Optimization of Wire-cut EDM of Aluminum alloy 6061 using Taguchi's approach for maximizing MRR

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Abstract— Wire electric discharge machining (WEDM) is one of the modern machining processes. The Taguchi method is proposed and used to optimize the machining parameters of the WEDM. MRR (Metal Removal Rate) determines the economics of machining and the rate of production. The aim is to investigate the effect of three process parameters, including pulse time, pulse and peak current. This paper deals with the appropriate approach to increase material removal rate in wire electrical discharge matching. The Taguchi L9 design (DOE) of the experiment was implemented. The orthogonal array, signal-to-noise (S / N) ratio and variance analysis (ANOVA) were used to study the material removal rate in the WEDM of Aluminum alloy 6061. Maximum flow was found to be the most effective factor in the rate of material removal. The effect of machining parameters on MRR-like response was investigated.

Keywords: Wire EDM: Taguchi method: MRR: Parameter optimization: ANOVA.

I. INTRODUCTION

In the model making industry, the machining process plays an important role, where cost and quality are two major factors. Wire Electrical Discharge Machining (WEDM) is a non-traditional process of removing materials from complex shapes to produce complex shapes and profiles.[**1**]

WEDM is based on the electrical discharge machining process, also known as the electro-erosion machining process. When the gap voltage is high enough (ie the breakdown voltage of the dielectric fluid reaches it), a high energy spark is produced which increases the temperature to about 10,000 ° C. In this way the metal is removed from the work piece**.[2]** Uses a thin wire of 0.1–0.3 mm diameter as a processing tool and mounted on a workpiece computer numerically controlled worktable. The two-dimensional shapes of the complex can be cut on the workpiece by the controlled movement of the X-Y work table. The constantly feeding wire through the spool is placed between the upper and lower diamond guides. The guides are usually CNC controlled and run on X-Y aircraft. The microprocessor used in CNC controllers also allows the machining of complex shapes with exceptionally high accuracy. There is no physical connection between the tool and the workpiece, with microprocessor tools cutting 300mm thick plates to die from hardened metals that are difficult to machine in other ways. Wire electric discharge machining depends on the removal of matter by repeated sparks between the electrodes. E, Workpiece and equipment**.[3]**

A. Literature Review

Guo et al. [1] Cells forming materials reinforced by wire-EDM at high travel speeds were investigated. Al2O320% particle reinforced materials with 6061 mixtures were used in this experiment. Regardless of high or low power, the experiment resulted in surface degradation. It was found to have little effect on surface roughness by electrical parameters, but had a significant effect on reducing the rate of choice of electrical parameters. It has been investigated that high voltage, high pulse duration, large machining current and high machining efficiency can be achieved at the correct pulse. Wire breakage is detected at low energies due to blind feeding, especially at low voltages and short pulse durations. Lalwani et. al. [2] RSM was applied to investigate the effect of cutting parameters on surface roughness in removing the hard turning of MDN250 steel using coated ceramic equipment in wire EDM. Puri and Bhattacharya [3] Worked on composite (Ti-6Al-4V) and used the Taguchi approach for the data mining process, which addresses the impact of various information parameters of the WEDM process on cutting rate and surface roughness. Rahman et al. [4] Matching is generally found for Australian Stainless Steel 304 by temporarily electric discharge machining. The test showed that the MRR and surface roughness were built with expansion. Manjaiah et al. [5] NITI has conducted a comprehensive investigation into the WEDM of various classes of materials. An increase in material removal rate with pulse-on and an improvement in surface roughness properties with a pulse-off time was found. High discharge power and spark intensity and pulse-off time are the reasons behind inadequate flushing in the long discharge time machining area. Subsequently, the desire-based multi-function optimization obtained the optimal WEDM parameters for optimization of SMA with an average roughness of 1.83--m and a material removal rate of 7.6 mm / min. Furthermore, the XRD study reported heat loss in the form of oxides and other phases, which occur much longer during the pulse. Bisaria and Shandilya [6]. Studied the effect of WEDM parameters on efficiency, elegance and surface roughness during machining of Ni50.89Ti49.11. They found Spark Off-Time, Spark On-Time and Servo Voltage to be important parameters. It is observed that the micro hardness on the surface of the machine is many times greater than the hardness of the starting material due to the formation of a repeating layer of 20-35 µm thickness. In addition, various oxides and chemical compounds, such as Cu5Zn8, Cu4O3, and TiO, form on the surface of the machine after WEDM. Varun and Venkaiah [7] The optimization strategy was used by combining gray relational analysis (GRA) with a genetic algorithm (GA) to optimize the response parameters. Experiments were carried out on EN- 353 working equipment to study the effects of input parameters. Zinc-coated copper wire with 0.25 mm is used as the electrode. Reaction parameters such as material removal rate (MRR), surface roughness (SR) and kerf width are observed. Saha and Mondal [8] The optimization technique was applied to combine gray relational analysis with principal component analysis to determine the optimal combination of process parameters in the WEDM for nano saturated hard-faced materials matching. Sinha et al. [9] The Taguchi method is used for single objective optimization and then the noise (S / N) ratio obtained from the Taguchi method is used in Principal Component Analysis (PCA) for multi-objective optimization. Huang and Liao [10] Gray relational analysis with L18 composite orthogonal arrays is applied to determine the optimal choice of the machining parameters for the wire electrical discharge matching process. Tosun et al. [11] The kerf widths were evaluated by the significance of the matching parameters on the MRR and determined using the analysis of variance (ANOVA). The variation of the output responses with the matching parameters was modelled mathematically using the regression analysis method.

