Mathematical Modelling of Electric Discharge Machining of Al (6351)-SiC-B_4C Hybrid Composite

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Abstract: The Electric Discharge Machining (EDM) has emerged as one of the major machining method for the machining of hard-to- machine materials and composites. This paper aims at creating a mathematical model for the machining of the Al(6351)-SiC-B_4C composites based on the experimental data and compare the same to identify the level of errors between the mathematical model and the experimental results. This paper was aimed as an attempt to develop a mathematical model for the output parameters viz. Electrode Wear ratio and Surface roughness based on the input parameters viz. current, pulse-on-time, pulse duty-factor and gap voltage.

Key words: Electric Discharge Machining, Mathematical modelling, linear regression model

I. INTRODUCTION

Composite material machining is the major area of research due to the enhanced use of composites in the manufacturing sector. Better strength to weight ratio, improved hardness and the flexibility in manufacturing for the application were observed to be the major reasons observed for this improved interest [1]. The major challenge faced by the manufacturers for usage of composites was its limitations in cost effective machining due to the inherent properties. The major concern in this non-conventional machining process was the control of the gap between the tool and the work piece, which was solved due to the inception of CNC based control systems [2]

Electric Discharge Machining (EDM) has emerged as one of the major contributor towards solving this challenge of machining of composites. The major challenge faced for machining using EDM is the optimisation of the parameters for economic machining of the components due to the complexity of the process [3]. The researches of the past decade is oriented towards optimising the process parameters and identifying the best inputs to obtain the required output. There has been a lot of works observed in the area of Electric Discharge Machining of Metal Matrix composites in the recent past [4]. The models developed by Kalajahi [5] and Sahu [6] have developed models in ANSYS relating the flushing efficiency with the pulse current and pulse on time.

The experimental analysis and optimisation can provide only a partial solution for the problem. The mathematical models can provide a more accurate result due to the equation based solutions which can be differentiated to obtain the maxima or minima as required for the better results. This paper aims at providing a mathematical modelling for the Electrode wear ratio (EWR) and Surface roughness (R_a).

II. MATHEMATICAL MODELLING

In this work, the mathematical modelling of the Experimental data carried out for the Al (6351)-SiC-B_4C hybrid composite is carried out and the results and the influence of each parameters will be discussed based on the mathematical model.

The experimental results are taken from previous work reported by Sureshkumar et al [1] and the mathematical modelling was carried out for these experiments. The generated equations were analysed using ANOVA. The experiments were carried out for four parameters with three levels of values and Taguchi method with L27 array was adopted for the DOE.

Table 1: Parameter Values for different levels

Factors	Levels		
	-1	0	+1
Current (A)	5	10	15
Pulse-on time	50	75	100
Pulse duty factor	4	6	8
Voltage	40	45	50

Revised Manuscript Received on December 29, 2019.

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Table 2: Matrix of Order with experimental results

Exp No	Current (A)	Pulse-on-time (μs)	Pulse Duty Factor	Gap Voltage (V)	EWR	Ra
1	-1	-1	-1	-1	1.32	6.31
2	-1	-1	0	0	1.15	4.88
3	-1	-1	+1	+1	1.59	4.86
4	-1	0	-1	0	1.09	6.19
5	-1	0	0	+1	1.08	7.78
6	-1	0	+1	-1	0.62	6.05
7	-1	+1	-1	+1	0.8	5.07
8	-1	+1	0	-1	0.24	6.75
9	-1	+1	+1	0	0.24	9.77
10	0	-1	-1	-1	1.63	6.98
11	0	-1	0	0	1.96	7.06
12	0	-1	+1	+1	2.01	7.38
13	0	0	-1	0	1.28	7.34
14	0	0	0	+1	1.65	7.85
15	0	0	+1	-1	0.8	8.54
16	0	+1	-1	+1	1.52	7.88
17	0	+1	0	-1	1.2	7.59
18	0	+1	+1	0	0.36	7.82
19	+1	-1	-1	-1	2.74	8.9
20	+1	-1	0	0	2.48	8.66
21	+1	-1	+1	+1	2.5	8.91
22	+1	0	-1	0	2.02	10.19
23	+1	0	0	+1	2.38	9.13
24	+1	0	+1	-1	0.62	9.07
25	+1	+1	-1	+1	2.48	9.55
26	+1	+1	0	-1	1.29	9.87
27	+1	+1	+1	0	1.18	10.38

