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Parametric Optimization of Wire Cut Electrical Discharge Machining on Al-9% PAC Composites using Desirability Approach

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ABSTRACT:

In aerospace and automobile industries manufacturing complex structures using un-conventional machining is increased due to their precision and accuracy. This research investigates the influence of input parameters such as discharge current, pulse on time, pulse off time and servo speed rate of wire cut electrical discharge machining (WEDM) on material removal rate and surface roughness using Box Behnken design supported with response surface methodology. Aluminium alloy 7075 reinforced with 9 % wt. of activated carbon composite is used to carry out the machining process. Most influencing parameters are subjected as the conductive and non-conductive parameters in WEDM process. To find out the significant influence of each factor, analysis of variance was performed. The mathematical model is established using desirability technique and then the optimal machining parameters are determined. The best achieved WEDM performances - material removal rate and surface roughness are 10.46 mm^3/min and 3.32μm respectively, by using optimum machining conditions - discharge current 2000mA, pulse on time 8.9μs, pulse off time 25μs and servo speed rate 150rpm at 0.8597 desirability value.

KEYWORDS:

Wire cut electrical discharge machining, Aluminium composites, Response Surface Methodology, Desirability method

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1. Introduction

In aerospace industries most of the machining processes use un-conventional machining like wire cut electric discharge machining (WEDM), laser cutting, abrasive jet machining due to their precision and accuracy. WEDM became a hotspot in assembling venture through the advances in electromechanical procedures and the need for quick, coordinated and mass assembling of scaled down items from super composites in aviation, automobile, biomedical, and spacecraft applications [1-2]. WEDM process is a variation of EDM system, where, a moving wire manufactured from thin copper, metal, or tungsten is utilized as terminal [3]. Movement of wire is overseen numerically to procure the difficult three-dimensional shapes on dubious to registering tool materials like super composites [4]. Aluminium and its alloys possess numerous advantageous properties like high point by point quality, brilliant erosion resistance, and over the top quality to weight proportion [5]. WEDM is a progressed machining process that could be utilized in machining of aluminium compounds. Because of its stochastic nature and the increased amount of factors involved, attaining the ideal parameters for machining proved to be a risk [5-7]. Hence, the machinability using WEDM strategy on aluminium needs to be investigated. Response surface method was utilized in experimentation and regression approaches to mannequin the association of the responses and input parameters [6, 10]. Ramanan et al [8] investigated on the experimental parameters and undertaken a multi-objective optimization of WEDM of aluminium composites. From survey of literatures [5-10], it has been found that numerous advancements of EDM and WEDM are witnessed. Associated to the current review, an endeavour for WEDM of aluminium matrix composites was performed in exploring the impact of process parameters on the reactions like material removal rate (MRR) and surface roughness (SR). RSM based box behnken design (BBD) has been utilized for directing the assessments. At last, desirability technique was utilized to predict the ideal process input parameters for optimum machining performances.

2. Experimental details

In the WEDM, the analyses were done with the instrument cathode as negative extremity, in the order acquired from the RSM. Dielectric liquid is provided consistently to contribute the cooling and flashing the wreckage and debris from the machining zone. The machining trials have been performed in a WEDM ELEKTRA SPRINT CUT 34 machine from M/s. Electronica Machine Tools Ltd. In this work, AA7075-9% PAC metal matrix composite and Tungsten have been chosen as the work piece and wire cathode respectively [8]. The course of action in WEDM instrument panel comprises a principle work table (X-Y) on which the work piece is clamped, a helper table (U-V) and wire drive system. The crossing wire is consistently sustained from wire feed spool and gathered on take up in moving spool. The work piece is upheld under pressure between a couple of wire aides situated at the inner sides of the work piece. Based on the past outcomes [4], the regular process input parameters like discharge current (IA), pulse on time (Ton), pulse off time (Toff) and servo speed (SS) rate were considered. Three level test plans for the process input parameters are considered as per their ranges given in Table 1.

Table 1: Input process parameters and their levels

Parameter	Symbol (unit)	Level 1	Level 2	Level 3
Current	IA (mA)	1500	1750	2000
Pulse on time	Ton (µs)	5	10	15
Pulse off time	Toff (µs)	25	50	75
Servo speed	SS (rpm)	50	100	150

3. BBD RSM results

Selected combinations of the process parameters are tested using BBD model to accomplish the correct output measures - MRR and SR as presented in Table 2. The analysis of variance (ANOVA) for MRR is carried out using Design Expert software. The obtained models for MRR and SR responses demonstrated that the predictions are significant - R^2 and adjusted R^2 are 97.84% and 98.71% for MRR and 97.64% and 98.33% for SR respectively. The lack of fit is insignificant (p-value is under 0.05).

