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Parametric Study of Dry WEDM Using Taguchi Method

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Abstract— Wire Electrical Discharge Machining (WEDM) is a non-traditional thermo-electric process capable of machining hard materials of highly complex three dimensional shapes. In this paper, the dry WEDM experimentation is conducted using oxygen as a dielectric medium. The deionized water is replaced by the oxygen as a dielectric medium to ameliorate the environmental impact in the machining surrounding and to mitigate the health hazard to the operators. The experimental studies have been conducted by varying the pulse width (T_w), pulse interval (T_i), open circuit voltage (V), and discharge current (I). The values of machining parameters have been obtained by using the Taguchi design of experimental method. The implication of input parameters of the material removal rate (MRR) and Surface Roughness (Ra) has been investigated by using Analysis of Variance (ANOVA). The optimum output machining parameter values are predicted using Taguchi analysis and verified by the conformation experiments.

Keywords— Dry WEDM, Oxygen Dielectric Medium, MRR, Ra, Taguchi method.

I. INTRODUCTION

The WEDM is a non-traditional machining process which uses spark erosion to produce the complex three-dimensional shapes can be machined using this process. The dry WEDM process is the environment friendly modification of the liquid WEDM process. The de-ionized water, kerosene is the dielectric medium in conventional WEDM which cause the environmental impacts. It produces harmful vapours like carbon monoxide, nitrogen oxide, xylene, formaldehyde and toluene during decomposition of the thermal erosion process [1]. In the dry WEDM process, the liquid dielectric medium is replaced by gas medium.

The NASA [2] was first reported dry electrical discharge drilling process using the air, oxygen gases dielectric medium. The comparative study of the performance of EDM under gas and distilled water as the dielectric medium was done in [3]. Reference [4] reported that strong oxidation produced by injecting oxygen at the sparking zone improves MRR in dry EDM. The report showed that by introducing oxygen dielectric corrosion was drastically reduced and accuracy also improved due to the small sparking gap and edge of the cut of the work material. Reference [5] developed a mathematical model for MRR in accordance with process parameters like gap voltage (V), discharge current, pulse duration and pulse interval. Reference [6] conducted experiments using the air and water as a dielectric fluid in the EDM and the influence of the process parameters were compared. They reported that maximum MRR is achieved in dry EDM with air without tool wear. Reference [7] analysed the effects of various input parameters like pulse width, pulse interval, input voltage, discharge current, and wire tension on the MRR. Reference [8] conducted experiments in 'quasi-explosion' mode to maximize the MRR in dry EDM. The results revealed that the process parameters were not influenced the tool wear rate. The near-dry EDM drilling experiments were conducted using gas liquid medium [9]. Computational Fluid Dynamics (CFD) model of near dry EDM milling was developed to analysis dielectric fluid flow path [10]. An empirical model for the MRR and Ra was developed using surface response method [11]. Then, the machining characteristic of the Stellite alloys was investigated in the near-dry EDM milling process by [12]. Very recently, the comparative study of near-dry WEDM process using air and oxygen-mist as a dielectric medium was investigated [13] and reported as the oxygen-mist dielectric medium has high machining rate then air-mist. It is observed from above mentioned study that there was no study in the field of oxygen dielectric medium of the dry WEDM process. In this research, the dry WEDM system has been established using oxygen as the dielectric medium to cut the composite material (AL6061 + 3% SiC) by on Taguchi design of experiment. The effects of input parameters of the material removal rate and surface roughness have been investigated by using Analysis of Variance (ANOVA). The optimum output machining parameters has been predicted using Taguchi analysis and verified using a set of conformation experiments.