Table 2 is taken as the input for the Design of ANOVA table and analysis

The mathematical modelling aims at providing a best suited equation for the output parameters for the provided input parameters. The equation finalised for this paper is of the form

$OP=\alpha_0+\alpha_1*A+\alpha_2*POT+\alpha_3*PDF+\alpha_{4*}V+\alpha_{12}*A*POT+\alpha_{13*}A*PDF+\alpha 14*A*V+\alpha_{23}*POT*PDF+\alpha_{24}*POT*V+\alpha_{34}*PDF*V+\alpha_{123}*A*POT*PDF+\alpha_{124}*A*POT*V$

Where OP is the output parameter (EWR/Ra); factors A for current, POT for Pulse-on-time, PDF for Pulse Duty Factor, V for Gap voltage, α_1, α_2, α_3, α_4 are the linear parameters of the factors A,POT,PDF and V; α_{12}, α_{13}, α_{14}, α_{23}, α_{24}, α_{34} are the linear-to-linear interaction factors of A,POT,PDF and V; α_{123}, $\alpha_{124,}$ are the linear-to-linear interaction for the factors A,POT,PDF and V and α_0 is the correction factor.

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III. RESULTS AND DISCUSSION

Since the simplest form of equations are linear, it was preferred in place of quadratic or cubic equations.

The final set of equations obtained are as follows:

EWR = 8.13 - 0.072 A - 0.0101 POT - 0.322 PDF - 0.246 V - 0.00019 A*POT - 0.0527 A*PDF + 0.0110 A*V - 0.00849 POT*PDF + 0.00106 POT*V + 0.0230 PDF*V + 0.000438 A*POT*PDF- 0.000054 A*POT*V------------(1)

Ra = 7.3 - 0.33 A - 0.218 POT - 3.51 PDF + 0.389 V + 0.0198 A*POT + 0.261 A*PDF - 0.0184 A*V + 0.0554 POT*PDF- 0.00172 POT*V- 0.0066 PDF*V - 0.00384 A*POT*PDF+ 0.000041 A*POT*V-------------(2)

Based on these equations, the ANOVA table was created to identify the level of effect of each factors on the output parameters.

A. Analysis of Electrode wear ratio

From the ANOVA table and the plot, it was observed that the Current is contributing the maximum in the variation of the Electrode Wear rate. The Pulse on time is the next major contributor in controlling the Electrode Wear ratio followed by the gap voltage

Table 3: Analysis of Variance- EWR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
A	1	5.0774	37.28%	0.0009	0.00089	0.01
POT	1	3.6180	26.56%	0.0008	0.00080	0.01
PDF	1	1.3668	10.04%	0.0167	0.01675	0.25
V	1	1.7113	12.56%	0.0749	0.07488	1.12
A*POT	1	0.0000	0.00%	0.0000	0.00003	0.00
A*PDF	1	0.3960	2.91%	0.1081	0.10806	1.61
A*V	1	0.1680	1.23%	0.0293	0.02931	0.44
POT*PDF	1	0.0572	0.42%	0.1454	0.14540	2.17
POT*V	1	0.0494	0.36%	0.0142	0.01415	0.21
PDF*V	1	0.1852	1.36%	0.1852	0.18515	2.76
A*POT*PDF	1	0.0461	0.34%	0.0504	0.05038	0.75
A*POT*V	1	0.0048	0.04%	0.0048	0.00480	0.07
Error	14	0.9396	6.90%	0.9396	0.06712	
Total	26	13.620	100.00			

