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Effect of WEDM process parameters on Fe-703 Low Alloy steel using Factorial Method

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Abstract

Wire Electrical discharge machining (WEDM) is a non-traditional manufacturing technique that has been widely used in generation of contour profiles, manufacturing of automotive, aerospace and surgical components. The most important performance measure in WEDM is the MRR and surface roughness. In this study, the experimental studies were conducted under varying pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}), peak current (I_P) and wire feed (W_F). Experimentation has been done by using Factorial method under different condition of parameters. 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.

Keywords- *WEDM; Factorial method; ANOVA; MRR, Ra*

I. INTRODUCTION

Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by main stream machining processes [1]. WEDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. WEDM is an electro thermal production process in which a thin single strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials. Electrical discharge machining is frequently used to make dies and moulds conductive.

Several researchers were attempted previously to improve the surface roughness and MRR on various materials. Sarkar et al. [2] Optimized the trim cutting operation of WEDM of γ-TiAl alloy for a given machining conditions by desirability function approach and Pareto optimization algorithm and superior performance as compared to desirability function approach. Response Surface Methodology (RSM) was used to develop a prediction model of surface roughness for machining mild steel. Bhangoria et al. [3] used the statistical and regression analysis of kerf width using DOE L_{32} (21×44) mixed orthogonal array Taguchi's method. Experimental results shown that both approaches can be optimise machining parameters (gap voltage, pulse on time, pulse off time, wire feed and dielectric flushing pressure) effectively, with consideration of the response kerf width.

Analysis of variance (ANOVA) technique was used to find the variables affecting the kerf width. Tzang et. al [4] analyzed the impact of process parameters in WEDM of pure Tungsten on metal removal rate and work piece surface finish. Sadeghl et al. [5] discussed effects of process parameters on surface roughness and MRR in WEDM of AISI D5 steel alloy. Regression was used to model the process and Tabu search algorithm was opted for optimization. It was found that discharge current and pulse interval are more influential on MRR and Surface roughness than open circuit voltage.

The purpose of this study is analyzing the effect of WEDM process parameters on response variable such as MRR and surface roughness. Also, it is intended to ascertain the ranges of different parameters required for the experimental design methodology used in this work.

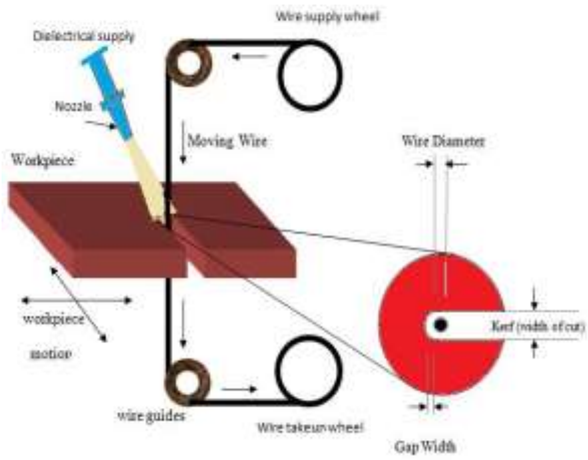

Figure 1. WEDM Process

II. EXPERIMENTATION

A. Experimental Set-up and Material

All the experiments were conducted on Super cut 734 CNC wire-cut EDM machine (Figure 2). The WEDM machine tool comprises of a main worktable (X-Y) on which the work piece is clamped; an auxiliary table (U-V) and wire drive mechanism. The main table moves along X and Y-axis and it is driven by the D.C servo motors. The travelling wire is continuously fed from wire feed spool and collected on take up spool which moves though the work piece and is supported under tension between a pair of wire guides located at the opposite sides of the work-piece. Figure 1 shows the experimental setup of WEDM machining process. The composition of Fe-703 Low Alloy steel work-piece material used for experimentation in this work is a given in Table 1. Zinc coated brass wire with 0.25 mm diameter (900 N/mm^2 tensile strength) was used in the experiments. The parameters, selected for different settings of pulse on time, pulse off time, peak current and wire feed were used in the experiments (Table 2).

