IJCTA, 9(5), 2016, pp. 2611-2619

An Analysis on Process Control of Machining in Electrical Discharge Machine by Hybrid Composites using DoE

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ABSTRACT

Now a day the process of control in machining using aluminium alloys is mostly used in electrical discharge machine in order to ease the machinability. Aluminium alloys reinforced with various particulates are used widely in automotive, aircraft and space applications due to their high strength to weight ratio, excellent processing characteristics as well as improved physical and mechanical properties such as hardness, strength and wear resistance. Conventional machining of these Al based MMCs composite possess several problems including severe tool damage and poor surface finish. Use of Non-conventional machining processes for control the process parameters of machining, Al MMCs can be of more advantageous since it is possible to obtain complex and intricate profiles readily with very little tool wear. In the present work, AlSi7Mg alloy based Metal Matrix Composite (MMCs) reinforced with tungsten carbide powder (WC) and graphite (Gr) were investigated for their parametric process control of machining behaviour using Wire electrical discharge machining (WEDM). Tungsten carbide powder (average particle size less than one microns) in varying weight fractions, 3% 6% 9% respectively along with 3% graphite powder (average particle size less than one microns) were added to the aluminium alloy to produce composites by stir casting method. Hardness measurements on composite specimens indicated that hardness showed an increase with increasing concentration of tungsten carbide (WC). Influence of control process parameters on Material removal rate and surface roughness during wire cut electric discharge machining were investigated. It was observed that material removal rate (MRR) showed a decrease with an increase in weight percentage of reinforcement while surface roughness (SR) showed an increase. Design of Experiments (DoE) was used to maximize the process parameters through the use of Taguchi approach.

Keywords: Analysis of variance, Design of Experiments, Material Removal Rate, Metal Matrix Composites, Surface Roughness, Tungsten Carbide and Wire electrical discharge machining.

1. INTRODUCTION

Metal Matrix Composites (MMCs) give a combination of matrix and reinforcement(s) properties resulting in a unique / enhanced properties required for a specific application. Present day MMCs are widely used in engineering applications due to a unique combination of stiffness, strength, hardness, low density, wear resistance, electrical and thermal conductivity as well as corrosion resistance. MMCs are the recent advancements of materials. Majority of the research in Al MMCs have been directed towards improvement in strength, hardness and wear resistance through the incorporation of suitable reinforcements. Typical reinforcement used in Al MMCs include both hard particles such as tungsten carbide, boron carbide which improve the wear resistance, as well as soft reinforcements like graphite and molybdenum disulfide, which act as lubricants to reduce friction during service[3],[4]. By proper control of factors such as size and weight fraction of reinforcement and significant improvement in mechanical properties. Increase in graphite reinforcement content however, leads to a decrease

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in the fracture toughness of the composites [1].Several investigations have shown that hybrid composites show better wear characteristics compared to MMCs containing a single reinforcement [5]. Conventional machining of Al MMCs composite material is difficult with very high tool wear rate and power consumption. Non-conventional machining processes such as laser beam machining, water jet machining, abrasive jet machining are more expensive and surface finish is also not very good [6,7]. However, Wire Electrical Discharge Machining (WEDM) is most widely used to control the process parameters for machining of metal matrix composites to avoid tool wear and breakage of tool in addition to get a smooth surface finish. In order to obtain quality machining in wire electric discharge machining, various machining parameters can be optimized. Excellent control of WEDM process is possible with accurate and efficient control of machining parameters [10]. Machinability of composite material is much better with wire electrical discharge machine compared to other types of machines. By using tungsten carbide (WC) as reinforcement only few experiments have been carried out. Limited investigations have been conducted in WEDM with Al Metal matrix Composites and that too with limited process control parameters considered for analysis [11]. Surface finish is one of the most important measures in assessing the quality of machined parts. Surface finish as measured by surface roughness is influenced by Pulse-on-time, Current and cutting speed during wire cut electrical discharge machining process [13].Material removal rate directly increases with increase in pulse-on-time and peak current, while decreasing with an increase in pulse-off time[14]. The present experimental study aims to investigate on wire electrical discharge machining using AlSi7Mg alloy reinforced with tungsten carbide powder and graphite powder and analyse the effect of various process parameters on material removal rate and surface roughness. Analysis of variance is used to measure a confidence level. DoE and Taguchi analysis was done to analyze and optimize the process parameters that influence the machining process.