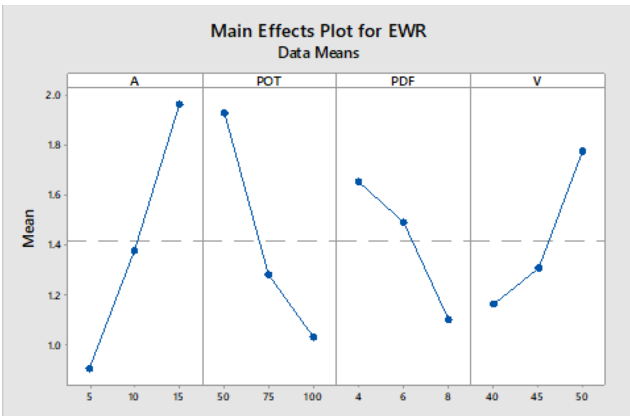

Fig 1: Main effects plot for Electrode Wear ratio

The pulse duty factor contributes the least. It can be observed that the interactions have very less contribution when compared with the individual factors in the determination of Electrode wear ratio

B. Analysis of Surface roughness

The main effects plot and the Anova table indicates that current is the major deciding factor for the surface roughness and the graph indicates that the increase of current considerably increases the surface roughness factor

Table4 : Analysis of Variance R_a

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
A	1	40.5	61.39%	0.0184	0.01837	0.855
POT	1	6.4082	9.71%	0.3715	0.37151	0.7
PDF	1	1.0609	1.61%	1.9984	1.99845	3.76
V	1	0.1512	0.23%	0.1881	0.1881	0.35
A*POT	1	0.407	0.62%	0.3727	0.37275	0.7
A*PDF	1	0.9577	1.45%	2.6569	2.65689	5
A*V	1	0.1102	0.17%	0.0827	0.08272	0.16
POT *PDF	1	4.3092	6.53%	6.208	6.208	11.69
POT *V	1	0.0914	0.14%	0.0374	0.03742	0.07
PDF*V	1	0.0151	0.02%	0.0151	0.01511	0.03
A*POT*PDF	1	4.522	6.85%	3.8803	3.88033	7.31
A*POT*V	1	0.0027	0.00%	0.0027	0.00273	0.01
Error	14	7.4331	11.27%	7.4331	0.53093	
Total	26	65.969	100.00%			

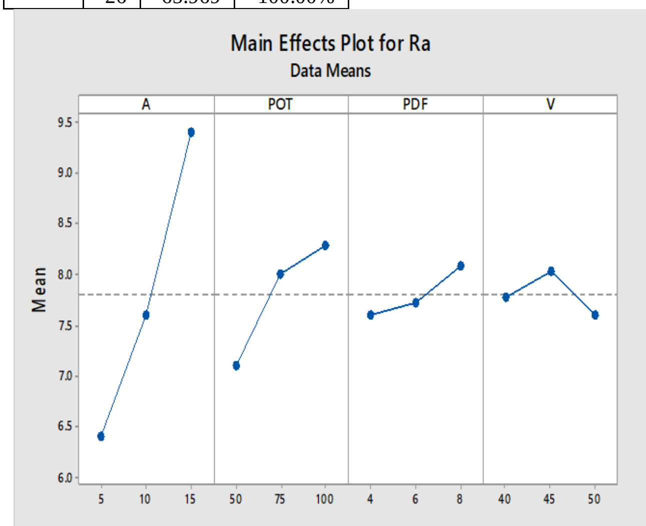

Fig 2: Main effects plot for Surface Roughness

IV. CONCLUSION

The Analysis was carried out for the two output parameters namely, Electrode wear ratio and surface roughness. It was observed that both the responses depends on the current supplied and it can be clearly seen that the increase of current increases both the output parameters. The gap voltage was observed to be insignificant for both the parameters. Therefore, the power required can be provided with a low current, high voltage condition to reduce the Electrode wear ratio and surface roughness. The Pulse on time is also a contributing factor for Electrode Wear ratio, but less significant for the surface roughness. A reduced pulse on time increases the Electrode wear ratio. It is recommended to have a higher pulse on time to reduce the electrode wear ratio. The other parameters, Pulse duty factor and gap voltage contributes less for the considered output parameters.

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