ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

Optimization of WEDM Parameters using Taguchi Technique in Machining of Metal Matrix Composite Material

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Abstract: **-- Wire Electrical Discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts of hard materials with complex shapes. Machine tool industry has made exponential growth in its manufacturing capabilities in last decade but still machine tools are not utilized at their full potential. In the present work, an attempt has been made to optimize the machining parameters in WEDM of aluminium silicon nitride (Al-10%Si3N4) for surface finish, accuracy and electrode wear based on (L27 Orthogonal Array) Taguchi technique. Experiments were carried out under varying pulse-on-time, pulse-off-time, current and bed speed. An orthogonal array, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) were employed to study the response variables in the WEDM of Al-10%Si3N4 metal matrix composite material. To validate the study, confirmation experiment has been carried out at optimum set of parameters and it was concluded that, optimized parameters have shown good results, so these parameters can be used to achieve good surface finish, accuracy and to minimize electrode wear than before.**

Keywords: ***Al-10%Si_3N_4, ANOVA, Taguchi Technique, WEDM.***

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional, thermo-electrical process, which erodes materials from the work piece by a series of discrete sparks between the work and tool electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric fluid. The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the process. As newer and more exotic materials are developed, and more complex shapes are presented, conventional machining operations will continue to reach their limitations. WEDM manufacturers and users emphasize on achievement of higher machining productivity with a desired accuracy and surface finish.
Composite materials (MMCs) are widely used in the diverse applications such as aircraft, automobile, sporting goods, marine vessels, audio equipment etc., because of its unique properties such as specific strength, fatigue strength, strength to weight ratio and corrosion resistance. In recent years, machining techniques have gained emphasis for product development as well as manufacturing. Machining of composite materials requires better understanding of cutting processes regarding accuracy and efficiency.

Aluminum Silicon Nitride (Al-Si3N4) is a Metal Matrix Composite (MMC) have higher thermal conductivity of 170 – 230 W/mK and low material density of 3.3 g/cm3 makes it ideal for weight sensitive applications.

In the past, many researchers have investigated the effect of the WEDM process parameters on surface roughness average and the kerf width of stainless steel (SS 304). Experiments conducted based on orthogonal array of Taguchi method are performed and grey relation analysis method applied to determine optimal WEDM parameters. Experimental factors are pulse-on time, pulse-off time and current. The result of analysis of variance (ANOVA) reveals that the pulse-on time is the most significant factor for multiple responses in WEDM process [1]. Optimization of process parameters using Taguchi technique with Grey relational analysis. The experimentation is carried using standard L27 orthogonal array. The multi-response optimization of the process parameters viz., metal removal rate (MRR), tool wear rate (TWR), taper (T), radial overcut (ROC), and surface roughness (SR) on electric discharge machining (EDM) of Al–10%SiCP as cast metal matrix composites using orthogonal array (OA) with Grey relational analysis is reported. The experimental result for the optimal setting shows that there is considerable improvement in the process. The application of this technique converts the multi response variable to a single response Grey relational grade and, therefore, simplifies the optimization procedure [2]. The effect of process parameters on surface roughness and kerf width in machining of Aluminum and mild steel in WEDM. Spark-on time, spark-off time, input current and wire feed are taken as cutting parameters. Optimization of process parameters is done using Taguchi technique. ANOVA shows the significant effect of parameters. Surface roughness and kerf width are measured using Surface profilometer and optical microscope respectively. From the result of ANOVA, spark on time and wire feed has significant effect on mild steel and aluminum [3]. Analysis of process parameters in wire EDM with Stainless Steel. Stainless steel 304 is used as a work piece, brass wire of 0.25mm diameter used as a tool and distilled water is used as dielectric medium. L'16 orthogonal array has been used. The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. Grey relational theory and Taguchi optimization technique are used for optimization. Surface roughness and kerf width are measured parameters. ANOVA resulted that the pulse on time has major influence on the surface roughness (μm) and kerf width (mm) in both the Taguchi optimization method and Grey relational analysis [4].

Optimization of machining parameters in WEDM of AISI D3 Steel. Experiments were carried out under varying pulse-on-time, pulse-off-time, peak current, and wire feed. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the surface roughness in the WEDM of AISI D3 Steel. It was observed that the discharge current was the most influential factors on the surface roughness. To validate the study, confirmation experiment has been carried out at optimum set of parameters and predicted results have been found to be in good agreement with experimental findings[5].