Table 1. Chemical composition of Fe-703 steel (wt%)

Material	C	Si	Cr	Mn	Ni	Mo	Cu
Fe-703	*0.21*	*0.22*	*0.02*	*0.55*	*0.011*	*0.001*	*0.17*

Table 2. Wire-EDM parameters and their levels

Parameters	Symbol	Unit	Level	
			Low	High
			(-1)	(+1)
Pulse-on-time	T_{ON}	µs	20	22
Pulse-off-time	T_{OFF}	µs	50	60
Peak cuirrent	I_P	Amp	180	200
Wire feed	W_F	mm/min	4	7

Figure 2. Experimental Setup

B. Measurment

Material removal rate was used as the response parameters to evaluate machining performance in this study. The MRR is calculated following formula

$$MRR = \frac{W_a - W_b}{\rho \times t_m} \frac{mm^3}{min} \qquad (1)$$

Surface roughness measurements has been done using a Stylus type roughness tester shown in Figure 3. Surface roughness measurements are taken on the work-piece in the transverse direction and this procedure repeated three times to obtain the average value of surface roughness and all he measurements of surface roughness cut-off length is taken as 0.8 mm.

Figure 3. Surface roughness Tester

C. Factorial Method

In a factorial experiment, the effect of varying the level of the various factor affecting the process output are investigated. Each complete trial replication of the experiment takes into account all the possible combination of the varying level of these factors effective factorial design ensures that the least no. of the experiment runs are conducted to generate the max amount of information about input variable effect the output of process (Table 3) [6].

Table 3. Design of the Experiments and Results

Sr. No.	T_{ON}	T_{OFF}	I_P	W_F	MRR	Ra
	µs	*µs*	*Amp*	*mm/min*	*mm^3/min*	*µm*
1	-1	-1	-1	-1	0.620	1.900
2	+1	-1	-1	-1	0.965	2.685
3	-1	+1	-1	-1	0.590	1.850
4	+1	+1	-1	-1	0.950	2.600
5	-1	-1	+1	-1	0.670	2.100
6	+1	-1	+1	-1	1.000	2.800
7	-1	+1	+1	-1	0.710	2.450
8	+1	+1	+1	-1	0.990	2.750
9	-1	-1	-1	+1	0.630	1.880
10	+1	-1	-1	+1	0.970	2.700
11	-1	+1	-1	+1	0.600	1.800
12	+1	+1	-1	+1	0.960	2.680
13	-1	-1	+1	+1	0.690	2.430
14	+1	-1	+1	+1	1.200	2.900
15	-1	+1	+1	+1	0.650	2.000
16	+1	+1	+1	+1	1.120	2.880

III. RESULT AND DISSCUSSION

After all test are conducted, decisions must be made confirming parameters affect the performance such as MRR and surface roughness and after that access to a mathematical model how can predict value amount close to the actual values.

The effect of process parameters on the material removal rate and is shown in Figure 4. The MRR is found to have an increasing trend with the increase of pulse on time and at the same time it decreases with the increase of pulse off time. This establishes the fact that material removal rate is proportional to the energy consumed during machining and is dependent not only on the energy contained in a pulse determining the crater size, but also on the applied energy rate or power widened resulting into a lower cutting rate. MRR increases with increase in the peak current values. The higher is the peak current setting, the larger is the discharge energy. This leads to increase in material removal rate. But, the sensitivity of the peak current setting on the material removal rate is stronger than that of the pulse on time. While the peak current setting is too high, wire breakage may occur frequently.

