

Prediction of Optimal Conditions for WEDM of Al 6063/ ZrSiO_{4(p)} Metal Matrix Composites using Response Surface Methodology (RSM)

Dr. T.Vijaya Babu¹, S.M .Gangadhar Reddy², Dhanaraj .B³, Satyanarayana Raju .P⁴

^{1,2,3}Professor, Department of Mechanical Engineering, Vardhaman College of Engineering, Shamshabad , Hyderabad , INDIA

⁴Assistant Professors, Department of Mechanical Engineering, Vardhaman College of Engineering, Shamshabad, Hyderabad, INDIA

ABSTRACT

In this paper, an attempt has been made to machine Al 6063/ ZrSiO_{4(p)} metal matrix composite using wire electric discharge machining. The objective is to investigate the influence of process parameters namely pulse on time, pulse off time, peak current and servo voltage on dimensional deviation . A Box-Behnken design approach of response surface methodology (RSM) is used to plan and analyze the experiments. The mathematical relationships between WEDM input process parameters and response parameter are established to determine optimal values of cutting rate mathematically. The Analysis of variance (ANOVA) and F-test are performed to obtain statistically significant process parameters. The generated optimal process conditions have been verified by conducting confirmation experiments and predicted results have been found to be in good agreement with experimental findings.

Keywords— WEDM, MMC, ANOVA, RSM, Dimensional deviation.

I. INTRODUCTION

WEDM is a spark erosion process used to produce complex two and three dimensional shapes through electrically conductive work pieces. A power supply delivers high-frequency pulses of electricity to the wire and the work piece and material is removed as a result of high energy discharge subjected on the work piece. WEDM has become an important non-traditional machining process, widely used in the aerospace, nuclear and automotive industries.

MMCs have found many successful industrial applications in recent past as high-technology materials due to their exceptional properties such as high strength-to-weight ratio, high toughness and lower value of coefficient of thermal expansion, light weight and

capability of operating at elevated temperatures .They also exhibit greater resistance to corrosion, oxidation and wear.

II. LITERATURE REVIEW

Al 6063/ ZrSiO_{4(p)} MMC's are widely used materials in many engineering applications due to their improved properties but very few research efforts are made and published on the combined effect of process parameters on the performance of WEDM process in machining of Al 6063/ ZrSiO_{4(p)} MMC . Al6063/ ZrSiO_{4(p)} MMC is selected as work piece material because it meets a wide range of applications including wear-resistant components, cutting tools, punches, engine parts, high temperature applications, medical and biomedical purposes etc. Table 1 shows the chemical composition of 6063 Aluminium alloy used as the base metal. In the present work, an attempt has been made to optimize process parameters of WEDM for machining of MMC using Response Surface Methodology and in particular Box-Behnken.

Designs to develop an empirical relationship between different process parameters namely Pulse on time (Ton), Pulse off time (Toff), Peak Current (IP) and Servo Voltage (SV) and output response namely dimensional deviation (DD).

The ANOVA is applied to identify the significance of the process parameters. Thereafter, Optimization of cutting rate is performed using desirability approach. A plate of rectangular shape (100mm x 80mm x 10mm) having 5% ZrSiO₄ particles (by weight) as reinforcement is prepared by stir casting process.

Chemical composition of Al 6063 alloy

Element	A	S	Fe	C	M	M	C	Z	T	Oth
	l	i		u	n	g	r	n	i	er
Compos	9	0.	0.	0.	0.	0.	0.	0.	0.	0.1

ition %	7.	6	35	1	1	9	1	1	1	5
wt	5									

Table 1: The chemical composition of 6063 Aluminium alloy used as the base metal

III. DESIGN OF EXPERIMENTS

The present work utilizes four varying input process parameters viz. Pulse on time (Ton), Pulse off time (Toff), Peak Current (IP) and Servo Voltage (SV) to investigate their effects on dimensional deviation (DD) during machining of Al 6063/ ZrSiO_{4(p)} MMC. The ranges of input parameters are selected on the basis of literature review and pilot study conducted by using one factor at a time approach. The selected process parameters along with their levels are listed in Table 2.