EDM machining of carbon–carbon composite. Experiments have been carried out to determine the optimal setting of the process parameters on the electro-discharge machining (EDM) machine while machining carbon–carbon composites. The parameters considered are pulse current, gap voltage and pulse-on-time; whereas the responses are electrode wear rate (EWR) and material removal rate (MRR). The optimal setting of the parameters are determined through experiments planned, conducted and analysed using the Taguchi method. It is found that the electrode wear rate reduces substantially, within the region of experimentation, if the parameters are set at their lowest values, while the parameters set at their highest values increase the MRR drastically [6]. Determined Optimum Surface Roughness in Wire Electric Discharge Machining of P/M Cold Worked Tool Steel (Vanadis-4E) using Taguchi technique. Taguchi L27 orthogonal array is selected for experimentation. The methodology parameters of WEDM procedure were pulse on time (ON), pulse off time (OFF), servo voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP). The impacts of the methodology parameters on surface roughness were assessed by the examination of change (ANOVA). The most essential associations, that impact surface roughness of machined surfaces, are between the pulse on time (ON) and pulse on time(ON), pulse off time(OFF) and Peak current(IP), and between pulse on time(on) and Peak current(IP). The effects of the process parameters viz. pulse on time, pulse off time, peak current, spark gap set voltage, wire tension and water pressure on replication characteristics cutting rate [7].

However, due to a large number of variables, even a highly skilled operator with a state-of-the-art, WEDM is rarely able to achieve the optimal performance. An effective way to solve this problem is to optimize machining parameters in WEDM.

II. EXPERIMENTAL WORK

Experiments were performed on CONCORD DK7720C four axes CNC WED machine. The basic parts of the WED machine consist of a wire electrode, a work table, a servo control system, a power supply and dielectric supply system. The CONCORD DK7720C allows the operator to choose input parameters according to the material and height of the work piece. The WED machine has several special features. Unlike other WED machines, it uses the reusable wire technology. i.e., wire can't be thrown out once used; instead it is reused adopting the re-looping wire technology. The experimental set-up for the data acquisition is illustrated in the Fig. 1. The WEDM process generally consists of several stages, a rough cut phase, a rough cut with finishing stage, and a finishing stage. But in this WED machine only one pass is used.

Fig. 1: Experimental Set-up

The gap between wire and work piece is 0.02 mm and is constantly maintained by a computer controlled positioning system. Molybdenum wire having diameter of 0.18 mm was used as an electrode. The control factors and fixed parameters selected are as listed in Table 1. The control factors were chosen based on review of literature and experts. Each time the experiment was performed, an optimized set of input parameters was chosen. In this study, four machining parameters were used as control factors and each parameter was designed to have three levels as shown in Table 1.

After conducting the experiment, response values are noted down and analysis has been done. Taguchi analysis was conducted to determine the optimal parameters and ANOVA was also performed to estimate magnitude of factors effects on the responses. The experiment was conducted in the same environmental condition for all the runs so that environmental noise factors can be minimized. Experimental design using L'27 orthogonal array is shown in Table 1.

Table 1 Experimental design using L'27 orthogonal array

Run	P-on (μs)	P-off (μs)	Current (A)	Bed Speed (μm/s)
1	20	5	4	30
2	20	5	5	35
3	20	5	6	40
4	20	6	4	35
5	20	6	5	40
6	20	6	6	30
7	20	7	4	40
8	20	7	5	30
9	20	7	6	35
10	24	5	4	35
11	24	5	5	40
12	24	5	6	30
13	24	6	4	40
14	24	6	5	30
15	24	6	6	35
16	24	7	4	30
17	24	7	5	35
18	24	7	6	40
19	28	5	4	40
20	28	5	5	30
21	28	5	6	35
22	28	6	4	30
23	28	6	5	35
24	28	6	6	40
25	28	7	4	35
26	28	7	5	40
27	28	7	6	30

III. RESULTS AND DISCUSSION

Experiments were conducted on machining of Al-10%Si3N4 composite material. The machine was used to conduct the experiment was CONCORD DK7720C four axes CNC WED machine. The experiments were performed based on L27 orthogonal array.

The input parameters were pulse-on time, pulse-off time, current and bed speed. Response variables are Surface roughness, Dimensional accuracy and Electrode wear.Surface roughness was measured using surfcom flex 50-A, Accuracy and Electrode wear were measured using Low Force Micrometer.

