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Parametric Optimization of Wire Electrical Discharge Machining of Composite Material

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Abstract: **wire electrical discharge machining (WEDM) is widely used in many industries for machining conductive materials. In this paper, parametric optimization of Wire electrical discharge machining of Composite material (Al+3%SiC) is evaluated. Selection of optimum machining parameters combination for obtaining maximum material removal rate and minimum the surface roughness is a challenging task in WEDM due to presence of large number of process variables and complicated process mechanisms. In general no perfect combinations exist, that results the best material removal rate and the best surface finish. This paper is an attempt to find the best affecting parameters for maximize material removal rate (MRR) and minimizing surface roughness (Ra). The Design of Experiment (DOE) and Analysis is conducted in Taguchi Method. The two out puts, MRR and Ra have been considered as the measures of process performance with four different control parameters (Pulse on, pulse off, Voltage and current).**

KEYWORDS **WEDM, MRR, Ra, Taguchi Analysis, ANOVA, Minitab 16 Software.**

1.0 INTRODUCTION

In recent years, the technology of wire electrical discharge machining (WEDM) has been improved significantly in recycling the electrode (wire) to meet various requirements machining fields, especially in the precision die industry. WEDM is a thermo-electrical process in which material is eroded from the workpiece by a series of discrete sparks between the workpiece and the electrode (wire).The work piece and electrode is separated by a thin film of dielectric fluid (dematerialized water) that is continuously fed to the machining zone to flush away the eroded particles. The movement of wire is controlled numerically to achieve the desired three-dimensional shape and accuracy in required dimensions.

It is evident to hold the wire in a designed position against the work piece because it repeats complex oscillations due to electro-discharge between each other. Normally, the wire is held by a roller guide at the upper and the lower parts. In most cases, the wire will be discarded once used but here wire is recycled.

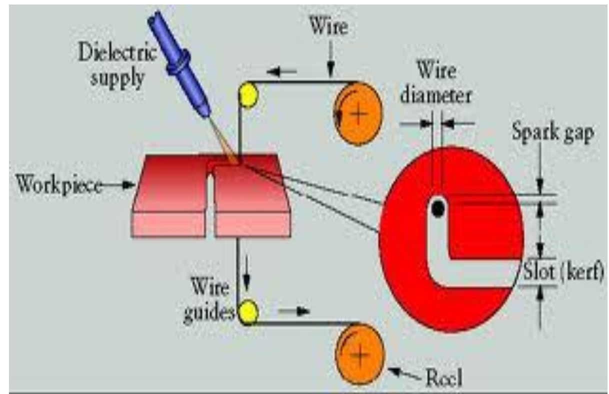

Fig 1: WEDM Setup–Details

2.0 MATERIAL SELECTION

This project work investigates the Machining properties of Composite Material (Al+3%SiC). The hardness of composite material was tested by using Brinell's method is 55 BHN, The material properties of aluminum(Al) and

Table 1: composition of Al 6061

Composition	Volume percentage
Aluminum, Al	95.8 - 98.6 %
Chromium, Cr	0.040 - 0.35 %
Copper, Cu	0.15 - 0.40 %
Iron, Fe	0.70 %
Magnesium, Mg	0.80 - 1.20 %
Manganese, Mn	0.15 %
Other, each	0.050 %
Other, total	0.15 %
Silicon, Si	0.40 - 0.80 %
Titanium, Ti	0.15 %
Zinc, Zn	0.25 %

Table 2: gives mechanical properties of Al

Density	2.7 g/cm^3
Melting Point	580°C(approx)
Modulus of Elasticity	70-80 Gpa
Poisson Ratio	0.33

Table 3: gives details about SiC

Properties	Values
Density (g/cc)	3.15
Mechanical Flexural Strength(MPa)	380
Elastic Modulus (GPa)	400
Poisson's Ratio	0.17
Hardness (Kg/mm^2)	2300
Fracture Toughness (MPa•m$^{1/2}$)	2.5
Thermal Expansion Coeff.10^{-6}/°C;	4.8
Thermal Conductivity(W/mK) @ 25 °C	115
Electrical Resistivity(ohm-cm)	10^(5)
Applications	Semiconductor Components.
Key Features	High purity, corrosion Resistance, Wear resistance

silicon carbide(SiC) are shown as below.