Parameters	Units	Level			Fixed parameters
		I	II	III	
Pulse on time(Ton)	mu	112	116	120	Wire feed
Pulse off time(Toff)	mu	50	55	60	Water pressure
Peak current (IP)	Amp	120	150	180	Wire tension
Servo voltage(SV)	Volts	50	65	80	Serve feed

Table 2: The selected process parameters along with their levels

Present work utilizes, Box-Behnken experimental design approach as it plans experiments within identified search space (assuming a=1). Four control factors are considered at three levels, therefore 29 experiments needed to be performed.

IV. RESULT AND DISCUSSIONS

The experiments are performed on a four axis Electronica EZEECUT NXG CNC Wire Cut Machine shown figure 1 (a) & (b) . A diffused brass wire of 0.25mm diameter is used as tool material and deionized water is used as dielectric to machine 6063 Aluminium based MMC. A 10mm x 8mm rectangular cut is taken on the work piece.

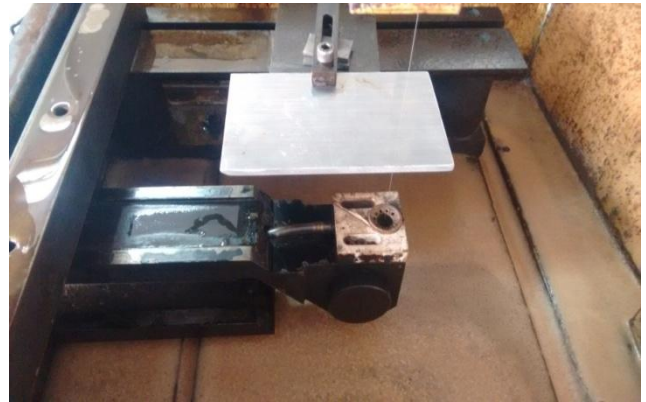


Figure1 (a): Rectangular piece fixed in the machine



Figure1 (b) Electronica EZEECUT NXG Machine

S.NO	Ton	T off	IP	SV	DD
1	112	50	150	65	115
2	120	50	150	65	460
3	112	60	150	65	110
4	120	60	150	65	440
5	116	55	120	50	255
6	116	55	180	50	425
7	116	55	120	80	225
8	116	55	180	80	415
9	112	55	150	50	135
10	120	55	150	50	480
11	112	55	150	80	85
12	120	55	150	80	470
13	116	50	120	65	190
14	116	60	120	65	270
15	116	50	180	65	440
16	116	60	180	65	410
17	112	55	120	65	77

18	120	55	120	65	390
19	112	55	180	65	170
20	120	55	180	65	490
21	116	50	150	50	430
22	116	60	150	50	380
23	116	50	150	80	415
24	116	60	150	80	350
25	116	55	150	65	360
26	116	55	150	65	340
27	116	55	150	65	315
28	116	55	150	65	310
29	116	55	150	65	297

Table 3 : Design and results for WEDM output response

Following equation represents the relation between dimensional deviation and control factors which is obtained by multiple regression technique. Backward elimination process is used to eliminate the non-significant factors to fit the quadratic model for cutting rate.

Regression Equation

$$DD = 315.6 - 187.2 \text{ Ton}_{112} + 34.83 \text{ Ton}_{116} + 152.4 \text{ Ton}_{120} + 14.6 \text{ Toff}_{50} - 14.17 \text{ Toff}_{55} - 0.4 \text{ Toff}_{60} - 82.0 \text{ IP}_{120} + 6.91 \text{ IP}_{150} + 75.1 \text{ IP}_{180} + 21.5 \text{ SV}_{50} - 18.76 \text{ SV}_{65} - 2.7 \text{ SV}_{80}$$

Analysis of Variance (ANOVA)