Observations on surface roughness (Ra)

From the Figure 2, the main effect plots for Al-10%Si3N4 composite material that, the factor Pulse-on time has largest effect on the Surface Roughness (Ra) as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

Figure 2 shows that surface roughness (Ra) of the material increases with the increase in Pulse-on from 20 to 28µsec. The surface roughness (Ra) of the material decreases in Pulse-off from 5 to 6µs and increases from 6 to 7µs. The surface roughness (Ra) decreases with Current from 4 to 5amps and then increases from 5 to 6 amps. The surface roughness (Ra) decreases with the increase in Bed speed from 30 to 35µm/sec and increases with increase in Bed speed from 35 to 40µm/sec.

Referring the ANOVA, the factor Pulse-on has more effect on the response variable for Surface roughness (Ra) followed by the pulse-off. This can also be seen from the main effect plot shown in the Figure 2. Based on this, the value of F in the ANOVA, the rank to the each factor or the magnitude is given.

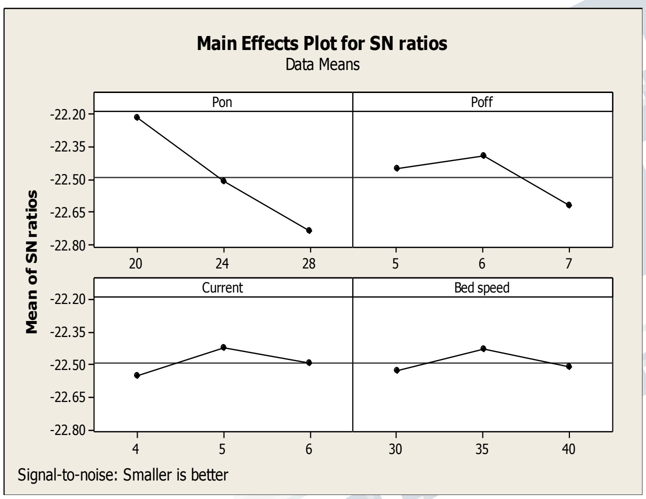

Fig. 2. Main effects plot for Surface Roughness (Ra)

Observations on Dimensional accuracy

From the Figure 3 the main effect plots for Al-10%Si_3N_4 composite material that, the factor Pulse-off has largest effect on the accuracy as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

Figure 3 shows that accuracy of the material increases with increase in Pulse on from 20 to 24µs and further decreases with increase in Pulse on from 24 to 28µs. Accuracy of the material decreases with increase in pulse off from 5 to 6µs and increases with increase in pulse off from 6 to 7□s. Accuracy of the material decreases with the increase in current from 4 to 5amps and increases with increase in current from 5 to 6amps. Bed speed has very less impact on dimensional accuracy.

Referring the ANOVA, the factor pulse-off has more effect on the response variable for Accuracy followed by the current. This can also be seen from the main effect plot shown in the Figure 3. Based on this, the value of F in the ANOVA, the rank to the each factor or the magnitude is given.

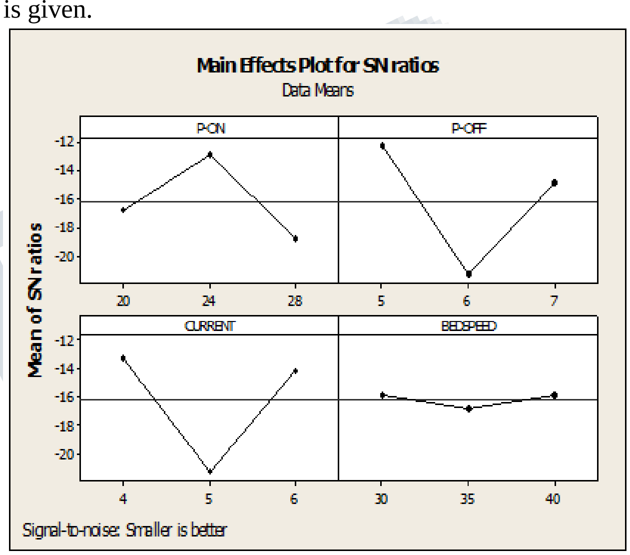

Fig. 3. Main effects plot for Dimensional Accuracy

Observations on Electrode wear

From the Figure 4, the main effect plots for Al-Si3N4 composite material that, the factor current has largest effect on the Electrode wear as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

Figure 4, shows that the Electrode wear of the material decreases with increase in Pulse on from 20 to 24µs and increases with increase in Pulse on from 24 to 28µs. The Electrode wear of the material decreases with increase in pulse off from 5 to 7µs. The Electrode wear of the material decreases with increase in current from 4 to 5amps but increases from 5 to 6amps. The Electrode wear of the material increases with increases in bed speed from 30 to 40µm/sec.

