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Experimental Investigation on Wire Electrical Discharge Machining for Al 6061-T6

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Abstract: *Wire electrical discharge machining(WEDM) is non-conventional machining process in which removal of material takes place between wire and workpiece gap due to spark generation. This paper reports experimental investigation of the effect of machining parameters (pulse-on time, pulse-off time, wire tension, wire feed, voltage) on the performance measure like kerf width(KW) and surface roughness(SR) during wire electrical discharge machining(WEDM) on aluminium 6061-T6 material. The Optimization of process parameters was done using Taguchi method with the help of Regression analysis on MINITAB 18 software.*

Keywords: *wire electrical discharge machining (WEDM), Aluminium alloy 6061-T6, Kerf width, Surface roughness*

I. Introduction

Wire Electrical Discharge Machining (WEDM) is an indispensable non-traditional machining process, capable of producing complex two and three-dimensional shapes with good accuracy and precision to satisfy the present day requirements of the manufacturing industries. It is used in the aerospace, automotive, die and tool industries and virtually in all the areas of conductive material machining regardless of their hardness or toughness. WEDM technology has grown tremendously since it was first introduced to the manufacturing industry in 1969 by Agie. In 1974, D.H. Dulebohn applied the optical-line follower system to automatically control the shape of the component to be machined by the WEDM process. By 1975, its popularity was rapidly increasing, as the process and its capabilities were better understood by the industry. It was only towards the end of the 1970s, when computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process .The general parameters studied are: Peak Current (Ip) ; Pulse Peak Voltage (VP) ; Wire Tension (WT) ; Wire Feed (WF) ; Pulse On Time (Ton) ; Pulse Off Time (Toff).

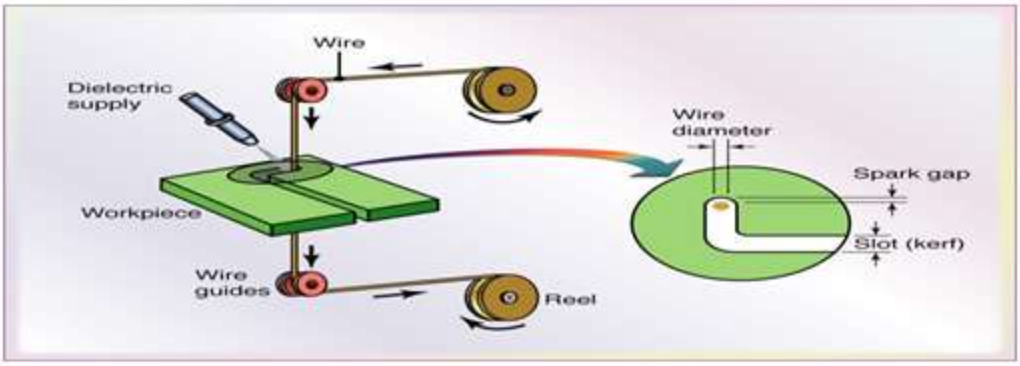

Fig.1: Wire electrical discharge machining. [2]

II. Literature Review

[1]. U.A. Dabade, S.S. Karidkar found that increases of pulse duration causes higher discharge energy and also increases in discharge current causes increase of discharge energy with affects of SR by increasing in diameter and depth of discharge craters. Input parameters were taken as Ton, Toff. When Ton increases MRR also increases due to discharge energy increases, when Toff decreases MRR increases.

[2]. Savanna M,Vinoth Kumar AmNirmala Kannan V & Stephan reported that increase in accuracy at highest material removal rate with minimum value of SR. Input parameters were taken as Gap voltage, pulse on time , pulse off time, wire tension, peak current and wire tension. And Output parameters MRR, Ra.

[3]. BijoMathew, Benkim, J.Babu. found out that increase in Ton causes increase in MRR. He also found that surface finish is good and dimensional deviation is accurate. Input parameters were taken as Ton, Toff, SV, WP, WF, WT. Output parameters were MRR, Ra, DD.