The effect of process parameters on the surface roughness and is shown in Figure 5. It is clear that from Figure the surface roughness has an increasing trend with the increase of pulse on time and at the same time it decreases with the increase of pulse off time. The surface roughness is most affected by the amount of discharge energy which increases with increase in pulse on-time. The surface roughness depends on the size of spark crater. A shallow crater together with a larger diameter leads to a better work-piece surface roughness. To obtain a flat crater, it is important to control the electrical discharging energy at a smaller level by setting a small pulse-on time (Ton). A large discharging energy will cause violent sparks resulting in a deeper erosion crater on the surface. Furthermore, greater discharge energy will produce a larger crater, causing a larger surface roughness value on the work-piece. It is seen from Figure 4 surface roughness increases with increase in the peak current values. The higher is the peak current setting, the larger is the discharge energy. This leads to increase in surface roughness.

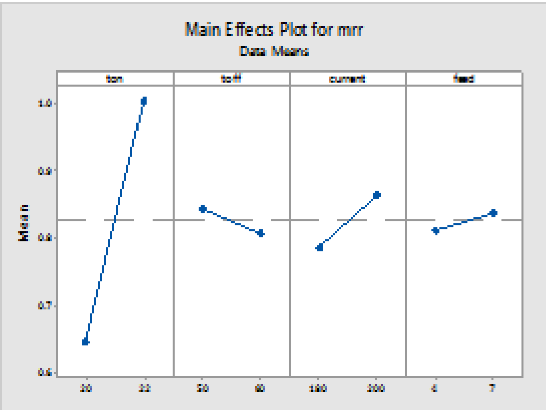

Figure 4 Effect of parameters on MRR

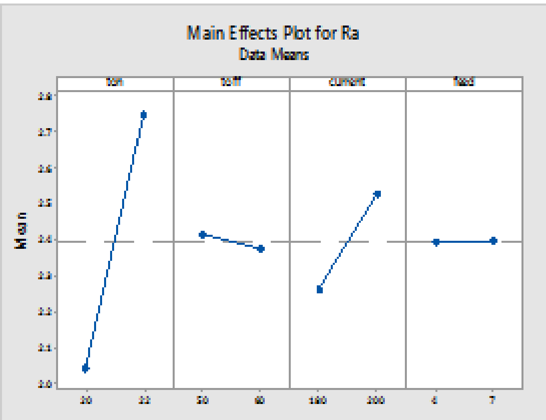

Figure 5. Effect of parameters on Surafce Roughness

A. *Normal Probability Plot*

The normal probability plot is a graphical technique to identify substantive departures from normality. This includes identifying outliers, skewness, kurtosis, a need for transformations, and mixtures. Normal probability plots are made of raw data, residuals from model fits, and estimated parameters. In a normal probability plot (also called a "normal plot"), the sorted data are plotted vs. values selected to make the resulting image look close to a straight line if the data are approximately normally distributed. Deviations from a straight line suggest departures from normality. Hence, it is proved, this experiment follow the normality assumption. The normal probability plots of residuals are shown in Figure 6 and Figure 7 for material removal rate (MRR) and Surface roughness (Ra) respectively [6].