3.0 COMPOSITE PREPARATION

The Preheated temperatures of die and particulates are 600^{o}c and 850^{o}c**.**The aluminum kept inside the crucible and small percentage of coverall is added (i.e. For1.5 kg of Al 7gm is added) Once the aluminum is melted (converted into liquid), some ingradiance like coverall (7 g), degas (7g) and nuclide (7 g) are respectively added into 1.5 kg of aluminum and impurities are removed using ladle by manually stirring. Then after, the particulates are added into liquid aluminum. The mixture of liquid aluminum and particulate (SiC) is stirred at 250 rpm show in fig 2. Then liquid mixture is poured inside the die and kept for air cooling up to 2 hrs and cast is taken out from the die.

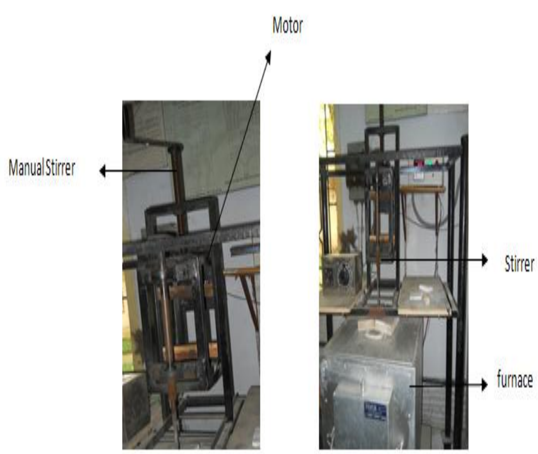

Fig 2: The stirring process of Aluminum and particulates**.**

3.1. Microstructure

SEM microphotographs of composites material (Al6061+3%SiC) are shown in Fig.3. From the microphotographs it is observed that the reinforcement particles silicon carbide are distributed throughout Al6061 matrix alloy and also exist a good bond between matrix and particles.

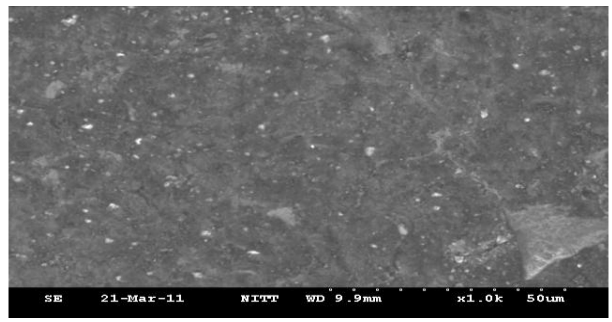

Fig 3: The distribution of SiC in Aluminum.

4.0. EXPERIMENTAL DETAILS

In the present work, the experiments have been conducted on 4-Axis CNC-WEDM machine (DK7720CH). All four axes movements are simultaneously controlled by four closed loop dc motor systems. WEDM process involves a number of machine setting parameters such as Current (C), Pulse-on time (**T**on), Pulse off time (**T**off) and Voltage (**V**). Some of the setting that affects material removal rate and surface roughness are the length of the wire wounded on wire drum, The pulse –ve (quick cut) and pulse +ve (slow cut),The quality of DM (deminaralized water), The gel mixed in DM water, The ratio of gel mixed in the DM water, The quality of gel, The properties of wire(electrode),and The properties of Work piece.

In this project Composite material (Al6061+3%SiC) chosen as the work material and its thickness (t) is10 mm with dimension of 100*100 mm^2. The material of wire is Molybdenum and its diameter is 0.18mm was used for all the experiments. The JR3A ointment is added in DM water in the ratio of 1:40-50 (for 1 liter DM water 40-50g of JR3A ointment is added).The Design of experiment is planned by using Taguchi's method and L-18 orthogonal array with 3 ×2 levels is selected.

Table 4: The obtained Orthogonal Array L18.

Voltage(A)	Pulse ON(B)	Pulse OFF(C)	Current(D)
1	1	1	1
1	1	2	2
1	1	3	3
1	2	1	1
1	2	2	2
1	2	3	3
1	3	1	2
1	3	2	3
1	3	3	1
2	1	1	3
2	1	2	1
2	1	3	2
2	2	1	2
2	2	2	3
2	2	3	1
2	3	1	3
2	3	2	1
2	3	3	2

Table 5: Factors and its ranges

Parameters	Range	Level	Division
Voltage(A)	0-1	2	0,1
Pulse ON(B)	0-30	3	20,25,30
Pulse OFF(C)	1-4	3	2,3,4
Current(D)	1-4	3	2,3,4