II. MATERIALS AND METHOD

A. Experiment

The experimental study was done on a CNC wire cut EX7732 EDM machine. The composition of the aluminum alloy 6061 work-piece material for use in this work is given in Table 1. A zinc coated brass wire of 0.25 mm (900 N / mm2 tensile strength) diameter was used in the experiments. The parameters, the different settings of the time pulse, the pulse of time, the peak current and were used in the experiments (Table 2). A photographic view of the machine and machining area is shown in Fig. 1 (a) and (b), respectively. Surface roughness was measured with the Mitutoyo Surfest SJ-2O1P on the workpiece after machining.

Fig.1 (1) Experimental set up

B. SELECTION OF MATERIAL

Aluminium alloy 6061, which readily machinable in any condition which best suitable for high tensile strength and wear resistance components. It is available in heat treated forms possess good homogeneous metallurgical structure and gives consistent machining and mechanical properties

Aluminum Alloy 6061

Aluminum alloys are sensitive to high temperatures. They tend to lose some of their strength when exposed to high temperatures of about 200-250°C. However, their strength can be increased at sub-zero temperatures. They also have good corrosion resistance. Aluminum 6061 alloy is the most commonly available and heat treatable alloy.

Table 1. Chemical Composition of Aluminum Alloy 6061

Element	Al	Mg	Si	Cu	Cr
Content= %	97.9	1	0.60	0.28	0.20

Table 2. Physical Properties of Aluminum Alloy 6061

Properties	Metric	Imperial
Density	2.7 g/cm^3	0.0975 lb/in^3
Melting point	588 ºC	1090 ºF

Table 3. Mechanical properties of Aluminum Alloy 6061

Properties	Metric	Imperial
Tensile strength	115 mpa	16680psi
Yield strength	48mpa	6962psi
Shear strength	83mpa	12038psi
Fatigue strength	63mps	8992psi
Elastic modulus	70-80gpa	10153-11603ksi
Poisson's ratio	0.33	0.33
Elongation	25%	25%
Hardness	30	30

III. METHODOLOGY

A. Taguchi Method

The Taguchi Method involves reducing the variation in a process through robust design of experiments. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources.

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on " ORTHOGONAL ARRAY " experiments which gives much reduced "variance" for the experiment with" optimum settings" of control parameters. Thus, the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

B. Material Removal Rate

MRR (Metal Removal Rate) determines the economics of machining and the rate of production. Machine removal rate (g / min) is calculated from the weight differences of the samples before and after machining. The mathematical formula used to measure the MRR for all experiments is given below

$$MRR = \frac{W_B - W_A}{D \times T}$$

where W_B, W_A is the initial and final weight of workpiece material,

D is density of material respectively, and

T is the time period of machining in minutes.

C. DESIGN OF EXPERIMENT

In the present study according to the Taguchi method, the robust design and L9 orthogonal array were used for the experiment. Based on machine tool, cutting tool (electrode) and workpiece efficiency, three matching parameters are considered as controlling factors: time, pulse, pulse of time, peak current, and the following, intermediate and high, three levels in each parameter. The factors and their levels were selected based on the pilot-based experiments of L1, L2 and L3, respectively. Table 4. Machining Parameters, Symbols and Their Ranges

Factor	Parameters	Unit	Level		
			L1	L2	L3
A	Pulse ON Time	μ sec	20	40	60
B	Pulse Off Time	μ sec	3	6	9
C	Peak Current	A	1	2	3

Table 5. Experimental Result of DOE Experiments

Trial no.	Pulse on time (A)	Pulse off time (B)	Peak current (C)	MRR
1	20	3	1	3.540
2	20	6	2	3.853
3	20	9	3	4.456
4	40	3	2	3.850
5	40	6	3	3.688
6	40	9	1	3.950
7	60	3	3	3.965
8	60	6	1	3.341
9	60	9	2	3.151

IV. RESULTS AND DISCUSSION

A. Effect on Material Removal Rate

The mail effect plot shown in figure are S/N ratio of the experimental responses are in given in table and the value of MRR for each process parameters and the respective levels are plotted. The optimal machining performance for MRR was obtained as 20µs pulse on time (level 1), 3µs pulse -off time (level 1), 3A peak current. The material removal rate gradually increases with increases of pulse on time from 20µs to 40µs and it rapidly increases from 40µs to 60µs and pulse off time from 3 µs to 6 gradually increases and from 6 µs to 9µs,it decreases rapidly and with increase of peak current 1A to 2A it remain constant at till mean value and again it starts decreasing.