[4]. BijoMathew, Benkim.B.A.,J.Babu. reported that from the ANOVA analysis, it is found that all parameters except WF & WT, significantly affects the utility function for MRR, SR & DD. They also found out some output parameters like Material removal rate,SF,DD, orthogonal array, good utility approach. Input Parameters were Ton, Toff, WP, WF, WT, SV. Output parameters were MRR, Ra, DD.

[5]. Pujari srinivasarao, Koonaramji, Beela Satyanarayana found that The Parameters Ton, Peak Current and SV have shown significant effect on both SR and MRR but differs in optimum levels. The results of genetic optimization clearly show that a sacrifice in cutting efficiency for the production of quality surfaces and vice versa. Input parameters were Ton, Toff, WP, WF, WT, SV, SF, IP. Output parameters were MRR, Ra.

[6]. Berjaya Biretta Kayak, Saba Shankar Mahapatra. Their output was to find Angular error, SR, cutting speed, optimize multiple perform. They observed that Third level of part thickness, first level of taper angle, third level of pulse duration, first level of discharge current, second level of wire speed, first level of wire tension provide the minimum value of angular error.

[7]. Rajashri Mukherjee, Shanker Chakraborty, Suman Samanta. Their research was selection of WEDM process parameters using non-traditional optimization algorithms. So they found out that (BBO) algorithm has a clear superiority over the others.

[8]. Brajesh Kumar Lodhi, Sanjay Agarwal. Reported that Lower amount of surface roughness show the high productivity of WEDM. Therefore, small the better are applied to calculate the S/N ration of SR respectively .Their optimization technique was Minitab statistical software, ANOVA, Taguchi Technique . Input parameters were Ton, Toff, IP, WF. Output parameters were Ra.

[9]. Zahid A khan, Arshad N. Siddhiquee, Noor zaman Khan, Urfi Khan, G. A. Quadir. Reported that Small variance of both SR & KW are desirable for good quality and accuracy in the machining operation. Material chosen was AISI D3 Steel. Input parameters were Ton, Toff, IP,. Output parameters were Ra, W.

[10]. Y.S. Liao, J.T. Huang, H. C. Su. Found out that optimization method was Taguchi quality design method, ANOVA. They reported that this methodology is not only time saving and cost effective but also efficient and precise in determining the machining parameters.

III. Experimentation Of WEDM

Experiments were performed on Ultra-cut SO (Electronica) CNC wire electrical discharge machine to study the surface roughness and kerf width at different setting of pulse-on time, pulse off time wire feed,wire tension, voltage. Performing a series of experiment, making measurements after every experiment so that analysis of observed data help to decide what to do next “which parameters should be varied and by how much”.

Fig 2. Machine setup of wedm

In order to observe the trends of influence for the selected input parameters, for their effects on surface roughness and kerf width, and to select the levels of this parameters for final experimentation, was conducted using ‘one factor at one time’ approach. L27 orthogonal array (three levels) with five input variables was selected for experimentation.

3.1 Material Selection

Aluminium alloy AL6061-T6 is used as work piece in this study. It is having Excellent joining characteristics, good acceptance of applied coatings. It combines relatively high strength, good workability and high resistance to corrosion. It is used in many applications like Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware, electrical fittings and connectors, decorative or misc. hardware, hinge pins, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valves and valve parts; bike frames. Table 2 shows the various process parameters with their values at three levels and L27 orthogonal array (with five input variables and three interactions assigned to different columns) respectively. Table 1 shows Composition of selected material as below,

Table 1. composition of work piece material

component	Weight %
Al	95.8-98.6
Cr	0.04-0.35
Cu	0.15-0.4
Fe	Max 0.7
Mg	0.8-0.12
Mn	Max 0.15
Ti	Max 0.15
Zn	Max 0.25
Si	0.4-0.8
Other each	Max 0.05
Other total	Max 0.15

Table 2. Selected machining parameters and their levels

Sr. No.	Parameter	Symbol	Level 1	Level 2	Level 3	Units
1	Pulse On Time	TON	110	115	120	µsec
2	Pulse Off Time	TOFF	40	50	60	µsec
3	Wire Tension	WT	8	11	15	Kgf
4	Wire Feed	WF	4	5	6	m/min
5	Voltage	V	10	20	30	volts