4.1. CALCULATIONS

The MRR is found out by using the formula

Eq.1, MRR= (2Wg + D) x t x L / T, mm^3/min

Eq.2, L = distance traveled by tool = a + b +c = 10+2+10 = 22 mm (shown in fig 3)

T = time taken for cut one profile, min

D = diameter of wire = 0.18 mm

Wire material = Molybdenum

Wg = Spark gap = 0.02 mm

t = thickness of the workpiece or height of the work piece = 10 mm

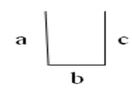

Fig 3: The profile designed for cutting

5.0. PARAMETRIC ANALYSIS IN TAGUCHI

The two Signal-to-Noise ratios test is conducted for MRR and Ra using Minitab 16 software.

5.0.1 smaller-the-better

Eq.3, S/N ratio for Ra = -10 Log_{10} [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics like "defects "etc. for which the ideal value is zero and also, when an ideal value is finite and its maximum or minimum value is defined. The difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

Eq.4, S/N ratio for Ra = -10 Log_{10} [mean of sum of squares of {measured - ideal}]

The Surface roughness S/N ratio values are calculated by selecting smaller is better option because the objective of surface roughness is to minimum

5.0.2 larger-the-better

Eq.5, S/N ratio for MRR = -10 Log_{10} [mean of sum squares of reciprocal of measured data]

In this case smaller - better is calculated and values are taken reciprocal to it

The material removal rate S/N ratio values are calculated by selecting larger is better option because the objective of material removal rate is to maximize.

5.1 Taguchi Analysis: MRR (mm^3 /min) versus voltage, pulse on, pulse off, current

Response Table for Signal to Noise Ratios Larger is better

Level	voltage	pulse on	pulse off	current
1	13.15	15.25	18.37	15.74
2	18.84	16.13	15.60	15.94
3		16.61	14.03	16.31
Delta	5.69	1.36	4.34	0.57
Rank	1	3	2	4

SNO	voltage	pulse on	pluse off	current	EXP NO	MRR	SN Ratio MRR Values
1	0	20	2	2	2	5.207881	14.33322121
2	0	20	3	3	9	3.968252	11.97198476
3	0	20	4	4	10	3.408449	10.65113666
4	0	25	2	2	11	5.716201	15.14214982
5	0	25	3	3	12	4.58173	13.2205892
6	0	25	4	4	4	3.896662	11.81385566
7	0	30	2	3	8	6.374893	16.08945818
8	0	30	3	4	7	4.443004	12.95353318
9	0	30	4	2	5	4.056968	12.16403197
10	1	20	2	4	6	10.75556	20.63265696
11	1	20	3	2	15	7.810623	17.85371328
12	1	20	4	3	16	6.337557	16.03843753
13	1	25	2	3	1	11.48584	21.20325315
14	1	25	3	4	3	8.940812	19.0275397
15	1	25	4	2	17	6.599938	16.39079675
16	1	30	2	4	13	13.80205	22.79887164
17	1	30	3	2	14	8.45647	18.54378217
18	1	30	4	3	18	7.156212	17.09366434

Table 6: the SN Ratio MRR Values

Eq.6, The regression equation is

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MRR = 5.42 + 4.41 voltage + 0.113
pulse on - 1.82 pulse off + 0.617
current
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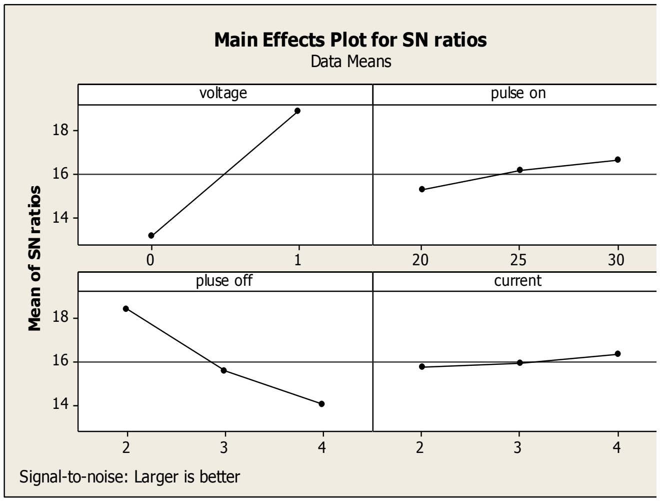