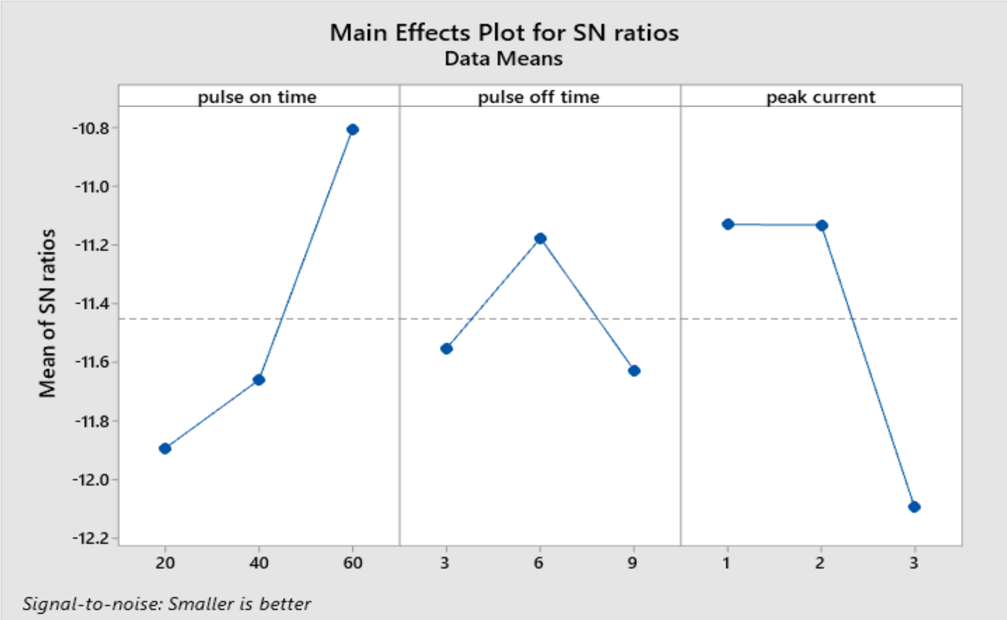

Fig. 2 S/N Ratio and Mail Plot Of MRR

Table 6. Response Table on MRR

Level	Pulse on time	Pulse off time	Peak current
1	-11.89	-11.55	-11.13
2	-11.66	-11.18	-11.13
3	-10.80	-11.63	-12.09
Delta	1.09	0.45	0.96
Rank	1	3	2

The response table (Table 6) illustrates the average of each response characteristic for each level of each factor. The table includes ranks based on delta statistics, which compare the relative magnitude of efforts. The delta statistic is the highest minus the lowest average for each factor. Minitab 19 assigns ranks based on delta values; rank 1 to highest delta value, rank 2 to the second highest and, so on. The ranks indicate the importance of each factor to the response.

The ranks and the delta values show that pulse on time have the greatest effect on MRR and is followed by peak current, and pulse off time in that order.

B. ANOVA Analysis for Material Removal Rate Aluminum Alloy 6061

From Table 7, its ANOVA can be seen and analyzed that associated p value of less than 0.05 for the model which shows that the model is statistically significant. In this study, the contribution of each of the machining parameters and their interaction was determined. The table also represent % contribution of the parameters on the response MRR. It observed that peak current is major influencing factor (30.24%), followed by pulse on time (29.50%) and pulse off time is (6.79%).

Table 7. ANOVA Table for Material Removal Rate Aluminum Alloy 6061

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
pulse on time	2	0.34788	29.50%	0.34788	0.17394	0.88	0.531
Pulse off Time	2	0.08002	6.79%	0.08002	0.04001	0.20	0.831
Peak Current	2	0.35654	30.24%	0.35654	0.17827	0.90	0.525
Error	2	0.39464	33.47%	0.39464	0.19732		
Total	8	1.17908	100.00%				

CONCLUSION

The investigation of wire EDM on Aluminum alloy 6061 have been done and the following conclusion are made.

1. In this study an attempt was made to maximize the material removal rate.
2. According to the ANOVA results, peak current is the most significant parameter on MRR whereas pulse-on time are less significant.
3. Pulse-off time has insignificant effect on MRR.
4. Desirability approach was employed for finding out the most optimal values of the process parameters.
5. The result of the optimization for maximum material removal rate are based on the optimization results, it has been found that pulse on time 60µs ,6 µs as pulse off time, and peak current obtain can be 1A or 2A.
6. The optimal values of the process parameters will increase the MRR to a great extent and help in maintaining the economy and increasing the productivity.

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