2. MATERIALS AND METHODS

In the present work, the matrix material used was AlSi7Mg alloy whose nominal chemical composition is given in Table 1. This alloy exhibits good mechanical properties, corrosion resistance and excellent castability. Tungsten carbide (WC-melting point (2870 C)) was chosen as the hard reinforcement for providing enhanced wear resistance. Graphite (Gr) was added as a soft reinforcement providing a lubrication effect and minimizing friction and wear. Hybrid composite specimens were prepared with varying weight percentages of WC (3% 6% 9%) along constant amount 3 wt% graphite (Gr).Composite specimens were prepared by stir casting method using a cast iron mould.

Table 1
Chemical composition by weight % of aluminum (LM25) matrix alloy

Si	*Mg*	*Cu*	*Fe*	*Mn*	*Ni*	*Zn*	*Al*
7.3	0.30	0.012	0.3	0.28	0.002	0.004	Remaining

2.1. Fabrication of Hybrid Composites

Metal matrix composites were fabricated by stir casting technique. Crucible furnace was used for melting the ingots. Al alloy ingots were heated to the desired temperature of 700 °C. The graphite crucible was covered with a flux in order to prevent oxidation of the molten metal. Small quantity of magnesium (2wt %) was added to the molten metal to improve the wettability of aluminium alloys and reinforcement. After the ingots were melted, required quantity of tungsten carbide and graphite particulate, preheated to 250 °C were added to the melt and then mixed continuously using a mechanical stirrer rotating at a speed of 500 r.p.m for uniform distribution of particles. The stirring process was continuously done for 10 to 12 minutes for proper mixing of matrix and reinforcement particles. The molten metal was poured into a cast iron mould to obtain a cylindrical shape specimen of 75 mm length and 15 mm diameter. Unreinforced aluminium alloy specimens were also cast for the purpose of comparison with the composites.

2.2. Machinability Studies on Composites

Design of experiments is an effective procedure to determine the individual and interactive effects of many control factors that would affect the results in output for design. The various process control parameters are pulse-off time, Input Power, Voltage, wire speed, wire tension and composition of the composites listed in Table 2 and Table 3. Voltage gap and water pressure were chosen as fixed variables shown in Table 4. A L27 orthogonal factor design was selected for the present study presented in Table 5 and Table 6. Analysis of Variance (ANOVA) was carried out to determine the percentage contribution of each control factors and to identify the significant process parameters. It aids in data analysis, optimization and prediction of optimum conditions. Material Removal Rate (MRR) of the work piece (amount of material removed per minute of time) and Surface Roughness were the desired outputs from the experimental investigation.

Table 2
Input process parameters and factors used in EDM of composites

Sr. No	*Process Parameters*	*Unit*	*Factors*
1	Pulse off time(Toff)	µs	A
2	Input Power(IP)	Amp	B
3	Voltage(V)	Volt	C
4	Wire Speed(Ws)	m/min	D
5	Wire Tension(Wt)	gms	E
6	Composition(C)	%	F

Table 3
Factors and levels used in EDM of composites

Factors	*Level 1*	*Level 2*	*Level 3*
A	1	2	3
B	4	6	8
C	8	12	16
D	4	10	16
E	5	10	15
F	3	6	9

Table 4
EDM process parameters with fixed value

Sr. No	*Process Parameters*	*Unit*	*Leve l1*
1	Voltage gap	Volt	45
2	Water Pressure	Kgf/cm2	14

Table 5
Design of Experiments using L27 orthogonal array for study of Material Removal Rate (MRR) during EDM of Composites

Sr. No	*A*	*B*	*C*	*D*	*E*	*F*	*MRR (mm3/min)*
1	1	4	8	4	5	3	4.928
2	1	4	8	4	10	6	4.247
3	1	4	8	4	15	9	3.683

(*contd...*)

(*Table 5 contd...*)

