Optimization of Wire EDM Machining Parameters for Optimum Material Removal Rate and Surface Finish in an Aluminum 7075-T651 Alloy

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Abstract **- Wire EDM (Electrical Discharge Machining) is a thermos-electrical process in which material is eroded by a series of sparks between the work piece and the wire electrode (tool). In the present work, the machining of Aluminum Al 7075-T 651 during Wire cut Electrical Discharge Machining (Wire EDM) with Brass as a wire electrode has been carried out to study the operational behavior of Al 7075-T651 and to understand the effect of WEDM input parameters on Material removal rate (MRR) and surface roughness (Ra) of aluminum alloy and use of Taguchi technique to optimize the process parameters. The process parameters in Wire EDM are used to control the performance measures of the machining process. Process parameters are generally controllable machining input factors that determine the conditions in which machining is carried out. These machining conditions will affect the process performance result, which are gauged using various performance measures. In this research, Taguchi technique has been used to formulate the experimental layout and to obtain optimum levels of input parameters. ANOVA method is used to analyze the effect of each parameter on the machining characteristics namely (MRR and Ra) and predict the optimal choice for each Wire EDM parameters namely Pulse on time (TON), Servo Voltage (SV) and Pulse off time (TOFF).**

Keywords— Wire cut Electrical Discharge Machining (WEDM), Taguchi technique, Analysis of Variation (ANOVA), Pulse on time (TON), Servo Voltage (SV), Pulse off time (TOFF).

I. INTRODUCTION

Machining is a term used to describe a variety of material removal processes in which a cutting tool removes unwanted material from a work piece to produce the desired shape. The term metal cutting is used when the material is metallic. Machining processes can be divided into traditional machining processes and non-traditional machining processes. The main parts of Wire EDM are shown in Figure 1. Electrode wire is connecting to cathode of impulse power source, and work piece is connecting to anode of impulse power source. When work piece is approaching electrode wire in the insulating liquid and gap between them getting small to a certain value, insulating liquid was broken through; very shortly, discharging channel forms, and electrical discharging happens. And release high temperature instantaneously, up to more than 10000 degree centigrade, and the eroded work piece gets cooled down swifty in working liquid and is flushed away.

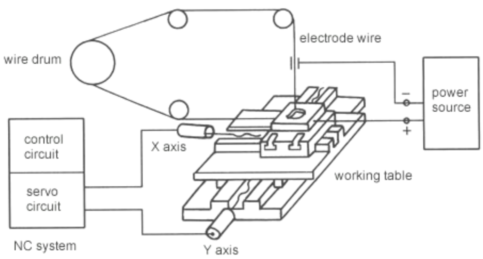

Fig.1. Main Parts of Wire EDM

Increasing pulse on time can increase the duration of each discharge which increases Material Removal Rate (MRR). It was found that the Material Removal Rate in Wire EDM increases with the decrease of pulse off time. Process parameters are controllable machining input factors that decides the conditions in which machining is accomplished. They influence the process performance result, which are measured using various performance methods. Among several optimizing techniques available, Taguchi technique is found to be very efficient and provide systematic path to design the experiments and optimize the manufacturing processes.

The aim of this research paper is to determine the optimum WEDM process parameters using Taguchi technique for maximum MRR and minimum Surface roughness of Al 7075-T651 alloy.

II. MATERIALS AND METHODOLOGY

A. Materials Used

Aluminum Al 7075-T651

The alloy chosen for this project is Al 7075. It is one of the high strength alloys that render favorably heat treatment and its chemical composition is given in the Table 2.1 The selected aluminum alloy is shown in Figure 2.1.

TABLE.1. Chemical Composition of Al7075 alloy

Con tent	Al	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sn	Ti	Zn	Cr
Wei ght %	90.245	1.597	2.215	0.057	0.257	0.074	0.047	0.024	0.010	0.031	5.206	0.237

Fig.2. Aluminum alloy Al 7075-T651

B. Wire EDM Methodology

A Wire EDM machine (ECO-Cut) was used as the experimental machine in this study. A pure brass wire with a diameter 0.25mm was used as an electrode to erode a work piece of Aluminum. The gap between work piece and the wire was flooded with a moving dielectric fluid (distilled water). Machining Experiments for determining the performance of Wire EDM machining for enhancing the MRR and surface finish were carried out by using distilled water as a dielectric fluid. The ranges of parameters selected are shown in Table 2.2. To perform the experimental design, three levels of three machining parameters (TON, TOFF, Servo Voltage) were selected from the Table 2.2 and the specification of WEDM is listed in Table2.3. The Wire EDM used in this research is shown in Figure 2.2.