3.2 Design of experiment based on Taguchi method

To evaluate the effects of cutting parameters of Wire EDM process in terms of cutting performance characteristics such as surface roughness and kerf width using Taguchi method. In this study Taguchi method, a

Fig.3 Profile cut for kerf width

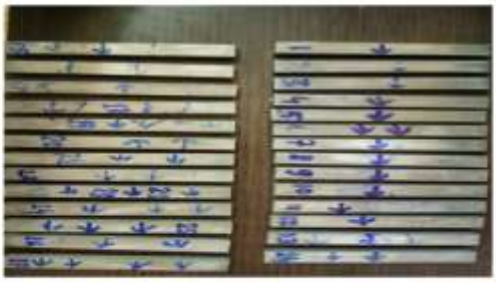

Fig.4 Cut for surface roughness

powerful tool for parameter design of performance characteristics for purpose of designing and improving the product quality.

Table 3. L'27 orthogonal array

SR NO.	Pulse On Time	Pulse Off Time	Wire Tension	Wire Feed	Voltage
1	110	40	8	4	10
2	110	40	8	4	20
3	110	40	8	4	30
4	110	50	11	5	10
5	110	50	11	5	20
6	110	50	11	5	30
7	110	60	15	6	10
8	110	60	15	6	20
9	110	60	15	6	30
10	115	40	11	6	10
11	115	40	11	6	20
12	115	40	11	6	30
13	115	50	15	4	10
14	115	50	15	4	20
15	115	50	15	4	30
16	115	60	8	5	10

17	115	60	8	5	20
18	115	60	8	5	30
19	120	40	15	5	10
20	120	40	15	5	20
21	120	40	15	5	30
22	120	50	8	6	10
23	120	50	8	6	20
24	120	50	8	6	30
25	120	60	11	4	10
26	120	60	11	4	20
27	120	60	11	4	30

IV. Optimization and Results

Experimental results as shown in table are analyzed to determine the influenced of various process parameters on surface roughness and kerf width by using the popular statistical software package MINITAB 18. Regression analysis is a statistical technique used to describe relationships among variables. The simplest case to examine is one in which a variable Y, referred to as the dependent or target variable, may be related to one variable X, called an independent or explanatory variable, or simply a regressor.If the relationship between Y and X is believed to be linear, then the equation for a line may be appropriately = $\beta1 + \beta2X$,where $\beta1$ is an intercept term and $\beta2$ is a slope coefficient. In simplest terms, the purpose of regression is to try to find the best fit line or equation that expresses the relationship between Y and X.

4.1Regression Analysis: Effect of parameters on surface roughness

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.008396	0.001679	1.29	0.304
Ton	1	0.000556	0.000556	0.43	0.520
Toff	1	0.000139	0.000139	0.11	0.747
Wt	1	0.007613	0.007613	5.86	0.025
WF	1	0.000000	0.000000	0.00	1.000
V	1	0.000089	0.000089	0.07	0.796
Error	21	0.027271	0.001299		
Total	26	0.035667			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0360362	23.54%	5.34%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.516	0.207	2.49	0.021	
Ton	-0.00111	0.00170	-0.65	0.520	1.00
Toff	0.000278	0.000849	0.33	0.747	1.00
Wt	-0.00586	0.00242	-2.42	0.025	1.00
WF	-0.00000	0.00849	-0.00	1.000	1.00
V	-0.000222	0.000849	-0.26	0.796	1.00

Regression Equation

$$W = 0.516 - 0.00111\ Ton + 0.000278\ Toff - 0.00586\ Wt - 0.00000\ WF - 0.000222\ V$$