Graphs 4: The Voltage & Pulse off increases means, MRR will increases & decrease respectively

5.2. Taguchi Analysis: Roughness (Ra) versus voltage, pulse on, pulse off, current

Response Table for Signal to Noise Ratios Smaller is better

Level	voltage	pulse on	pulse off	current
1	-11.89	-11.71	-12.94	-12.44
2	-13.42	-12.80	-12.68	-12.68
3		-13.46	-12.35	-12.84
Delta	1.53	1.75	0.58	0.40
Rank	2	1	3	4

SNO	voltage	pulse on	pulse off	current	EXP NO	Avg, Ra	Ra SN RatioValues
1	0	20	2	2	2	3.541	-10.98251854
2	0	20	3	3	9	3.3409	-10.47726953
3	0	20	4	4	10	3.42	-10.68052212
4	0	25	2	2	11	4.105	-12.26626323
5	0	25	3	3	12	4.126	-12.31058447
6	0	25	4	4	4	3.961	-11.95609685
7	0	30	2	3	8	4.405	-12.87891825
8	0	30	3	4	7	4.49	-13.04492682
9	0	30	4	2	5	4.1799	-12.42331784
10	1	20	2	4	6	4.43	-12.92807452
11	1	20	3	2	15	4.22	-12.50624902
12	1	20	4	3	16	4.31	-12.6895454
13	1	25	2	3	1	4.96433	-13.91721286
14	1	25	3	4	3	4.89213	-13.78995978
15	1	25	4	2	17	4.243333	-12.55414298
16	1	30	2	4	13	5.400057	-14.64796688
17	1	30	3	2	14	4.96667	-13.9213061
18	1	30	4	3	18	4.91	-13.82162984

Table 7: The Ra SN Ratio Values

Eq.7, The regression equation is

Ra = 1.95 + 0.752 voltage + 0.0848 pulse on -0.152 pulse off + 0.111 current

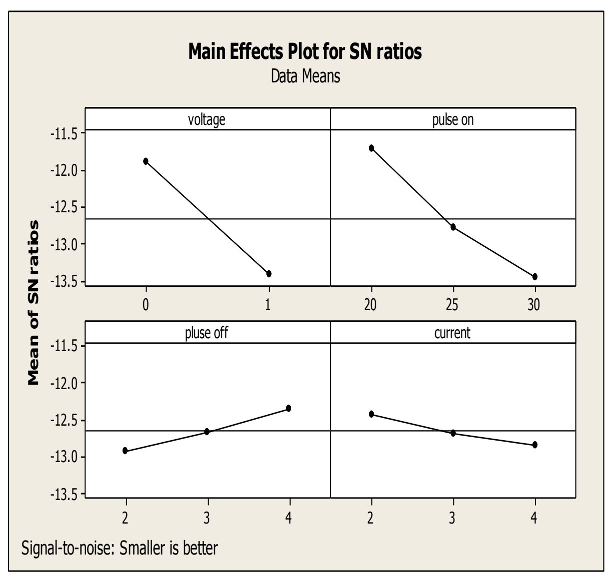

Fig 5**:** Pulse ON and Voltage increases means, Ra will increases respectively.

6.0. PARAMETRIC ANALYSIS IN ANOVA

The different average is insufficient to delve deeper into group-by-group comparisons. General Linear Model can estimate the differences between specific groups and allows to make such comparisons. The ANOVA analysis is conducted in Minitab software 16.

6.1 Parametric Analysis of MRR

6.1.1 General Linear Model: MRR versus voltage, pulse on, pulse off, current

Factor	Type	Levels	Values
voltage	random	2	0, 1
pulse on	random	3	20, 25, 30
pluse off	random	3	2, 3, 4
current	random	3	2, 3, 4

Analysis of Variance for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
voltage	1	87.521	87.521	87.521	124.03	0.000
pulse on	2	3.867	3.867	1.934	2.74	0.112
pluse off	2	41.877	41.877	20.939	29.67	0.000
current	2	4.861	4.861	2.431	3.44	0.073
Error	10	7.056	7.056	0.706		
Total	17	145.183				

S = 0.840022 R-Sq = 95.14% R-Sq(adj) = 91.74%

Unusual Observations for MRR

Obs	MRR	Fit	SE Fit	Residual	St Resid
16	13.8020	12.3516	0.5600	1.4505	2.32 R

6.2. Parametric Analysis of Roughness (Ra)

6.2.1. General Linear Model: Ra versus voltage, pulse on, pulse off, current

Factor	Type	Levels	Values
voltage	random	2	0, 1
pulse on	random	3	20, 25, 30
pluse off	random	3	2, 3, 4
current	random	3	2, 3, 4

