Parametric Optimization of Wire Electrical Discharge Machining by Taguchi Technique on Composite Material

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***Abstract*— In this present study, Al7075+10%Al_2O_3 metal matrix composite (MMC) were fabricated using stir casting method. The five parameter namely voltage, pulse-on, pulse-off, current, bed speed were chosen as factors to study the output responses in terms of material removal rate (MRR) and surface roughness (Ra) while machining Al7075+10%Al_2O_3 metal matrix composite (MMC) in wire Electrical Discharge Machining (WEDM). Experimentation has been carried out using Taguchi's L18 orthogonal array. Evaluation of output responses has been done by Signal to Noise (S/N) ratio analysis and to determine the significant effect of each parameter Analysis of Variance (ANOVA) was carried out. Optimal value of parameters which maximize material removal rate (MRR) and minimize surface roughness (Ra) were determined based on experimental result, In addition mathematical model have developed for output responses.**

Keywords—WEDM, MRR, Ra, Taguchi orthogonal array, minitab-17 software.

I. INTRODUCTION

A composite is a material which is comprised of two or more materials. The main part of the composite is called as matrix material and the material mixed is called as reinforcement. The composite are mainly classified in to three groups Polymer matrix composites (PMCs), Metal matrix composites (MMCs), Ceramic matrix composites (CMCs). To produce Polymer matrix composites (PMCs), Metal matrix composites (MMCs), Ceramic matrix composites (CMCs) reinforcement are added. The advantage of using composite are light weight, high strength, corrosion resistance, high impact strength, design flexibility, dimension stability and so on. Aluminium matrix composite (AMC) exhibit outstanding combination properties such as high strength, high stiffness, thermal and electric conductivities from these magnificent property AMC's are used in aerospace, automobile, defense and in many other sectors. These composite can be fabricated by using stir casting method. In which reinforcement material can be mixed with molten metal by mechanical stirring process. This method can reduce the final cost and produce large quantity. Wire electrical discharge machining (WEDM) is a thermo-electrical process which is classified under non-traditional machining process. WEDM is effectively and successfully used to machine MMC. WEDM is similar to EDM material removal process were wire is used as cutting tool as shown in Fig-1. The discrete sparking between work piece and wire, erodes the material from the work piece in the presence of dielectric fluid which is flushed continuously to working zone and also flush the eroded particles and acts as coolant. Taguchi orthogonal array is used to conduct the experiment with less number of experiment and get better result. The experimental result is transformed to S/N ratio and ANOVA are used to determine optimum value and relative contribution of each factor on output responses.

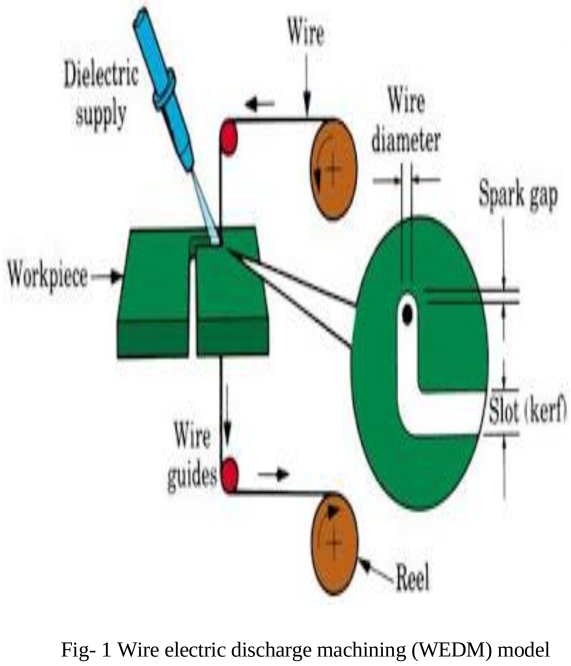

Fig- 1 Wire electric discharge machining (WEDM) model

II. EXPERIMENTAL STUDY

A. Material Selection

1) Matrix Material

Aluminium Al7075 alloy was considered as the matrix material based on mechanical properties like machinability, fatigue strength, corrosion resistance are excellent compared to other Aluminium alloy.