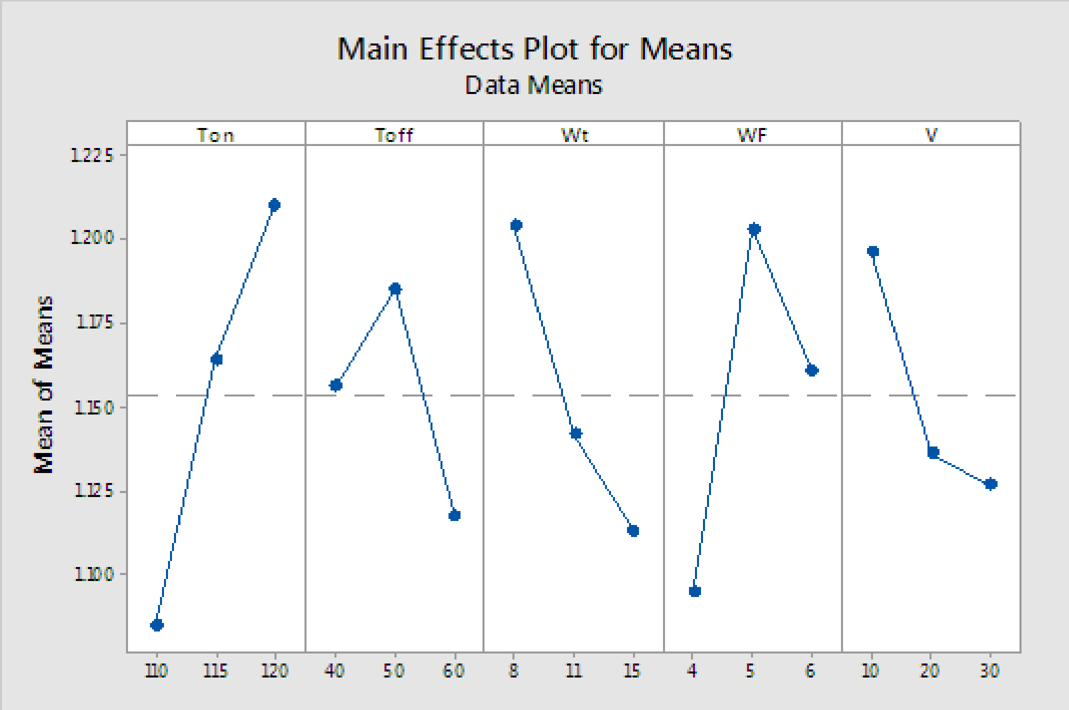

Fig.5 Graph of effect of input Parameters on surface roughness

4.2Regression Analysis: Effect of parameters on kerf width
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.58048	0.11610	7.74	0.000
Ton	1	0.30811	0.30811	20.54	0.000
Toff	1	0.03042	0.03042	2.03	0.169
Wt	1	0.08320	0.08320	5.55	0.028
WF	1	0.07788	0.07788	5.19	0.033
V	1	0.08087	0.08087	5.39	0.030
Error	21	0.31495	0.01500		
Total	26	0.89543			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.122465	64.83%	56.45%	42.46%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.804	0.704	-1.14	0.266	
Ton	0.02617	0.00577	4.53	0.000	1.00
Toff	-0.00411	0.00289	-1.42	0.169	1.00
Wt	-0.01936	0.00822	-2.36	0.028	1.00
WF	0.0658	0.0289	2.28	0.033	1.00
V	-0.00670	0.00289	-2.32	0.030	1.00