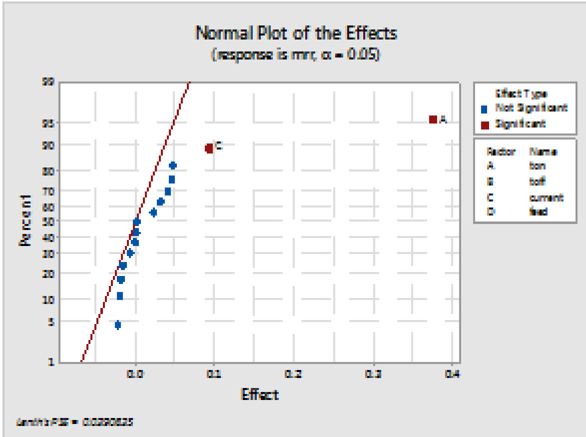

Figure 6. Normal Probability plot for MRR

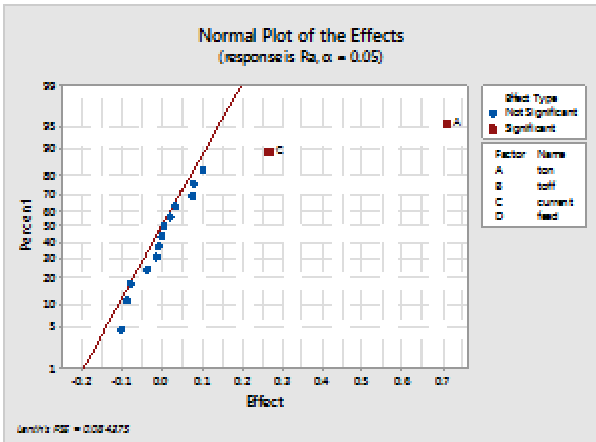

Figure 7. Noraml probability plot for Ra

B. *Analysis of Variance (ANOVA)*

ANOVA is a statically based, objective decision making tool for detecting any differences in average performance of groups of items tested. An ANOVA table consists of sum of squares, corresponding degree of freedom, the F-ratio corresponding to the ratios of two mean squares, and the contribution proportions from each of the control factors.

In order to statistically analyze the results, ANOVA was performed. Process variables having p-value<0.05 are considered significant terms for the requisite response characteristics. ANOVA for MRR (Table 4 and 5) indicates that the T_{ON} & I_P are significant parameters affecting Material Removal rate and surface roughness respectively.

Table 4. ANOVA for Material Removal Rate

Parameters	DOF	SS	MS	F-Value	P %
T_{ON}	1	0.5606	0.5606	222.7	0.000
T_{OFF}	1	0.0019	0.0019	0.77	0.399
I_P	1	0.0346	0.0346	13.97	0.003
W_F	1	0.0066	0.0066	2.66	0.131
Error	11	0.0273	0.0024		
Total	15	0.6311			

Table 5. ANOVA for Surface Roughness

Parameters	DOF	SS	MS	F-Value	P %
T_{ON}	1	2.0128	2.0128	116.27	0.000
T_{OFF}	1	0.0054	0.0054	0.31	0.586
I_P	1	0.2822	0.2822	16.30	0.002
W_F	1	0.0001	0.0001	0.01	0.933
Error	11	0.1904	0.0173		
Total	15	2.4910			

IV. CONFIRMATION EXPERIMENT

Confirmontory experimnt are carried out at the parameters settings corresopnding to maximum material removal rate and minimum surafce rougness inTable 6, check the validity of the optimization results.

Table 6. Optimal Machining Parameters

Response	*Optimal machining parameters*				Prediction	*Experiment*
MRR	T_{ON} (+)	T_{OFF} (-)	I_P (+)	W_F (+)	1.2 mm^3/min	1.25 mm^3/min
Ra	T_{ON} (-)	T_{OFF} (+)	I_P (-)	W_F (-)	2.45 µm	2.634 µm

It is observed from Table 6 that the error between the predicted and experimental results is less than, which confirm the good reproducibility of the results.

V. CONCLUSION

The effect of WEDM process parameters in terms of material removal rate and surface roughness of Low alloy steel (Fe-703), using Factorial Method. Based on the experimental results and analysis, the following conclusions can be follows:

- For maximum material removal rate and minimum surface rouhness optimal combination of process parameters are pulse on time (22µs), pulse off time (50µs), peak current (200A), wire feed (7mm/min) and pulse on time (20µs), pulse off time (60µs), peak current (180A), wire feed (4mm/min) respectively.
- Peak current (I_P) and pulse on time (T_{ON}) contributes most significantly towards MRR and Surface roughness as the difference value is highest, followed by pulse off time and wire feed.
- Experimental value 1.25 for MRR is very close to the predicted 1.2 and Experimental value 2.634 for surface roughness is very close to the predicted 2.45. It shows very good reproducibility and confirms the success of the experiments.
- The confirmation experiments shows that the error associated with MRR and surface roughness is 4 % and 7 % respectively.

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