Table - I Chemical composition of Al7075

Contents	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti	Al
Composition (%)	6	3	2	0.3	0.6	0.5	0.4	0.3	Bal

2) Reinforcement

Al2O3 (Alumina) of size 50 - 100 microns was used as reinforcing particles with the proportions of 90% and 10%. In engineering ceramic family Alumina is widely used and it is cost effective material which have excellent combination of properties. With the fine grain alumina has wide range of application.

Table - II Chemical composition of AL_2O_3

Contents	SiO_2	Fe_2O_3	TiO_2	Na_2O	AL_2O_3
Composition (%)	0.15	0.05	0.15	0.45	Bal

B. Composite Preparation

The present study was conducted by taking Aluminium Al7075 as a base matrix and Al2O3 of size 50 - 100 microns was used as reinforcing particles with the proportions of 90% and 10% wt. respectively. Aluminium Al7075 alloys were melted using 6kw melting furnace (silicon element heating) at a temperature of 740^0c for 30 min. Then the mixture was stirred using a ceramic coated metallic stirrer rotating at 300 rpm for 15 minutes and then it was poured in to a metallic mould which was preheated.

1) Metallographic Study

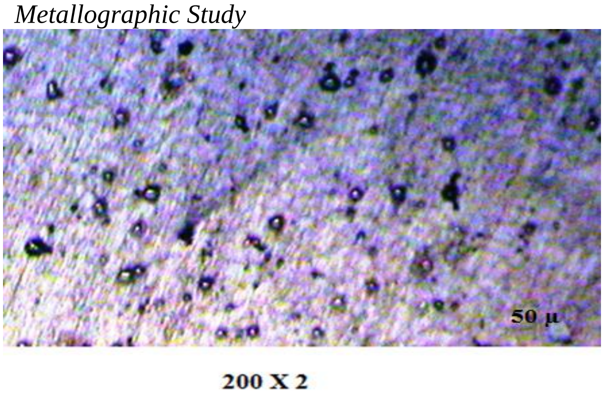

Fig- 2 Microstructure

To investigate the distribution of discontinuous reinforcement matrix in the fabricated specimen, the quality of specimen was checked by metallographic study using optical microscope connected to computer imaging system and scanning electron microscope. Microstructure of composite specimen was observed at 200X. From the Fig-2 uniformly distributed reinforcement was revealed.

C. Wire Electrical Discharge Machining (WEDM)

The experiments was conducted by using DK-7732 WEDM machine tool which is manufactured by CONCORD United Products Ltd. Based on the thickness, material the operator can select the input parameter from the manual provided by the manufacturing company. Molybdenum wire of Diameter 0.18mm was used and demineralized water plus JR3A gel is used as a dielectric fluid to carry out experiments. The selection of process parameter were based on machine capability. The parameters like Voltage, pulse-on, pulse-off, current, bed speed were chosen to carry out the experiments

Table- III Machining parameter used in experiments

parameters		Level			
		I	II	III	Units
A	Voltage	75	100	----	Volts
B	Pulse-ON	40	30	20	µ sec
C	Pulse-OFF	9	12	15	µ sec
D	Current	2	4	6	Amps
E	Bed speed	50	150	250	µm/sec

Material removal rate (MRR) can be calculated using Eq. (1).

$$MRR = \frac{(2*Wg+D) * t * L}{T} \qquad \text{Eq. (1)}$$

Where,

Wg = spark gap - “0.02mm”
D = Diameter of wire - “0.18mm”
T = Time taken to cut “min”
L = Distance travelled by tool – “60mm”
t = Thickness of work piece – “10mm”

Surface roughness was measured using Mitutoyo Surftest SJ-210 portable surface measuring unit.