Sr. No	*A*	*B*	*C*	*D*	*E*	*F*	*MRR (mm3/min)*
4	1	6	12	10	5	3	6.972
5	1	6	12	10	10	6	6.472
6	1	6	12	10	15	9	5.132
7	1	8	16	16	5	3	8.163
8	1	8	16	16	10	6	8.884
9	1	8	16	16	15	9	6.176
10	2	4	12	16	5	6	3.860
11	2	4	12	16	10	9	3.568
12	2	4	12	16	15	3	4.178
13	2	6	16	4	5	6	6.682
14	2	6	16	4	10	9	6.896
15	2	6	16	4	15	3	5.962
16	2	8	8	10	5	6	6.785
17	2	8	8	10	10	9	5.872
18	2	8	8	10	15	3	5.549
19	3	4	16	10	5	9	4.378
20	3	4	16	10	10	3	5.112
21	3	4	16	10	15	6	4.071
22	3	6	8	16	5	9	3.982
23	3	6	8	16	10	3	4.583
24	3	6	8	16	15	6	4.111
25	3	8	12	4	5	9	6.826
26	3	8	12	4	10	3	7.305
27	3	8	12	4	15	6	7.683

Table 6
Design of experiments using L27 orthogonal array for study of Surface Roughness (SR) during EDM of composites

Sr. No	*A*	*B*	*C*	*D*	*E*	*F*	*SR(μm)*
1	1	4	8	4	5	3	2.82
2	1	4	8	4	10	6	2.84
3	1	4	8	4	15	9	2.83
4	1	6	12	10	5	3	2.82
5	1	6	12	10	10	6	2.85
6	1	6	12	10	15	9	2.87
7	1	8	16	16	5	3	2.90
8	1	8	16	16	10	6	2.97
9	1	8	16	16	15	9	2.96
10	2	4	12	16	5	6	2.81
11	2	4	12	16	10	9	2.79
12	2	4	12	16	15	3	2.75

(*contd...*)

(*Table 6 contd...*)

Sr. No	*A*	*B*	*C*	*D*	*E*	*F*	*SR(μm)*
13	2	6	16	4	5	6	2.93
14	2	6	16	4	10	9	2.92
15	2	6	16	4	15	3	2.87
16	2	8	8	10	5	6	2.86
17	2	8	8	10	10	9	2.86
18	2	8	8	10	15	3	2.76
19	3	4	16	10	5	9	2.89
20	3	4	16	10	10	3	2.82
21	3	4	16	10	15	6	2.83
22	3	6	8	16	5	9	2.84
23	3	6	8	16	10	3	2.68
24	3	6	8	16	15	6	2.77
25	3	8	12	4	5	9	2.86
26	3	8	12	4	10	3	2.80
27	3	8	12	4	15	6	2.84

3. RESULTS AND DISCUSSION

3.1. Effect Of Input Process Control Parameters On Material Removal Rate (MRR)

To analyze the experimental results analysis of variance (ANOVA) was used to determine the important control parameters of machining process. ANOVA for material removal rate is listed in Table 7.The main effect plot for means and signal to noise ratio are shown in Figures 1 and 2.

Table 7
Analysis of Variance for Material Removal Rate

Source	*DF*	*Seq SS*	*Adj MS*	*F*	*P*
A	2	2.721	1.3606	5.64	0.016
B	2	35.332	17.6661	73.17	0.001
C	2	9.083	4.5417	18.81	0.000
D	2	2.519	1.2594	5.22	0.020
E	2	2.866	1.4331	5.94	0.014
F	2	2.903	1.4517	6.01	0.013
Residual Error	14	3.380	0.2414		
Total	26	58.805			

From figure 2, as the level of pulse-off time increases, Material Removal Rate decreases gradually. Increase in input power and voltage will lead to an increase in the metal removal rate which in turn leads to discharge of higher energy flow into the metal. It causes wire breakage**.** It is observed that with an increase in wire speed, the metal removal rate decreases [20]. With reference to wire tension, metal removal rate slightly increases at first and thereafter shows gradual decrease as the reinforcement content increased. High hardness of the composites results in reduced wire tension and hence the material removal rate decreases with higher WC content. Hence larger-the-better approach was used to determine the SN ratio of metal removal rate.