Fig. 2.2 Wire EDM (Eco-Cut)

Table 2.2 Process parameters and their ranges in Wire EDM

Sl no	Name of parameters	Symbol	Range
1	Pulse on time	T_{ON}	100-131 µs
2	Pulse off time	T_{OFF}	00-63 µs
3	Peak current	IP	10-12 amps
4	Servo voltage	SV	00-99 volts
5	Wire feed	WF	01-15 m/min
6	Wire tension	WT	01-15 µN
7	Servo feed	SF	2000-2999 mm/min

III. EXPERIMENTATION PLAN

A. Selection of Process parameters and their Levels

In order to optimize the WEDM process for maximum Material Removal Rate and minimum Surface Roughness of aluminum alloy, the range of parameters are selected for control factors. The control factors selected are TON, TOFF and S.V. The range selected for TON is 100,103, 106 and for TOFF the range selected is 40,45, 50 and for S.V, the range selected is 15,20,25. Table 3.1 shows the control parameters selected and their corresponding levels with an objective to achieve maximum MRR and minimum surface roughness (Ra).

Table 3.1 Control Parameters and their Levels

Control factors	Level 1	Level 2	Level 3
(T_{ON}) Pulse on time (µs)	100	103	106
(TOFF) Pulse off time	40	45	50
(S.V) Servo Voltage (V)	15	20	25

B. Design of experiments and data analysis

For the three control parameters and three levels selected, a set of 9 experiments are performed based on L9 orthogonal array as shown in Table 3.2. The MRR, Ra determined from experiments and Signal to Noise ratio computed are tabulated.

In Wire EDM machine MRR is calculated by using the following equation,

MRR= (Cutting speed)x(work height) (1)

Where 'cutting speed' in mm/min was measured during each trial and work height in mm is constant.

Surface Roughness number (Ra) expressed in microns is determined by

Ra = (h1+h2+-----+hn)/n (2)

Where h1, h2 h3 are the peak values and n is the number of peaks selected.

The loss function (L) for objective of Higher is Better (HB) and Lower is Better (LB) are defined as follows:

$$L_{HB} = 1/n \sum_{i=1}^{n} 1/y_{MRR}^{2} \quad (3)$$

$$LLB = 1/n \sum_{i=1}^{n} y_{Ra}^{2} \quad (4)$$

Where “n” indicates the number of experiments and y_MRR and yRa are the response for Material removal rate (MRR) and Surface Roughness (Ra) respectively .The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below.

S/N ratio for MRR = -10 log10 (LHB) (5)

S/N ratio for Ra = -10 log10 (LLB) (6)

The S/N ratios and experimental measured values of MRR and Ra are computed using equations (1) to (6).

Table 3.2 Experimental Design using L9 Orthogonal Array

Trial no	T_{on} (μs)	T_{off} (μs)	SV (V)	MRR (mm^2/min)	Surface Roughness Ra (μm)	S/N ratio MRR	S/N ratio Ra
1	100	40	15	47.52	1.904	33.5375	-5.5933
2	100	45	20	36.17	1.960	31.1670	-5.8451
3	100	50	25	26.24	1.840	28.3793	-5.2964
4	103	40	20	56.00	3.177	34.9638	-10.0403
5	103	45	25	44.00	3.508	32.8691	-10.9012
6	103	50	15	41.44	3.126	32.3484	-9.8998
7	106	40	25	88.32	3.221	38.9212	-10.1598
8	106	45	15	86.44	3.418	38.6332	-10.6754
9	106	50	20	56.70	3.513	35.0717	-10.9136

C. *Analysis of Variation (ANOVA)*

In order to understand the impact of various factors and their interactions, analysis of variance (ANOVA) table is determined to find out the order of significant factors as well as interactions. Table 3.3 shows the results of the ANOVA with the material removal rate. The last column of the Table indicates that the main effects are highly significant (all having very small p- values). It can be concluded that TON (p=.029) and TOFF (p=0.091)) have greater influence on MRR. For surface roughness the ANOVA results are shown in Table 3.4, where TON (p=.017) have greater influence on surface roughness (Ra).