D. Experimental Design

Dr.Genichi Taguchi developed Taguchi method which was built on traditional concepts of Design of Experiment (DOE). R.A. Fisher introduced the DOE technique to study the multiple variables simultaneously. Orthogonal array (OA) is a specially constructed table based on DOE technique to reduce the number of experiments. The L18 (2*3) orthogonal array was chosen to conduct the experiment as shown in Table- IV

Table- IIV L18 (2*3) orthogonal array

L18 (2*3) Orthogonal array					
Exp	Voltage	Pulse ON	Pulse OFF	Current	Bed speed
No.	volts	(µs)	(µs)	Amps	(µm/s)
1	75	40	9	2	50
2	75	40	12	4	150
3	75	40	15	6	250
4	75	30	9	2	150
5	75	30	12	4	250
6	75	30	15	6	50

7	75	20	9	4	50
8	75	20	12	6	150
9	75	20	15	2	250
10	100	40	9	6	250
11	100	40	12	2	50
12	100	40	15	4	150
13	100	30	9	4	250
14	100	30	12	6	50
15	100	30	15	2	150
16	100	20	9	6	150
17	100	20	12	2	250
18	100	20	15	4	50

After conducting the experiments results were evaluated by using, S/N ratio and ANOVA to find the optimal value and relative parameter influence on output responses i.e. (MRR, Ra).

The S/N ration is classified as "Larger the better", "Nominal the better" and "Smaller the better". The S/N ratio for MRR and Ra was calculated by logarithmic transformation function as shown in Eq. (2). "Larger the better" and Eq. (3) "Smaller the better" respectively S/N ratio and tabulate in Table- V

MRR = -10 log (∑ (1/y2)/n) Eq. (2)

RA = -10 log (∑y2/n) Eq. (3)

III. RESULT AND DISCUSSION

The analysis of experimental results were carried out by using minitab-17. The results were transformed to signal to noise ratio of MRR and Ra for Al7075+10%Al_2O_3 metal matrix composite (MMC).

Table- V Eexperimental results

L18 (2*3) Orthogonal array

Exp. No.	MRR	S/N ratio MRR	Ra	S/N ratio Ra
	mm3/min	(dB)	(μm)	(dB)
1	5.641	15.027	1.784	-5.028
2	16.500	24.350	1.528	-3.682
3	17.984	25.098	1.572	-3.929
4	13.895	22.857	1.737	-4.796
5	17.671	24.945	1.739	-4.806
6	5.906	15.426	1.387	-2.842
7	5.901	15.418	1.645	-4.323
8	17.886	25.050	1.567	-3.901
9	8.800	18.890	1.749	-4.856
10	30.137	29.582	1.405	-2.954
11	5.911	15.434	1.576	-3.951
12	17.483	24.853	1.595	-4.055
13	28.884	29.213	1.759	-4.905
14	5.880	15.387	1.617	-4.174
15	11.681	21.350	1.768	-4.950
16	17.862	25.039	1.458	-3.275
17	14.270	23.089	1.729	-4.756
18	5.877	15.383	1.501	-3.528

A. Signal to Noise (S/N) ratio

The S/N ratio graph for material removal rate (MRR) is shown in fig 3. from the graph the optimum value obtained are Voltage 100 volts, Pulse-ON 40(μs), Pulse-OFF 9(μs), Current 6 Amps, Bed speed 250 (μm/s). This optimum value gives maximum MRR. The S/N ratio graph for surface roughness (Ra) is shown in fig 4. from the graph the optimum value obtained are Voltage 100 volts, Pulse-ON 40 (μs), Pulse-OFF 15 (μs), Current 6 Amps, Bed speed 50 (μm/s). This optimum value gives minimize Ra.