II. EXPERIMENTAL SETUP AND PROCEDURE

The experiments have been performed using ST CNC-E3 (MCJ) WEDM machine as shown in Fig. 1. The servo control system is used to operate the x and y axis of the machine. The maximum displacement of table in x axis and y axis is about 300mm and 250mm of accuracy of 5µm respectively. The dry WEDM unit has been developed and fitted to the WEDM machine. It developed to satisfy the basic requirements like high velocity gas flowing through the nozzle. The dry WEDM Experimental setup is shown in Fig. 2. The effect of various input parameters was analysed by conducting a set of experiments using oxygen as the dielectric medium. The ramification of input parameters like open circuit voltage (V), pulse width (Tw), pulse interval (Ti) and discharge current (I) on MRR and Ra has been studied. The nozzle is fixed in such a way that it doesn't touch the wire and the work specimen. The high velocity dielectric aims at the enhancement of material removal due to oxidation and removal of machining debris. The machining conditions are shown in Table 1.

The high pressure oxygen is received from the cylinder is supplied through the convergent nozzle into the discharge gap. The nozzle tube is fitted to the upper bed of the machine, so the nozzle tube moves with respect to the bed. In this project, the composite material (AL6061 + 3% SiC) is the work piece with the dimension of 100mm×100mm×6mm. The wire material is Molybdenum with the diameter of 0.18mm. The design of experiments is planned by using Taguchi method and L-18 orthogonal array with 1 factor at 2 levels and 3 factors at 3 levels. The MRR is calculated by

$$MRR = \frac{(2wg + D) \times t \times L}{T}$$

Where,

Wg - Spark gap between the wire and work piece and is equal to 0.02mm,
D - Diameter of wire (mm),
t - Thickness of the work piece or height of the work piece (mm).
L - Distance travelled by the tool (i.e., 22mm for each experiment),
T - Time taken to cut one profile (min),

The surface roughness are measured by surface tester SJ-201P, the stylus moves one forward stroke and one return stroke to measure the surface roughness. The measuring range of surface tester is about 350 µm. The measuring force is about 4MN. The tester has straight accuracy of about 0.01 µm /100 µm. The stylus is made up of diamond of the radius of skid is 40mm and tip radius of 5 µm. The measuring speed of tester is about 0.5mm/s during forward stroke and 0.8 mm/s during the return stroke. easy way to comply with the paper formatting requirements is to use this document as a template and simply type your text into it.

Fig 1. ST CNC-E3 (MCJ) WEDM machine

***Table 1*: Machining Conditions**

Work Material	Al composite material (AL6061 + 3% SiC)
Wire Tool Materials	99% Molybdenum
Diameter of Wire tool	0.2mm
Dielectric Medium	Pure Oxygen

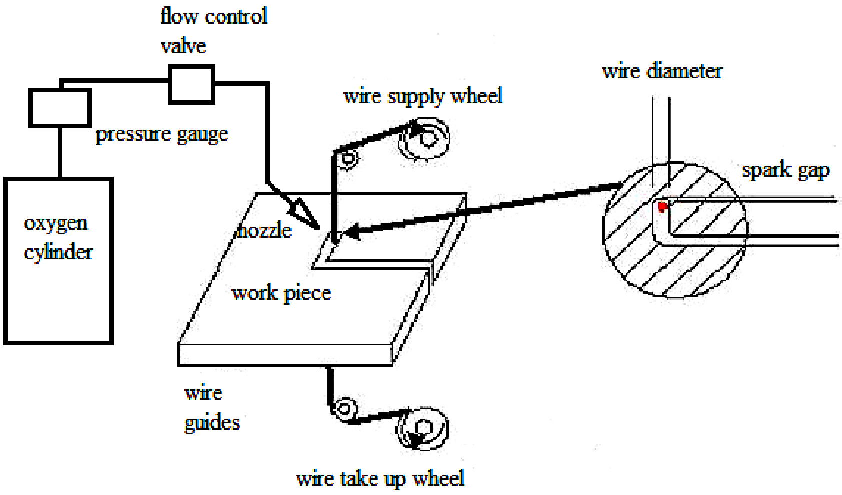

Fig 2. Dry WEDM Experimental Setup

Table 2:**Machining settings used in the experiments**

Factor	Units	Levels	Values
Voltage	Volt	2	75,100
Pulse Width	µm	3	20,25,30
Pulse Interval	µm	3	12,20,28
Spark Current	Ampere	3	2,3,4