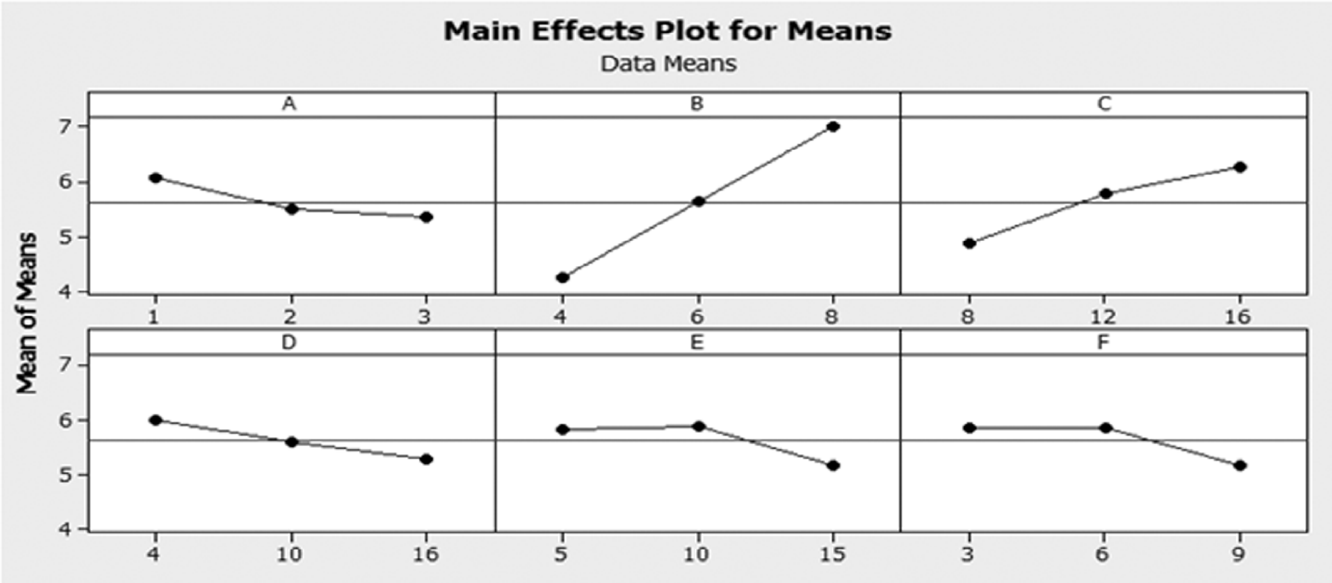

Figure 1: Main effects of significant parameters for means in Material removal rate