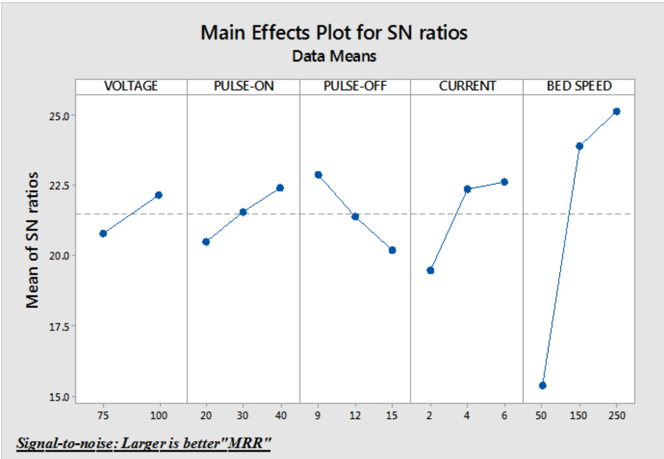

Fig. 3. Signal to noise ratio graph for material removal rate (MRR)

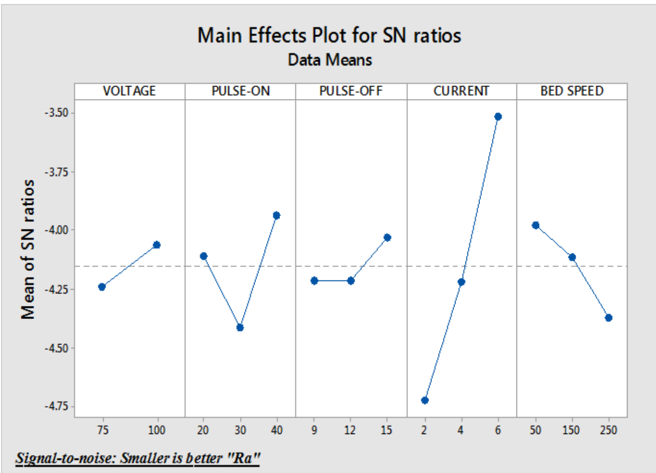

Fig. 4. Signal to noise ratio graph for surface roughness (Ra)

The Response Table for S/N ratio for Material Removal Rate (MRR) and surface roughness (Ra) is shown in Table-VI and Table-VII

Table-VI Taguchi Analysis: MRR v/s Voltage, Pulse On, Pulse Off, Current, Bed Speed

Response Table For Signal To Noise Ratios Larger Is Better					
Level	*Voltage*	*Pulse-On*	*Pulse-Off*	*Current*	*Bed Speed*
1	20.78	20.48	22.86	19.44	15.35
2	22.15	21.53	21.38	22.36	23.92
3	-------	22.39	20.17	22.60	25.14
Delta	1.36	1.91	2.69	3.16	9.79
Rank	5	4	3	2	1

Table-VII Taguchi Analysis: Ra v/s Voltage, Pulse-No, Pulse-Off, Current, Bed Speed

Response Table For Signal To Noise Ratios Smaller Is Better					
Level	***Voltage***	***Pulse-On***	***Pulse-Off***	***Current***	***Bed Speed***
1	-4.240	-4.107	-4.214	-4.723	-3.974
2	-4.061	-4.412	-4.212	-4.217	-4.110
3	------	-3.933	-4.026	-3.512	-4.368
Delta	0.180	0.479	0.187	1.210	0.393
Rank	5	2	4	1	3

B. Analysis Of Variance (ANOVA)

The ANOVA results for Material Removal Rate (MRR) and surface roughness (Ra) are shown in Table VIII and IX and Fig 5 and 6 shows the Percentage contributions of Material Removal Rate (MRR) and surface roughness (Ra)

Table-VIII Regression Analysis: MRR v/s Voltage, Pulse On, Pulse Off, Current, Bed Speed

Analysis of variance					
Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Regression	5	860.68	172.14	16.01	0.000
Voltage	1	42.95	42.95	3.99	0.069
Pulse-On	1	44.31	44.31	4.12	0.065
Pulse-Off	1	99.69	99.69	9.27	0.010
Current	1	104.76	104.76	9.74	0.009
Bed Speed	1	568.97	568.97	52.92	0.000
Error	12	129.01	10.75	-----	-------
Total	17	989.70	--------	-----	-------