A. Exploratory Experiments

One Variable at a Time (OVAT) is initially used for studying the MRR and SR. Here one variable at a time is varied and its effects on MRR and SR are studied while keeping all other variables at fixed value. For each input parameter, five different levels of experiment have been done and single run is performed for each level. Though OVAT analysis doesn't provide clear picture of the phenomena over the entire range of input parameters, it accentuates some important characteristics. The range value levels for later stage experiments are decided by using this OVAT analysis.

B . Design of Experiments based on Taguchi Method

A specially designed experimental procedure is required to identify the performance characteristics under optimal machining parameters and to evaluate the effects of machining parameters on the performance characteristics [14,15]. The classical methods cannot be used because, when the number of input parameters increases, large numbers of experiments have to be done [16, 17]. In this paper, Taguchi method is used to identify the optimal machining parameters for maximum MRR and minimum SR in dry WEDM. In Taguchi method the process parameters are separated into two main groups. One is control factor and another is a noise factor [18]. The noise factors denote all factors that cause variation and the control factors are used to select the best conditions for stability in the design of the manufacturing process. Taguchi proposed orthogonal arrays to acquire the characteristic data, and to analyze the performance measure of the data to decide the optimal process parameters [15, 18]. The orthogonal array forms the basis for the experimental analysis using Taguchi method. In this paper four machining parameters were used as control factors and one factor was designed to have 2 levels and the other three factors were designed to have 3 levels (Table 2). A L18 orthogonal array table with 18 rows was chosen for the experiments (Table 3).

III. DATA ANALYSIS AND DISCUSSION

The analysis of variance was used to identify the important machining parameters and its effect on MRR and SR. In Taguchi method [18], a loss function is used to calculate the deviation between the experimental value and the desired value. The signal-to-noise (S/N) ratio is then derived from the loss function. Lower is better (LB), nominal is best (NB), higher is better (HB) are the three types of S/N ratios available depending upon the type of characteristics. In dry WEDM, higher MRR and lower SR reflect the better performance. Therefore "LB" is chosen for the SR and it is calculated as the logarithmic transformation of the loss function as shown below.

Lower is better characteristic $\eta_{ij} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$ (1)

"HB" is chosen for the MRR and is calculated as the logarithmic transformation of the loss function as shown below.

Higher is better characteristic $\eta_{ij} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$ (2)

The greatest value of ηij corresponds to the optimal level of machining parameters. The above mentioned equations [1, 2] was applied to calculate the ηij values for each experiment of L18 [Table 3]. On analyzing the S/N ratio, the optimal machining performance for the surface roughness was obtained at 75V open circuit voltage (level 1), 20µm pulse width (level 1), 28µm pulse interval (level 3) and 2Amp spark current (level 1). The effect of machining parameters on surface roughness is shown in Fig.3. The optimum value of material removal rate was obtained at 100V open circuit voltage (level 2), 30µm pulse width (level 3), 12µm pulse interval (level 1) and 4Amp spark current (level 3). The effect of machining parameters on material removal rate is shown in Fig. 4. Accurate and optimum combination of machining parameters and their relative importance on surface roughness and material removal rate was obtained using ANOVA. The result of ANOVA is shown in [Tables 4, 5] respectively. From the Fig. 3 open circuit voltage and pulse width are the most significant parameters which effect surface roughness, while the pulse interval and spark current on surface roughness were insignificant. From Fig. 4 we can conclude that open circuit voltage and pulse interval are the most significant parameter which effect material removal rate, while pulse width and spark current have less effect on material removal rate.