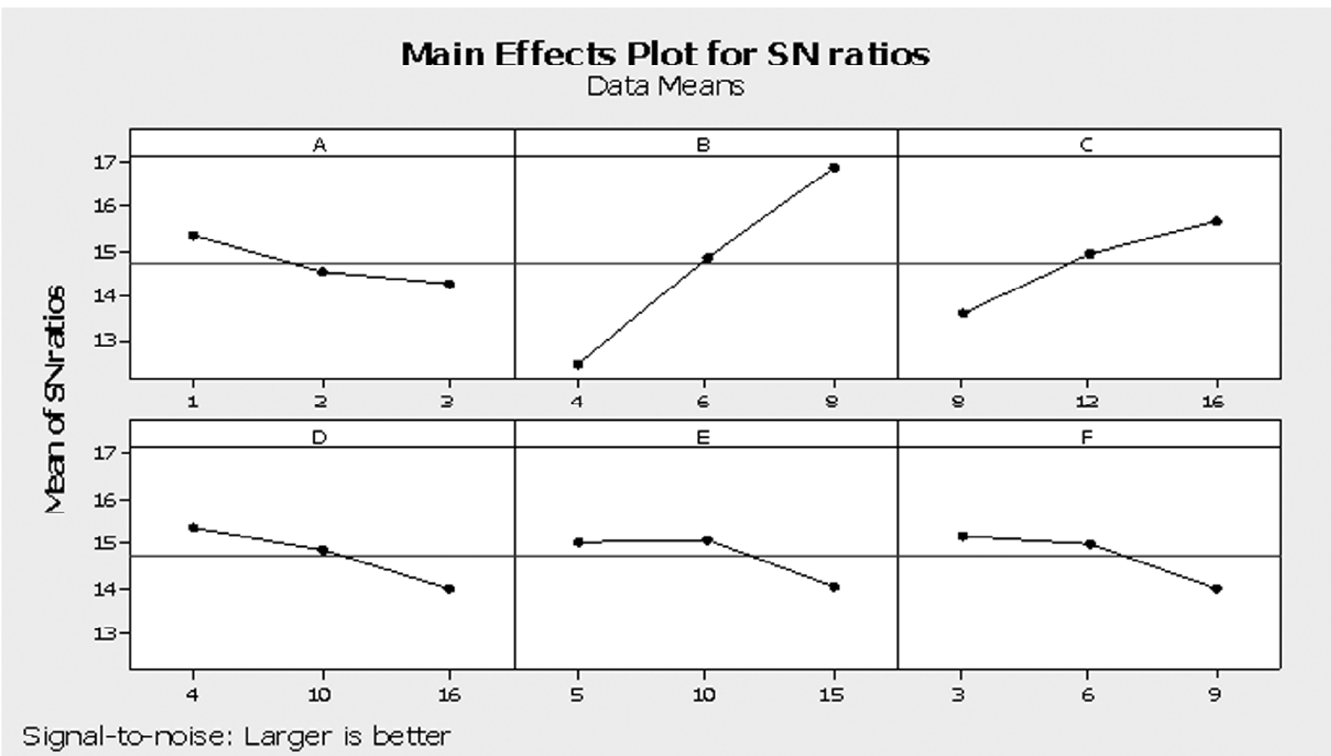

Figure 2. Main effects of significant parameters for SN ratios in Material removal rate

3.2. Effect of Input Process Control Parameters on Surface Roughness (SR)

ANOVA for surface roughness is listed in Table 8.The main effect plot for means and signal to noise ratio are shown in Figures 3 and 4.

Data on the analysis of the surface roughness indicate that surface roughness decreased with increase in pulse-off time because of increased gap. Increase in input power and voltage led to an increase in surface roughness due to increase in discharge energy in addition to producing larger crater. This in turn leads to a higher surface roughness value. It can also be observed that increase in wire speed and wire tension significantly influences the surface roughness of the finished composite samples. Hence it can be concluded that increase in percentage of reinforcement results in increase of surface roughness.

Table 8
Analysis of Variance for Surface Roughness

Source	*DF*	*Seq SS*	*Adj MS*	*F*	*P*
A	2	0.015756	0.007878	17.66	0.001
B	2	0.010422	0.005211	11.68	0.002
C	2	0.011289	0.022144	49.65	0.000
D	2	0.003267	0.001633	3.66	0.053
E	2	0.003889	0.001944	4.36	0.034
F	2	0.022400	0.011200	25.11	0.002
Residual Error	14	0.006244	0.000446		
Total	26	0.106267			

