Optimization Of Wire Electric Discharge Machining OfComposite Material (Al6061/Sicp) Using Taguchi Method

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Abstract- When precision is crucial, wire electrical discharge machining (WEDM) is widely employed in industry to machine conductive materials. In this research, the Taguchi method is used to investigate and optimise WEDM parameters. Pulse on-time (Ton), Pulse off-time (Toff), and Discharge current were the three process parameters that were chosen (or pulse current). Using a L9 orthogonal array, the experiments were conducted in accordance with the design of experiments methodology. Surface Roughness (SR) signal to noise (S/N) ratios were computed for each experiment. Response graphs and analysis of variance (ANOVA) were used to analyse the data. According to the experimental findings, the ideal conditions—minimum surface roughness—were produced by pulse on-time of 5 s, pulse off-time of 3 s, and discharge current of 2 A.

Keywords- *Taguchi method; Optimization; WEDM; Surface roughness; Composite materiall*

I. INTRODUCTION

In comparison to non-reinforced alloys, Metal Matrix Composites (MMCs) are a new generation of engineered materials with improved physical and mechanical characteristics. In the automotive, aerospace, and defence industries, this makes them appealing for a wider range of applications. MMCs have extremely tough and abrasive reinforcing. As a result, they limit their ability to economically machine metal. It is extremely challenging to produce intricate shapes in such materials using conventional techniques. Unconventional material removal methods present an alluring alternative to traditional machining due to excessive tool wear and high tooling costs. WEDM is one of the numerous unorthodox techniques that has various industrial uses. Each work material must first undergo machining characterisation in order to develop high-quality, economically sound products.

Wire breakage was found to pose limitations on the cutting speed of MMC [4]. Open-gap voltage, Pulse-on period was the most significant influencing machining parameters, for controlling the MRR. Wire tension and wire feed rate are the most significant parameters influencing the surface roughness [5]. Due to presence of TiC particles and formation of Fe_2O_3 while machining results in the unstable machining process. NRBFN technique has several advantages like less complexity, requirements fewer training samples, easy input-output mapping, and less chance of getting local least convergence [6]. The material removal rate of wire electrochemical discharge machining of Al_2O_3 reinforced aluminium alloy 6061 was compared with WEDM machining of same material [7].

TAGUCHI METHOD

Taguchi method was developed by Dr. Genichi Taguchi. This method involves three stages: system design, parameter design, and tolerance design. In the Taguchi method, the experimental values are transformed into a signal-to-noise (S/N) ratio η. The term “signal” represents the desirable value (mean) for output characteristic and the term “noise” represents the undesirable value for the output characteristic. Usually there are three categories of the performance characteristic in the analysis of the S/N ratio, that is, the lower-the-better, nominal-the-better and the higher-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. The optimal level of the process parameters is the level having highest S/N ratio. Furthermore, ANOVA is performed to see which process parameters are statistically significant.

Smaller-is-better:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right) \quad (1)$$

Nominal-is-better:

$$\eta_{ij} = -10\log\left(\frac{1}{ns}\sum_{j=1}^{n} y_{ij}^2\right) \quad (2)$$

Larger Nominal-is-best:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} \frac{1}{y_{ij}^2}\right) \quad (3)$$

Where, y_{ij} is the i^{th} experiment at the j^{th} test, n is the total test and s is the standard deviation.

The factor levels that have maximum S/N ratio are considered as optimal. The aim of this study was to produce minimum surface roughness (Ra) in WEDM machining operation. Smaller-the-better quality characteristic is used for surface roughness as smaller Ra values represent better or improved surface finish.

II. WEDM MACHINING EXPERIMENTS

Wire electrical discharge machining (WEDM), is a non-traditional machining method that is widely used to pattern tool steels for die manufacturing. In the WEDM process, a small wire is engaged as the tool electrode. The dielectric medium is usually de-mineralized (DM) water. The work piece is mounted on the table of the machine. The movement of the wire is controlled numerically to achieve the desired complex two and three-dimensional shapes for the work piece. WEDM uses electro-thermal mechanism to cut electrically conductive material. The material is removed by a series of discrete discharges between the wire electrode and the work piece in the presence of a dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The region in which discharge occurs is heated to extremely high temperatures, so that the work surface is melted and removed. The dielectric then flushes away the debris.

A. *Selection of cutting parameters and their levels*

In this study, a WEDM machine (DK-7712) was used to perform experiments. Aluminum alloy Al6061 was reinforced by hard Silicon carbide powder (10µm) SiC 10% in weight and this metal matrix composite material was synthesized by stir casting technique. Specimens were prepared that cutting area is 10mm ×10mm square shaped. The specimens were machined using WEDM, DM water as the dielectric. A round molybdenum wire with a diameter of 0.18 mm was used as the electrode, running with a high speed in the machining process.

Fig. 1: WEDM experimental set-up

Machining experiments for determining the optimal machining parameters were carried out by setting: For each experiment the combinations of the 3 input parameters viz. Discharge Current (*A*) in the range of 2A to 4A, Pulse on-time (*B*) in the range of 05 µs to 15 µs, Pulse off-time (*C*) in the range of 3 µs to 5 µs, all having 3 levels (Table 1). These were chosen through review of literature, experience, and some preliminary investigations.

TABLE 1
FACTORS AND LEVELS USED IN EXPERIMENT

Symbol	Machining parameter	Unit	Level 1	Level 2	Level 3
A	Discharge Current	A	2	3	4
B	Pulse on-time	µs	05	10	15
C	Pulse off-time	µs	3	4	5

B. *Machining performance measure*

Out of various surface finish parameters i.e. roughness average (R_a), which is most widely used in industry, was selected in this study. Different settings of Pulse on-time, Pulse on-time and Discharge Current were used to conduct the experiments. The surface roughness of all the specimens was measured using the Mitutoyo SV2100 CNC Surface Finish instrument for a sampling length of 5 mm, as per the recommendations of ASME B-46.1-2002.