Table 3.3 ANOVA table for MRR

Source	DOF	SS_A	MSS_A	F-value	P-value
T_{ON}	2	2604.99	1302.5	33.71	0.029
T_{OFF}	2	770.98	385.49	9.98	0.091
SV	2	110.73	55.37	1.43	0.411
Error	2	77.27	38.63		
Total	8	3563.96			

Table 3.4 ANOVA table for Ra

Source	DOF	SS_A	MSS_A	F-value	P-value
T_{ON}	2	4.0853	2.04269	57.59	0.017
T_{OFF}	2	0.0597	0.02989	0.84	0.543
SV	2	0.0068	0.00344	0.70	0.911
Error (MSS_E)	2	0.0709	0.03547		
Total (SS_T)	8	4.2229			

D. *Determination Of Material Removal Rate (Mrr) And Surface Roughness (Ra)*

Material removal rate is the amount of material removed per unit time by the cutting tool. Material removal rate (mm2/min) in a WEDM process is determined by multiplying the cutting speed(mm/min) and Work height (mm). Surface Roughness is the measure of the texture of the surface. It is quantified by the vertical deviations of a real surface from its ideal one. If these variations is maximum then surface is rough surface, if variations is minimum then the surface is smooth. The measurements are usually made along a line, running at right angle to the general direction of tool marks on the surface and expressed in micrometer.. The Figure 3.1 shows the Mitutoyo Surface Roughness tester used to measure the surface roughness.

Fig. 3.1 Mitutoyo Surface Roughness tester

IV. RESULTS AND DISCUSSION

A. *Determination of optimum parameters*

The effect of three process parameters on MRR and Ra is shown graphically in Figure 4.1 and Figure 4.2. From the main effect plots, the level corresponding to the higher S/N ratio is obtained. Using MINITAB 18, response tables for S/N ratio of MRR and Ra is calculated as shown in Table 4.1 and Table 4.2. Based on the analysis of S/N ratio, the optimum process parameters for MRR and Ra along with their corresponding levels are obtained and is shown in Table 4.3 and Table 4.4.

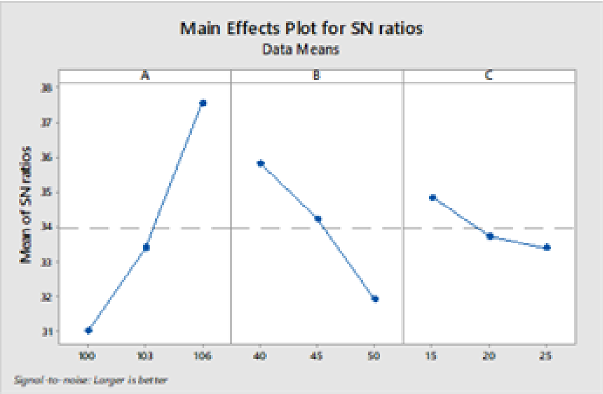

Fig 4.1 Main effects plot for MRR

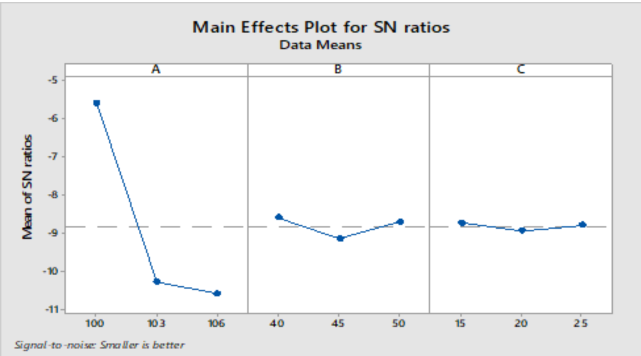

Fig 4.2 Main effects plot for Ra

Table 4.1 Response table for S/N ratio of MRR

Levels	A (T_{ON})	B (T_{OFF})	C (SV)
1	31.03	35.81	34.84
2	33.39	34.22	33.73
3	37.54	31.93	33.39
Delta	6.51	3.87	1.45
Rank	1	2	3