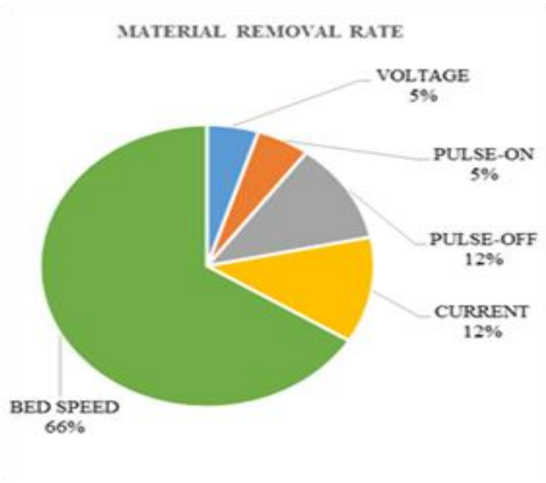

Fig. 5 Percentage contributions by process parameters on MRR

Table-IX Regression Analysis: Ra v/s Voltage, Pulse-No, Pulse-Off, Current, Bed Speed

Analysis of variance					
Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Regression	5	0.177183	0.035437	4.05	0.022
Voltage	1	0.005000	0.005000	0.57	0.464
Pulse-On	1	0.002977	0.002977	0.34	0.570
Pulse-Off	1	0.003888	0.003888	0.44	0.517
Current	1	0.148964	0.148964	17.04	0.001
Bed Speed	1	0.016354	0.016354	1.87	0.196
Error	12	0.104894	0.008741	-----	-------
Total	17	0.28076	--------	-----	-------

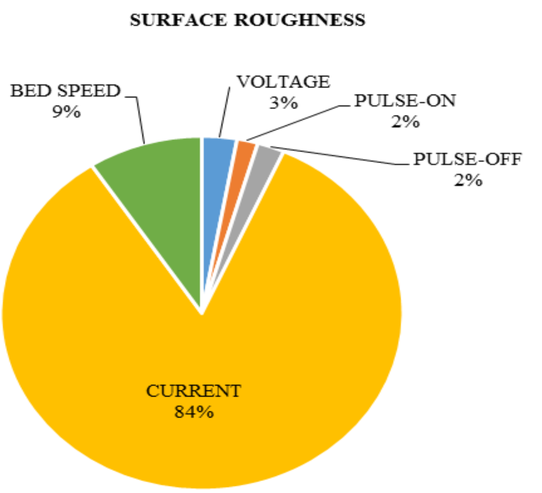

Fig 6 Percentage contributions by process parameters on Ra

C. Mathematical Model

Multiple linear regression (MLR) model is performed by the help of MINITAB-17 software. This model is used to predict various performance measures in WEDM process. The Equation (4) and (5) shows the mathematical model, Table X and XI shows the model summary. Experimental value and predicted value are compared as shown in figure 7 and figure 8 of Material Removal Rate (MRR) and surface roughness (Ra) respectively.

Table - X Model summary for MRR

Model summary			
S	*R-sq*	*R-sq (adj)*	*R-sq (pred)*
3.27887	86.96%	81.53%	71.74%

Coefficients					
Term	*Coef*	*SE Coef*	*T-Value*	*P-Value*	*VIF*
Constant	-7.50	7.61	-0.99	0.344	-----
Voltage	0.1236	0.0618	2.00	0.069	1.00
Pulse-On	0.1922	0.0947	2.03	0.065	1.00
Pulse-Off	-0.961	0.316	-3.05	0.010	1.00
Current	1.477	0.473	3.12	0.009	1.00
Bed Speed	0.06886	0.00947	7.27	0.000	1.00

Regression Equation

MRR = -7.50+ 0.1236 Voltage + 0.1922 Pulse-On - 0.961 Pulse-Off + 1.477 Current + 0.06886 Bed Speed. Eq. (4)