III. DETERMINATION OF OPTIMAL CUTTING PARAMETERS

In this section, the use of an orthogonal array to reduce the number of cutting experiments for determination of optimal cutting parameters is presented. Results of the cutting experiments are studied by using the S/N and ANOVA analyses.

Based on the results of these analyses, optimal cutting parameters for minimum surface roughness are obtained and verified.

A. Analysis of the signal-to-noise (S/N) ratio

In this study, the lower-the-better performance characteristic is selected to obtain minimum surface roughness. The experimental results for surface roughness and the corresponding S/N ratio using equation (1) are shown in Table 2.

TABLE 2
L_9 ORTHOGONAL ARRAY WITH THE VALUES OF RESPONSE VARIABLES

run	LEVEL OF CONTROL PARAMETERS			Measured response parameter	S/N Ratio for SR
	Discharge Current (A)	Pulse on Time (B)	Pulse off Time (C)	Surface Roughness	
1	2	5	3	2.331	-7.352
2	2	10	4	3.781	-11.552
3	2	15	5	3.326	-10.438
4	3	5	4	3.110	-9.854
5	3	10	5	3.872	-11.758
6	3	15	3	3.793	-11.579
7	4	5	5	3.572	-11.059
8	4	10	3	4.638	-13.327
9	4	15	4	4.967	-13.921

Since the experimental design is orthogonal, it is then possible to separate out the effect of each cutting parameter at different levels. The mean S/N ratio for each level of the cutting parameters is summarized and called the mean S/N response table for surface roughness (Table 3).

TABLE 3
RESPONSE TABLE FOR AVERAGE S/N RATIO FOR SURFACE ROUGHNESS

	Control factors		
Levels	***A***	***B***	***C***
1	-9.78	-9.42	-10.75
2	-11.06	-12.21	-11.77
3	-12.77	-11.97	-11.08

Figures 2 show the mean S/N ratio graph for surface roughness. The S/N ratio corresponds to the smaller variance of the output characteristics around the desired value. From Table 3, the overall mean for the S/N ratio of SR found to be −11.20. Analysis of the result leads to the conclusion that factors at level A_1, B1, C_1, gives best SR.

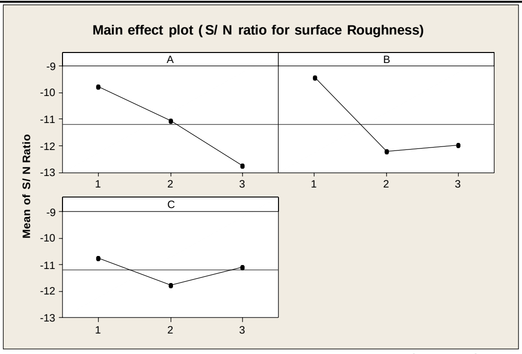

Figure 2: The smaller the better S/N graph for surface roughness.

B. Analysis of variance (ANOVA)

The purpose of ANOVA was to investigate which machining parameters significantly affected the performance characteristics. This was accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error.

TABLE 4
RESULTS OF THE ANOVA FOR SURFACE ROUGHNESS

Symbol	Machining Parameter	DF	SS	MS	F Value	Prob > F	P (%)
Model		6	29.50	4.916	43.94	0.022	
A	Discharge Current		13.48	6.742	60.26	0.016	45.36
B	Pulse on-time	2	14.38	7.190	64.27	0.015	48.38
C	Pulse off-time	2	1.63	0.817	7.306	0.120	5.50
Error		2	0.22	0.111			0.76
Total		8	29.71				100.0
	DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, P- % Contribution						

C. Results and discussion

The Model F-value of 43.95 implies the model is significant. There is only a 2.24% chance that a "Model F-Value" this could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B is significant model terms.

Pulse on-time (T_{on}) with a contribution of 48.38% has the greatest effect on the machining output characteristics. Parameter A i.e. Discharge current with a 45.38% share is the next most significant influence on the output parameters, followed by Parameter C i.e. machine’s Pulse off-time, (T_{off}) 5.5%. Surface finish quality was better when applying smaller pulse time. This is because of small particle size and crater depths formed by electrical discharge. As a result, the best surface finish will be produced. The selection of these machining parameters for WEDM of any material should be used for a higher surface quality is required. It was observed that when

Discharge current and particularly pulse on time increased, machined work piece surface exhibited a higher surface roughness due to irregular topography. Discharge current had an effect on surface roughness at low pulse time, but the influence of pulse on- time was more significant than Discharge current at higher pulse times. It was noticed that high Discharge current and pulse times will produce a poor surface finish due to deeper and wider crates on the machined surface. Excellent machined surface quality could be obtained by setting machining parameters at a low short pulse on- time.

IV. CONCLUSIONS

To determine the impact of different WEDM process parameters on surface roughness, a series of tests were conducted. ANOVA is used to assess the relative importance of the machining parameters and each one's individual impact on the surface roughness. These outcomes were attained:

- • With a contribution of 48.38%, pulse on-time (Ton) has the biggest impact on the machining output characteristics. The second most important factor affecting the output parameters is Parameter A, or discharge current, with a 45.38% share, followed by Parameter C, or machine pulse off-time (Toff), at 5.5%.
- Surface roughness at the best combination is 2.331 µm.
- The following factor-level settings have been identified to yield the best combination;

Input parameter A – Level 1, (Discharge Current - 2A) Input parameter B – Level 1, (Pulse on-time - 5µs)

Input parameter C – Level 1, (Pulse off-time - 3µs)

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