Table 4.2 Response table for S/N ratio of Ra

Level	A (T_{ON})	B (T_{OFF})	C(SV)
1	-5.578	-8.598	-8.723
2	-10.280	-9.141	-8.933
3	-10.583	-8.703	-8.786
Delta	5.005	0.543	0.210
Rank	1	2	3

From Figure 4.1 and Figure 4.2, the optimum process parameters for maximum MRR and minimum Ra is identified and shown in Table 4.3 and Table 4.4.

Table 4.3 Optimum Process parameters for higher MRR

Parameter	Level	Optimum
T_{ON}	1	100
T_{OFF}	1	40
SV	1	15

Table 4.4 Optimum Process parameters for lower Ra

B. Material Removal Rate (MRR)

Using optimum process parameters obtained for higher MRR (T_{ON} =100, T_{OFF} =40, SV = 15), machining was conducted to determine material removal rate and by using optimum parameters obtained for Ra (T_{ON} =106, T_{OFF} =40, SV = 15), surface roughness of Aluminum alloy was determined. Table 4.5 and Table 4.6 lists the MRR and Ra of Aluminum alloy.

Table 4.5 Material removal rate of Aluminum alloy

Trial #	Material Removal Rate (MRR), mm^2/min	Average MRR mm^2/min
01	87.56	88.24
02	86.15	
03	83.20	
04	96.05	

Table 4.6 Surface Roughness of Aluminum alloy

Trial #	Surface Roughness (Ra) in µm	Average Ra (µm)
01	1.895	1.904
02	1.913	
03	1.908	
04	1.900	

C. Confirmation experiment for Ultimate Tensile Strength

The optimal combination of Control parameters has been determined. However, the final step is to predict and verify the improvement of the observed values through the use of the optimal combination level of process parameters. The estimated S/N ratio for MRR and Ra can be calculated with the help of following prediction equation:

$$\hat{n} = n_m + \sum_{i=1}^{p} (\bar{n} - n_m)$$

The confirmation experiment is performed by conducting a test with specific combination of the factors and levels previously evaluated. After determining the optimum conditions and predicting the response under these conditions, a new experiment was designed and conducted with the optimum levels of process parameters for MRR and Ra. Table 4.7 and Table 4.8 shows the comparison of the experimental results for the optimal conditions with predicted results for higher MRR and lower Ra.

Table 4.7 Prediction v/s Experimental result for MRR

Optimal machining parameters		
	Prediction	Experimental
Level	T_{ON} 3, T_{OFF} 1, SV 1	T_{ON} 3, T_{OFF} 1, SV 1
S/N Ratio for MRR	40.23	38.91
MRR	89.12	88.24
percentage error	0.99%	

Optimal machining parameters		
	Prediction	Experimental
Level	T_{ON} 1, T_{OFF} 1, SV 1	T_{ON} 1, T_{OFF} 1, SV 1
S/N Ratio for Ra	-5.2490	-5.5933
Ra	1.83	1.904
percentage error	4.04 %	

TABLE 4.8 PREDICTION V/S EXPERIMENTAL RESULT FOR RA

I. CONCLUSION

The experimental investigation on the optimization of WEDM process parameters of Aluminum alloy for MRR and Ra leads to the following conclusions:

- The optimum process parameters in WEDM for higher MRR and lower Ra is determined for Al 7075-T651 alloy using Taguchi's technique. WEDM parameters for higher MRR determined is T_{ON}=106, T_{OFF}=40 and SV=15 and for lower Ra, T_{ON}=100, T_{OFF}=40 and SV=15.
- T_{ON} is the most significant WEDM parameter for higher MRR and lower Ra.
- The experimental and predicted values of MRR and Ra shows good agreement.
- The experimental MRR and Ra value of aluminum alloy for optimum WEDM parameters is 88.24 mm^2/min and 1.904µm respectively. The predicted MRR and Ra value of aluminum alloy for optimum WEDM parameters is 89.12 mm^2/min and 1.83µm respectively.

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