Analysis of Variance for Avg, Ra, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
voltage	1	2.54456	2.54456	2.54456	135.18	0.000
pulse on	2	2.18492	2.18492	1.09246	58.04	0.000
pluse off	2	0.27751	0.27751	0.13876	7.37	0.011
current	2	0.15095	0.15095	0.07548	4.01	0.053
Error	10	0.18823	0.18823	0.01882		
Total	17	5.34618				

S = 0.137198   R-Sq = 96.48%   R-Sq(adj) = 94.01%

Unusual Observations for Avg, Ra

Obs	Avg, Ra	Fit	SE Fit	Residual	St Resid
15	4.24333	4.48183	0.09147	-0.23849	-2.33 R

7.0. RESULTS

7.0.1. Taguchi Analysis

The Larger MRR is obtained at $A_2B_3C_1D_3$= 1, 30, 2, 4 = 13.802mm^3/min (Say D1).

The Smaller Roughness is obtained at $A_1B_1C_3D_1$ = 0, 20, 4, 2 = 3.01 µm (Say D2).

7.0.2. Anova Analysis

The Larger MRR is obtained at $A_2B_3C_1D_3$= 1, 30, 2, 4 = 135.802 mm^3/min (Say D3).

The Smaller Roughness is obtained at $A_1B_1C_3D_1$ = 0, 20, 4, 2 = 4.24 µm (Say D4)

7.0.3. Error

Table 8: The error in out puts

SNO	Anova Analysis – Taguchi Analysis	Error
1	D1 – D3	0.00
2	D2 – D4	1.23

7.0.4. Comparison test

Table 9: The comparison test for optimized parameters (refer D1 & D2) by changing dielectric fluid

Work Piece Material (Al6061+3%SiC)	Deminaralized Water (DM) (1litre DM:40-50g JR3A)	Compressed air (Pressure is 5 bar)
MRR	13.802 mm^3/min	12.357 mm^3/min
Ra	3.01 µm	2.96 µm
Hardness (Brinell hardness)	60 BHN	53 BHN

8.0. DISCUSSION ON RESULTS

The objective of this project is to find the optimized parameters which influence Material removal rate (MRR) and Surface Roughness (Ra).

The influence of parameters on MRR is, voltage increases will increases MRR highly and stands in first place, Pulse off increases will reduces MRR highly and stands in second place, Pulse on increases will increases MRR slightly and stands in third place, current increases will increases MRR slightly and stands is fourth position.

The influence of parameters on Ra is, pulse on increases will increases Ra highly and stands in first place, Voltage increases will increases Ra highly and stands in second place, Pulse off increases will reduces Ra slightly and stands in third place, current increases will increases Ra slightly and stands is fourth position.

The influence of parameters and optimization is performed using Taguchi Method and ANOVA is conducted with the help of General linear Method in Mini Tab 16 software respectively.

The comparison test is conducted for optimized results by changing dielectric fluids. The hardness, Ra and MRR of the workpiece will increases when machining is performed in the presents of deminaralized water. The hardness, Ra and MRR of the workpiece will decreases when machining is performed in the presents of compressed air (Oxygen).

9.0. CONCLUSION

The selected parameters to determine the larger MRR and smaller Ra are Voltage (A), Pulse on (B), Pulse off (C) and Current (D).

The parameters like Voltage and Pulse off are mostly affecting on MRR .The Voltage and Pulse off increases means, MRR will increase and decreases respectively.

The parameters like Pulse on and Voltage are mostly affecting on Ra.The Pulse on and Voltage increases means, Ra will increases respectively.

The reading are taken by keeping some of the parameters constant that are the frequency is 3,the distance between sensors are 20 cm (the length of wire wound on drum) and the pulse is 3(quick cut).

The strength of regression equation (values fitness) for both MRR and Ra is more than 95% that is analyzed using ANOVA.

The error between the Taguchi analysis and Anova analysis is very minute for MRR and Ra that are 0.00 and 1.23 respectively.

The hardness, Ra and MRR of material is increased when workpiece is machined using DM water as dielectric fluid. The hardness, Ra and MRR decreases when workpiece is machined using air as dielectric fluid.

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