Table 2: BBD responses from experiments

Exp No	IA (mA)	Ton (µs)	Toff (µs)	SS (rpm)	MRR (mm^3/min)	SR (µm)
1	1750	5	50	150	9.54	3.37
2	1750	10	75	50	6.84	4.03
3	1500	10	75	100	8.2	3.79
4	2000	10	50	150	7.99	3.43
5	1750	10	50	100	8.82	3.69
6	1750	10	50	100	8.82	3.69
7	1750	10	25	150	10.8	3.54
8	1500	10	50	150	10.26	3.71
9	1500	15	50	100	8.45	3.83
10	1750	5	75	100	7.56	3.32
11	2000	15	75	100	9.66	3.72
12	2000	5	75	150	9.6	3.3
13	1750	15	75	50	8.14	4.01
14	1750	10	25	100	9.36	3.71
15	1750	15	75	50	7.62	3.11
16	1750	15	50	150	11.1	3.71
17	1750	10	75	100	8.34	3.63
18	2000	10	25	50	8.04	3.68
19	1750	5	50	100	8.04	3.47
20	1750	5	25	100	8.58	3.43
21	1750	15	25	100	11.62	3.66
22	2000	10	50	100	7.98	3.53
23	1500	15	50	100	9.57	4.01
24	1500	10	25	100	9.31	3.47
25	1500	10	50	50	6.98	4.05
26	1750	10	50	100	8.82	3.89
27	2000	10	75	100	8.64	3.57

Table 3 gives the impact of individual and the predicted model for MRR. This model has achieved a 95% certainty level. The obtained BBD response equation for MRR is given by,

$$MRR = 8.79 + 0.042\ IA + 0.81\ Ton - 0.52\ Toff + 1.29\ SS \quad (1)$$

MRR is highly sensitive to Ton and IA. For an increase in Ton, expansive vitality being distributed. This produces more grounded flashes leading to a greater material removal [5].

Table 3: ANOVA for MRR

Parameter	Sum of squares	Df	Mean square	F value	P-value
MRR (mm^3/min)	25.76	4	13.57	21.15	< 0.0001
IA (mA)	0.02	1	0.043	8.87	0.8381
Ton (µs)	7.08	1	14.91	25.11	0.0008
Toff (µs)	3.73	1	7.86	2.27	0.0104
SS (rpm)	16.52	1	34.83	19.66	< 0.0001
Error	0.76	4	0.19		
Total	36.2	26			

Table 4 gives the ANOVA for SR. Suitability of this model for 95 % certainty level has been noticed. The obtained BBD response for SR is given by,

$$SR = 3.67 + 0.10\ IA - 0.17\ Ton + 0.046\ Toff + 0.16\ SS \quad (2)$$

It is observed that when Toff increases, the IA increased from 1750mA to 2000mA. Further, it is also evident that the SR decreases with increase in IA. SS is definitely impacting the SR. With increases in IA, huge vitality being dispersed. This disintegrates more material with more grounded flashes.

Table 4: ANOVA for SR

Parameter	Sum of squares	Df	Mean square	F value	P-value
SR (µm)	1.1	4	0.27	21.15	< 0.0001
IA (mA)	0.12	1	0.12	8.87	0.0069
Ton (µs)	0.33	1	0.33	25.11	< 0.0001
Toff (µs)	0.03	1	0.03	2.27	0.146
SS (rpm)	0.26	1	0.26	19.66	0.0002
Error	0.048	4	0.012		
Total	36.2	26			

4. Desirability optimization results

Desirability is an independent function which varies from zero being outside of the limits to one at meeting the objective. Design Expert statistical software is used with the desirable and optimum settings to meet necessary goals for MRR and SR. A set of 51 optimal solutions is derived for the design space for individual response characteristics – IA, Ton, Toff and SS. Fig 1 shows the bar graph of desirability for response values. Certain conditions possessing greatest desirability value is chosen as optimum situation for the anticipated response. Desirability 3D plots are drawn by holding the input parameters in range and responses at minimum. Figs. 2 and 3 show the contour and surface plot of each response using Design Expert solver. A linear ramp function is applied between either the low value and the goal or the high value and the goal as the weight for every parameter was set to 1. Table 5 reports the desirability range of input process parameters and the foreseen values of various response characteristics.

