on}3S_v3$, whereas for surface roughness optimal setting of process parameters are $I_p3T_{on}2S_v1$.
3. The error estimated between predicted MRR and surface roughness with experimental MRR and surface roughness at the optimal setting of process parameters is within ±5%.
4. Proposed Taguchi analysis is consistent as the error estimated between predicted and experimental values at an initial set of process parameters are within ±5%.

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