***Table 3:* Experimental design using *L*18 orthogonal array**

S.No.	**Gap Voltage**	**Pulse On Time**	**Pulse Off Time**	**Spark Current**	**MRR mm^3/min**	**Ra µm,**
1	75	20	12	2	3.087	2.43
2	75	20	20	3	1.847	2.23
3	75	20	28	4	1.287	2.31
4	75	25	12	2	3.595	3.00
5	75	25	20	3	2.461	3.02
6	75	25	28	4	1.776	2.85
7	75	30	12	3	4.254	3.30
8	75	30	20	4	2.322	3.38
9	75	30	28	2	1.936	3.07
10	100	20	12	4	8.635	3.32
11	100	20	20	2	5.690	3.11
12	100	20	28	3	4.217	3.20
13	100	25	12	3	9.365	3.85
14	100	25	20	4	6.820	3.78
15	100	25	28	2	4.479	3.13
16	100	30	12	4	11.681	4.29
17	100	30	20	2	6.335	3.86
18	100	30	28	3	5.035	3.80

***Table 4:*Analysis of Variation Test for Ra**

Level	Voltage	Pulse Width	Pulse Interval	Spark Current
1	2.843	2.767	3.365	3.100
2	3.593	3.272	3.230	3.233
3		3.617	3.060	3.322
Delta	0.750	0.850	0.305	0.222
Rank	2	1	3	4

***Table 5:*Analysis of Variation Test for MMR**

Level	Voltage	Pulse Width	Pulse Interval	Spark Current
1	2.507	4.127	6.769	4.187
2	6.917	4.749	4.246	4.530
3		5.260	3.122	5.420
Delta	4.410	1.133	3.648	1.233
Rank	1	4	2	3

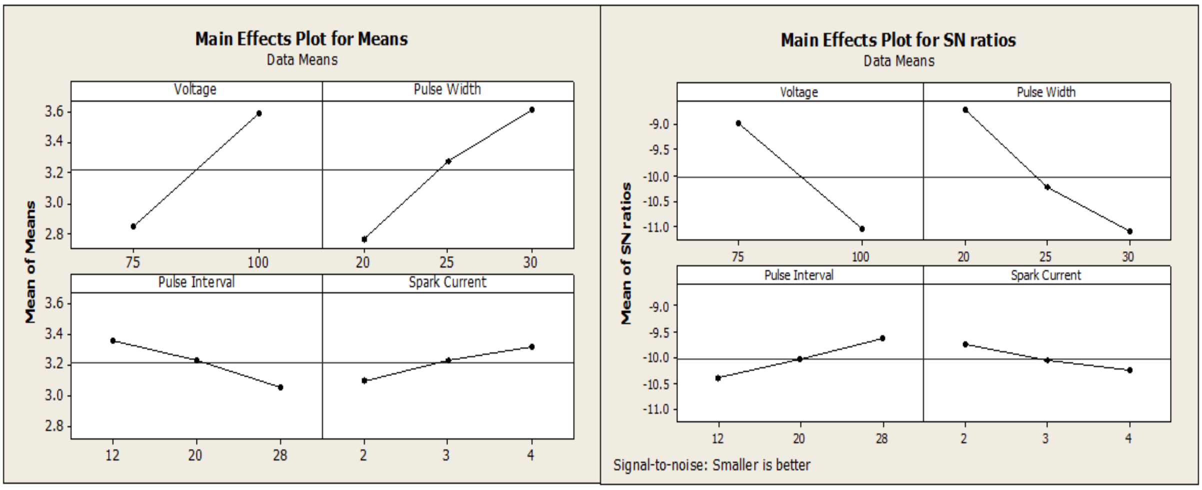

Fig 3. Mean and SN Ratio Plot for Minimization of Surface Roughness (Ra)