Regression Equation

Ra = -0.804 + 0.02617 Ton - 0.00411 Toff - 0.01936 Wt + 0.0658 WF - 0.00670 V

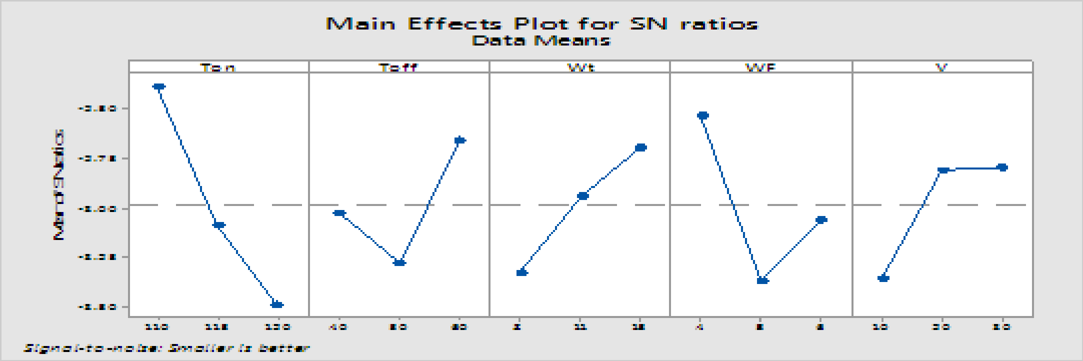

Fig.6 Graph of effect of input Parameters on kerf width

V. Results and Discussions

The experimental results are collected for the surface roughness and kerf width are listed table 3 and 27 experiments were conducted using Taguchi (L27) experimental design methodology small values of both surface roughness and kerf width are desirable for good quality and accuracy in machining operation. Thus the data sequences have a "the-smaller-the-better-characteristics" for both surface roughness and kerf width

Table no.4 result table of kerf width and surface roughness

Sr.No.	Pulse On Time	Pulse Off time	Wire Tension	Wire Feed	Voltage	Kerf Width	Surface Roughness
1	110	40	8	4	10	0.31	1.815
2	110	40	8	4	20	0.34	1.748
3	110	40	8	4	30	0.4	1.872
4	110	50	11	5	10	0.37	1.991
5	110	50	11	5	20	0.30	1.992
6	110	50	11	5	30	0.35	1.931
7	110	60	15	6	10	0.31	1.854
8	110	60	15	6	20	0.33	1.545
9	110	60	15	6	30	0.30	1.768
10	115	40	11	6	10	0.35	2.1335
11	115	40	11	6	20	0.30	1.9155
12	115	40	11	6	30	0.31	1.976
13	115	50	15	4	10	0.3	2.075
14	115	50	15	4	20	0.33	1.855
15	115	50	15	4	30	0.28	1.754
16	115	60	8	5	10	0.34	2.060
17	115	60	8	5	20	0.46	2.107
18	115	60	8	5	30	0.35	2.061
19	120	40	15	5	10	0.36	2.246
20	120	40	15	5	20	0.3	2.156
21	120	40	15	5	30	0.31	1.968
22	120	50	8	6	10	0.33	2.339
23	120	50	8	6	20	0.33	2.303
24	120	50	8	6	30	0.34	2.164
25	120	60	11	4	10	0.31	2.036
26	120	60	11	4	20	0.33	1.810
27	120	60	11	4	30	0.3	1.849

Surface roughness increases with the pulse on time and decreases with increases in pulse off time. When servo voltage increases from 10V-30V, surface roughness also increases because of high discharge energy spark, which makes the surface rough. When wire tension increases roughness value first and then decreases. The effect of wire feed, when it is increases surface roughness decreases. As surface roughness is "lower the better" type quality from fig.5, it can be seen that pulse on time at (level 1), pulse off time at (level 3),wire tension at (level 3),wire feed at (level 1),voltage at (level 3).

Kerf width decreases with pulse on time increases and decreases with decreasing in pulse off time. Small value of wire tension results in kerf width increases. When wire feed increases from 4-6mm/min kerf width increases. minimum the voltage kerf width is maximum. As kerf width is "lower the better" type quality from fig.6 it can be seen that pulse on time at (level 1), pulse off time at (level 3), wire tension at (level 3), wire feed at (level 1), voltage at (level 3)

VI. Conclusion

In this work, effect of parameters namely pulse on time (Ton), pulse off time (Toff), wire tension, wire feed rate and voltage on surface roughness and kerf width of AL6061-T6 material is analyzed. Conclusions observed are as follows,

- Optimum set of process parameters which gives minimum surface roughness (Ra) is Pulse on time = 110 µs; Pulse off time = 60 µs; Wire tension = 15 Kgf; Wire feed rate = 4 mm/min; Voltage = 30 V.
- Minimum surface roughness observed at optimum parameter setting is Ra = 1.78 µm.
- Optimum set of process parameters which gives minimum kerf width is Pulse on time = 120 µs; Pulse off time = 40 µs; Wire tension = 15 Kgf; Wire feed rate = 5 mm/min; Voltage = 30 V.
- Minimum kerf width observed at optimum parameter setting is W = 0.29936 mm
- From the confirmation test, it can be seen that the error is lower than 5%, therefore the technique of optimization seems to hold good enough for this investigation.

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