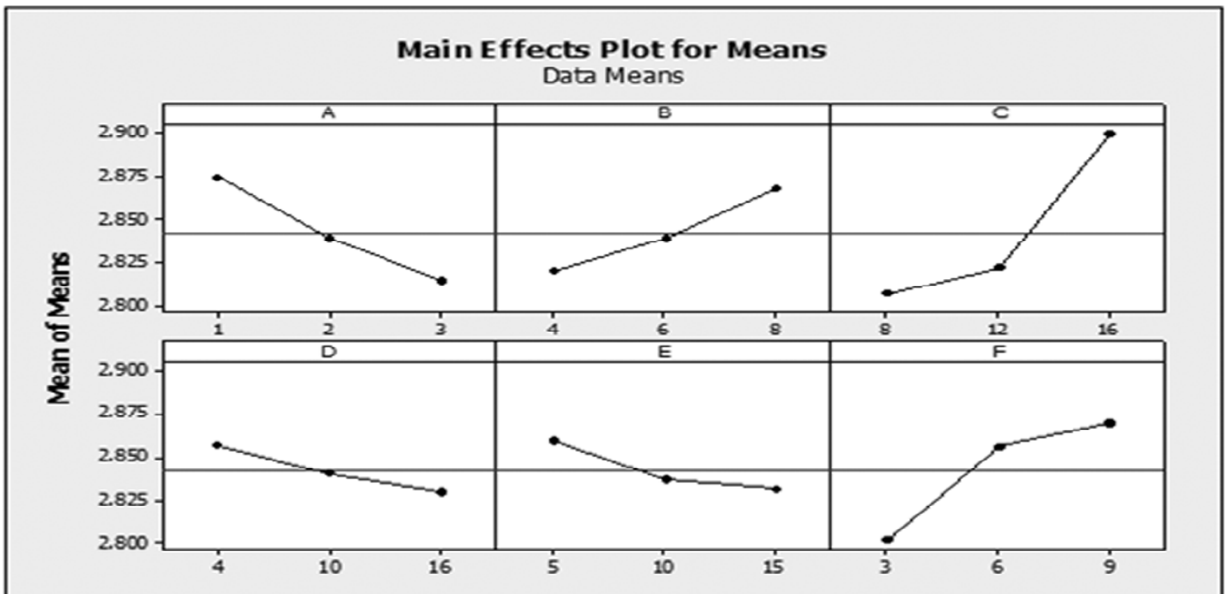

Figure 3: Main effects of significant parameters for means in Surface Roughness

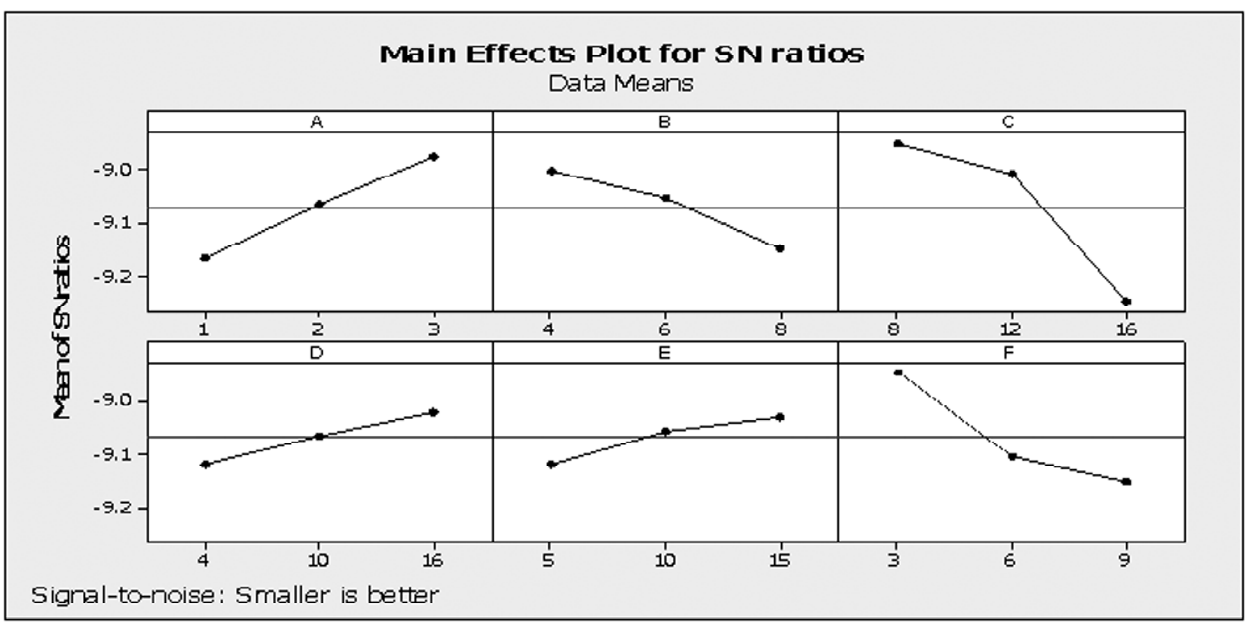

Figure 4: Main effects of significant parameters for SN ratios in Surface roughness

3.3. Confirmation Experiment

A confirmation experiment was conducted for both MRR and SR under optimum conditions predicted by DOE analysis listed in Table 9 .The difference between actual values and predicted values was calculated. Both values are close to each other. It was seen that the input power influences metal removal rate the most, while the pulse-off time influences the surface roughness.

Table 9
Confirmation Result

Respond Error Performance	*Optimize value of Input process control parameters*						*Predicted Value*	*Actual Value*	*Error (%)*
	A	B	C	D	E	F			
MRR(mm3/min)	1	6	12	10	5	3	6.631	6.938	4.42
SR(μm)12	2	4	12	16	15	3	2.73	2.88	5.20

4. CONCLUSIONS

In these studies, metal removal rate is strongly influenced by control the process of input power and voltage Surface Roughness of composites was significantly influenced by Pulse-off time. In this analysis reinforcement plays a major role in increasing the surface finish and also decreases the metal removal rate. All the other control factors of MRR and SR have less significant effect during wire electrical discharge machining of composites. It is observed from confirmation test for optimisation of process parameters the percentage of error between predicted value and actual value of MRR and SR was found to be 4.42% and below 5.20%.

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