IV. CONFIRMATION EXPERIMENTS

The confirmation experiment is the final step in the first iteration of the design of experiment process. Confirmatory experiments are done to validate the conclusion drawn from the analysis phase. The confirmatory experiment is performed with specific levels previously evaluated. In this study after predicting the response under optimum conditions, a new experiment was conducted with the optimum levels of machining parameters. The results of experimental confirmation using optimal machining parameters are shown in [Table 6]. The optimum level of material removal rate was predicted as V2Tw3Ti1C3 and the predicted result is 10.2306. The experimental result is about 10.512 with an error percentage of about 2.75%. The optimum level of surface roughness was predicted as V1Tw1Ti3C1 and the predicted value is 2.115, while the experimental result is about 2.31 with an error percentage of about 9.219%. The error percentage could be further reduced by increasing the number of measurements.

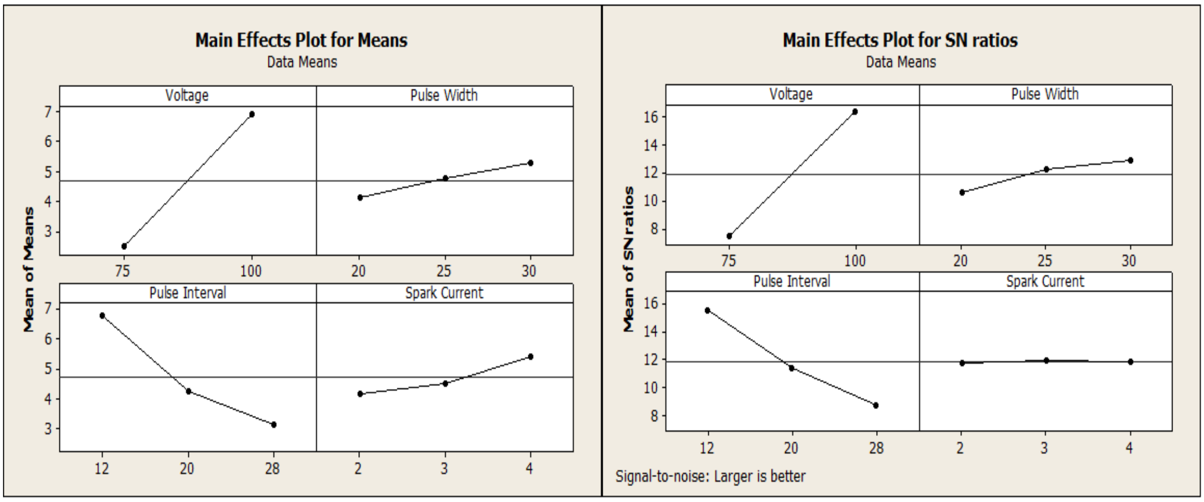

Fig 4. Mean and SN Ratio Plot for Maximization of Material Removal Rate (MRR)

***Table 6:* Confirmation experiment**

Output Parameters	Optimum Levels	Predicted Result	Experimental Result
MRR (mm3/min)	V2Tw3Ti1C3	10.2306	10.512
Ra (μm)	V1Tw1Ti3C1	2.115	2.31

V. CONCLUSIONS

In this study, the dry WEDM experiments are conducted using oxygen gas as a dielectric medium. The following observations have been obtained as described below:

- The factors like open circuit voltage, pulse width, pulse duration and discharge current are selected for maximization of material removal rate and minimization of surface roughness of the dry WEDM process.
- From analysis we can come to the conclusion that the open circuit voltage at level 2 and pulse width at level 3 is recommended for minimization of surface roughness. Open circuit voltage at level 2 and pulse interval at level 1 is recommended for the maximization of material removal rate.
- The results of the confirmation experiment well satisfied with the predicted optimal settings. An error of about 2.75% is observed for material removal rate and an error of about 9.219% is found with surface roughness. It is expected that the error can be reduced if more number of replications are taken during experimental stage.
- It is to be noted that the optimal levels of factors for both the objective differ widely. In future, the mathematical models for the output response will be generated to optimize both the objective functions.

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