Referring the ANOVA, the factor current has more effect on the response variable for electrode wear followed by

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the pulse-on. This can also be seen from the main effect plot shown in the Figure 4. Based on this, the value of F in the ANOVA, the rank to the each factor or the magnitude is given.

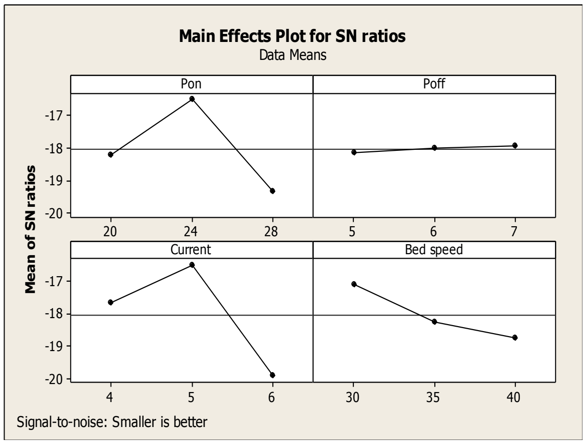

Fig. 4. Main effects plot for Electrode Wear

Verification Experiment

Conducting a verification experiment is a crucial final step of a Robust Design project. Its purpose is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. If the observed S/N ratios under the optimum conditions are close to their respective predictions, then one can conclude that the additive model on which the matrix experiment was based is a good approximation of the reality. Then, adopt the recommended optimum conditions for the process or product, as the case may be. In the machining process case study, parameters are optimized and are tabulated in the previous sections. The confirmation run was conducted taking these optimized parameters for the Al-10%Si_3N_4 composite material considered in the study. The results obtained from the confirmation runs are tabulated in the below Table 2 and Table 3 respectively.

Table 2 Initial Parameter Readings

Parameters	Initial Parameter Readings		
	Ra (µm)	Accuracy (µm)	Electrode wear (µm)
P-on (µsec)	20	20	20
P-off (µsec)	5	5	5
Current (Amp)	4	4	5
Bed speed (µm/sec)	30	30	30
Response obtained	2.98	2	8

Table 3 Optimized Parameter Readings

Parameters	Optimized Parameter Readings		
	Ra (µm)	Accuracy (µm)	Electrode wear (µm)
P-on (µsec)	20	24	24
P-off (µsec)	6	5	7
Current (Amp)	5	4	5
Bed speed (µm/sec)	35	30	30
Response obtained	1.98	1	5

From the Table 2 and Table 3, one can observe that, the optimized parameters have considerable effect on the response variables Surface roughness, Accuracy, Electrode Wear for Al-10%Si3N4 MMC material.

IV. CONCLUSIONS

The present study was concerned with machining of Al-10%Si_3N_4 composite material. The machine was used to conduct the experiment was CONCORD DK7720C four axes CNC WED machine. The experiments were performed based on L27 orthogonal array. The input parameters were pulse-on time (20, 24, 28 µ sec), pulse-off time (5, 6, 7 µ sec), current (4, 5, 6 amps) and bed speed (30, 35, 40 µ/sec). Response variables are Surface roughness, Dimensional accuracy and Electrode wear. After the experiment conducted, response variables were tabulated and analysis was conducted. Single objective optimization was performed based on Taguchi technique. After the process parameters are optimized, ANOVA was performed to determine the relative magnitude of the each factor on objective functions.

The following are the important conclusions drawn from the present work.

Al-10%Si_3N_4 composite material has to be machine with low pulse-on (20µsec), pulse-off(6 µsec), current (5amps) and bedspeed (35µm) to achieve good Surface finish.

Machining at Low Pulse-off (5µsec) and Low current (4amps) can minimize dimensional error.

Machining at current (5amps) and low Pulse on (24µsec) Electrode Wear observed is minimum.

After the confirmation experiment, it was concluded that, the optimized parameters have shown good results, so these parameters can be used to achieve good surface finish, Dimensional accuracy and Electrode wear than before.

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