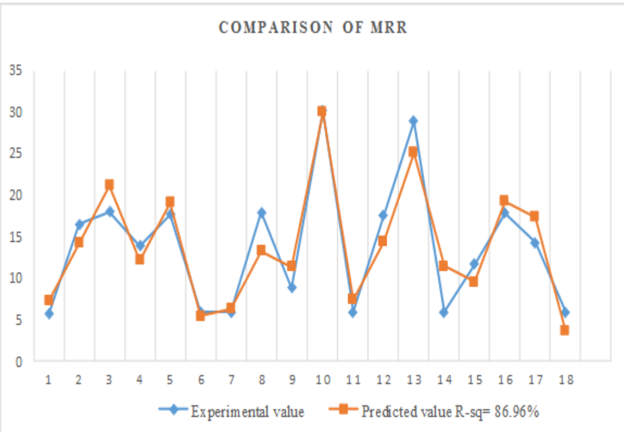

Fig. 7 comparison of MRR between experimental and predicted

Table –XI Model summary for Ra

Model summary			
S	*R-sq*	*R-sq (adj)*	*R-sq (pred)*
0.0934940	62.81%	47.32%	14.95%

Coefficients					
Term	*Coef*	*SE Coef*	*T-Value*	*P-Value*	*VIF*
Constant	2.021	0.217	9.32	0.000	-----
Voltage	-0.00133	0.00176	-0.76	0.464	1.00
Pulse-On	-0.00157	0.00270	-0.58	0.570	1.00
Pulse-Off	-0.00600	0.00900	-0.67	0.517	1.00
Current	-0.0557	0.0135	-4.13	0.001	1.00
Bed Speed	0.000369	0.000270	1.37	0.196	1.00

Regression Equation

Ra =2.021 - 0.00133 Voltage - 0.00157 Pulse-On – 0.00600Pulse-Off - 0.0557 Current +0.000369 Bed Speed. Eq. (5)

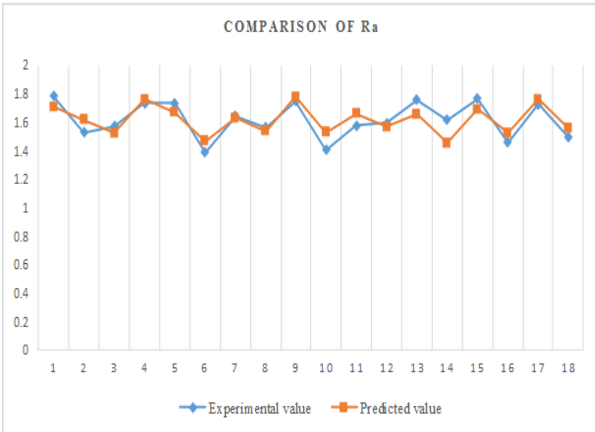

Fig. 8 comparison of Ra between experimental and predicted

Table –XII Optimum Value

Response	Factor				
	Voltage (volts)	Pulse-on (µs)	Pulse-off (µs)	Current Amps	Bed speed (µm/s)
MRR (mm3/min)	100	40	9	6	250
Ra (µm)	100	40	15	6	50

IV. CONCLUSION

Al7075+10%Al_2O_3 metal matrix composite (MMC) was fabricated successfully using stir casting process and Taguchi L18 orthogonal array was used to conduct the experiment. From the S/N ratio and ANOVA analysis the following conclusion were drawn

1. Using taguchi method MRRR and Ra were optimized individually.
2. Bed speed is the most influential parameter which significantly affect the material removal rate (MRR). The voltage, pulse-on, pulse-off, current are less influential parameters.
3. According to proposed levels of factors used in this work to maximize MRR can be achieved by selecting combination of parameters, Voltage 100 (volts), Pulse-on 40 (µs), Pulse-off 9(µs), Current 6 Amps, Bed speed 250 (µm/s).
4. Current is the most influential parameter which significantly affect the surface roughness (Ra). The voltage, pulse-on, pulse-off, Bed speed are less influential parameters.
5. For achieving minimum surface roughness the optimum condition are Voltage 100 (volts), Pulse-on 40 (µs), Pulse-off 9(µs), Current 6 Amps, Bed speed 250 (µm/s).

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