Table 5: Range of input parameters and responses for desirability

Parameter	Goal	Lower limit	Upper limit	Lower weight	Upper weight
IA (mA)	In range	1500	2000	1	1
Ton (µs)	In range	5	15	1	1
Toff (µs)	In range	25	75	1	1
SS (rpm)	In range	50	150	1	1
MRR (mm3/min)	Maximize	6.84	11.62	1	1
SR (µm)	Minimize	3.3	4.11	1	1

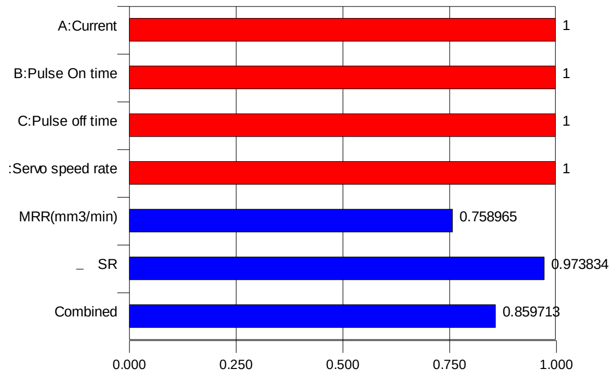

Fig. 1: Bar graph of desirability for response values

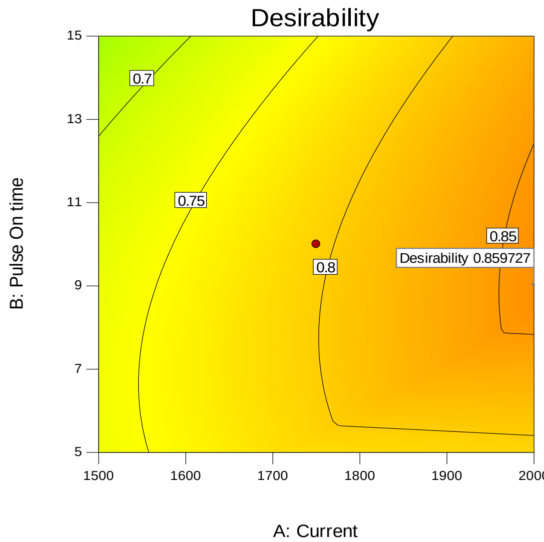

Fig. 2: Contour plot of desirability between input parameters

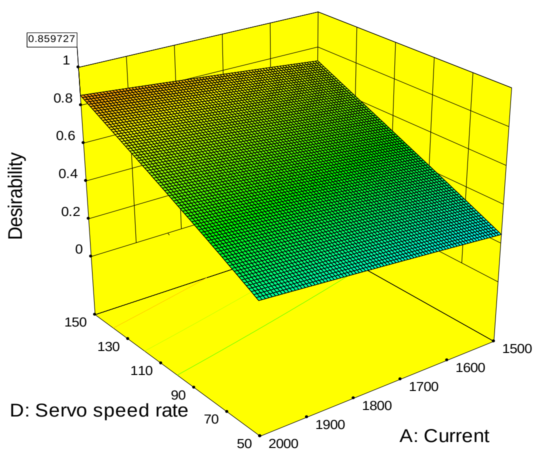

Fig. 3: Response plot of desirability between input parameters

Table 6 presents the experimental and predicted optimum responses based on the desirability optimisation approach. The error associated with the experimental results and predicted values is practically small, i.e., less than 5%.

Table 6: Desirability optimization results

Parameter	Optimum	Experimental	Error %
MRR (mm3/min)	10.4374	11.5451	1.148
SR (µm)	3.3219	3.1412	2.0346
Desirability	0.8597	-	
IA (mA)	2000		-
Ton (µs)	8.9074		-
Toff (µs)	25.001		-
SS (rpm)	150		-

5. Conclusion

Based on the experimental results during WEDM process of Al-9%PAC metal matrix composite, mathematical modelling is developed and checked for regression of MRR and SR. It is found from the ANOVA results that IA, SS and Ton have significant effect on MRR and SR. The optimized results produced from these techniques are discussed by desirability approach which predicted high MRR of 10.43mm^3/min and SR of 3.32µm when the input parameters are discharge current (2000mA), pulse on time (8.9µs), pulse off time (25µs), and servo speed rate (150rpm) with a desirability of 0.8597. This optimization results clearly exhibit the best possible WEDM process input parameters over the techniques used individually.

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