SOURCE	DF	Adj SS	AdjSS	F-value	P-value
Ton	2	363823	181912	170.44	0.000
Toff	2	3606	1803	1.69	0.210
IP	2	74801	37401	35.04	0.000
SV	2	6886	3443	3.23	0.061
Error	20	21347	1067		
Lack of fit	16	18789	1174	1.84	0.294
Pure error	4	2557	639		
Total	28	476470	-		

Table 4: ANOVA for response surface of reduced quadratic model of dimensional deviation

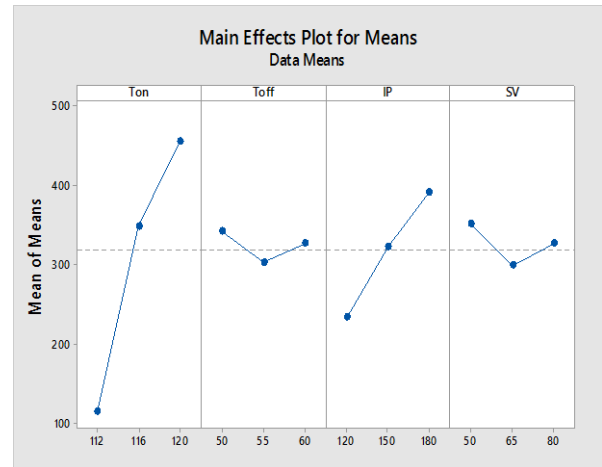


Fig 2: Main effects plots for means

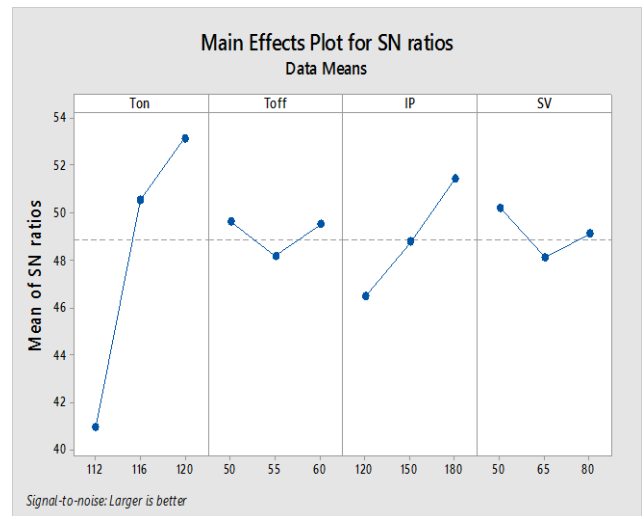


Figure 3 : Main effects plots SN ratios

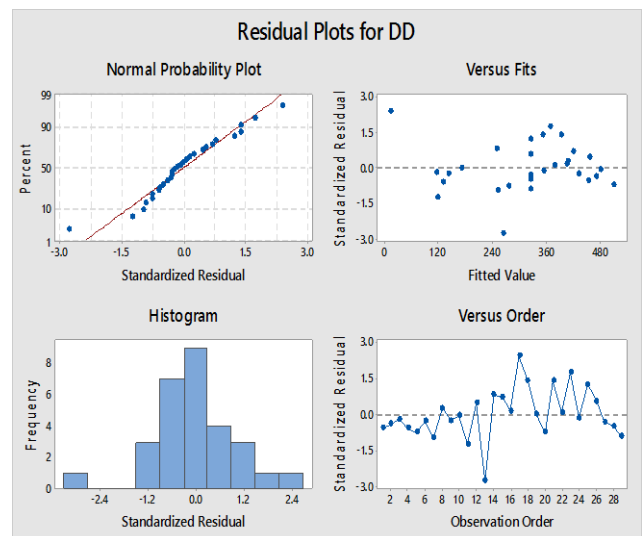


Figure 4: Residual plots for dimensional deviation

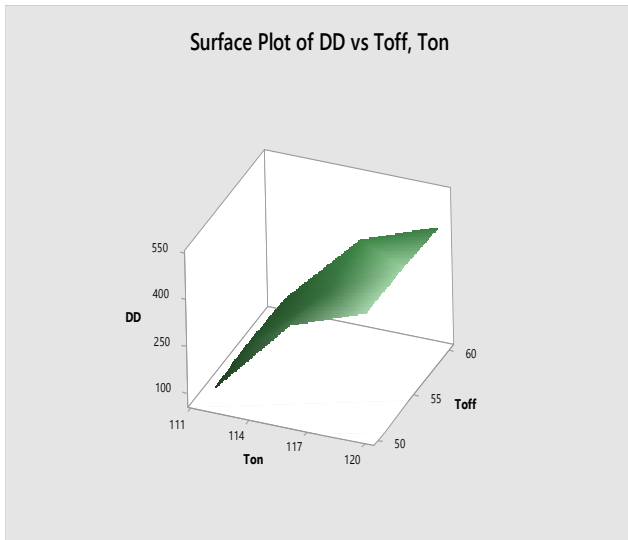


Figure 5 : Surface plots for DD Vs Toff , Ton

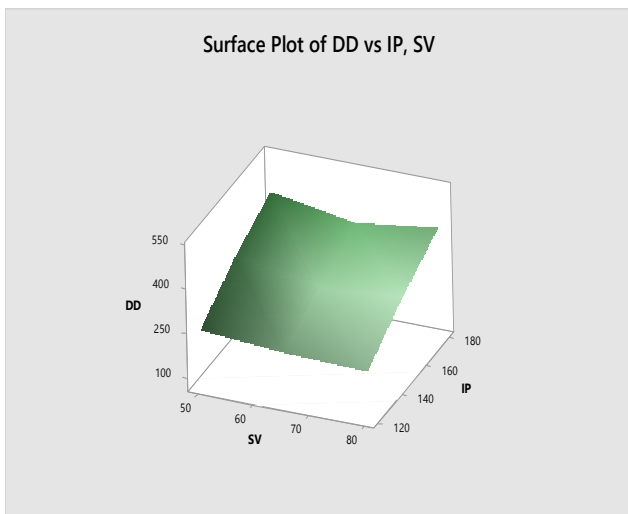


Figure 6 : Surface plots for DD Vs IP,SV

Figure 2, Figure 3 and Figure 4 shows main effect plots , SN ratio and residual plots for dimensional deviation .It indicates the main effects also follow the same trends as exhibited by interactions. Dimensional deviation is found to increase with increase in Ton and IP and decrease with increase in Toff and SV . Figure 5 shows the surface plots of Ton and Toff on DD. It clearly shows that DD attains a peak value at higher value of Ton and at a lower value of Toff. This is because a high value of Ton and corresponding lower value of Toff, causes spark to occur for longer duration which leads to higher energy discharge causing faster and greater erosion of material. It also shows that DD attains a minimum value at low value of Ton and high value of Toff . Figure 6 explains the interaction of IP and SV on DD which shows that DD decreases at higher value of Toff and at a higher value of SV. This is because a high value of Toff and corresponding higher value of SV causes spark.

V. CONCLUSION

Present work explore the WEDM of Al 6063/ ZrSiO₄(p) metal matrix composites. The quadratic models for cutting rate is developed to correlate the effects of process parameters namely pulse on time, pulse off time, peak current and servo voltage with dimensional deviation. An experimental plan of the Box-Behnken based on the RSM was applied to perform the experimentation work. Optimization of cutting rate is carried out using desirability approach. From this study, following conclusions are drawn. Main effect of pulse on time, pulse off time, peak current and servo voltage and interaction effect of pulse on time and pulse off time, pulse on time and peak current, pulse on time and servo voltage, pulse off time and peak current, pulse off time and servo voltage and interaction effect of peak current and servo voltage found to be significant from the ANOVA of cutting rate. It was found experimentally that increasing the pulse on time and peak current, the cutting rate increases, whereas increasing the pulse off time and servo voltage decreases the cutting rate. The higher discharge energy associated with the increased pulse on time, peak current and lesser pulse off time and servo voltage leads to more powerful explosions which increases the cutting rate. The effect of production of craters is more pronounced on the surface of the machined work piece when peak current is increased to a high level and servo voltage is kept at lower level.

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