Optimization of process parameters of cryogenic treated D-3 in WEDM by Taguchi Approach

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ABSTRACT

Cryogenic treated high carbon high chromium alloy cold tool steels (D-3) are used in production of high performance dies, punches, blanking and punching tools, extrusion tools, etc. cryogenic treatment is a process of keeping the specimen in cold environment to increase its wear resistance and relieving its residual stresses. Due to its high hardness Wire Electric Discharge Machine (WEDM) seems a good option for machine hard material. In this paper, the effects of various process parameters of WEDM as pulse width, time between two pulses, maximum feed rate, servo reference mean voltage, short pulse time and wire mechanical tension, have been experimented for optimizing surface roughness (sr) while machining cryogenic treated D-3 material. Experimental observations are based on Taguchi's L-27 orthogonal array has been done. Signal-to-Noise (S/N) ratio, Analysis of Variance (ANOVA) and various plots are used to find the optimum process parameter with a least surface roughness. The confirmation experiments has been done for validate the results calculated by using taguchi method.

Keywords - **ANOVA, D-3, Taguchi Technique, wire electric discharge machine,**

1. INTRODUCTION

Wire Electrical Discharge Machining (Wire-EDM) is an electro thermal production process in which a thin single-strand metal wire along with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. The accuracy and the surface finishes obtained from WEDM makes it perfect for applications of manufacturing stamping dies, extrusion dies and extrusion tools. Without the WEDM it requires a lot of time for grinding and finishing the parts. The pulse width, time between two pulses, maximum feed rate, servo reference mean voltage, short pulse time and wire mechanical tension, have been optimized to find the best surface finish while machining cryogenic treated D-3 material Among the various performance measures, the workpiece surface finish, which determines the final quality of the finished part, is of utmost importance.

Pandey and Jilani [1] worked on the machining characteristics using distilled water, tap water and a mixture of both. They observed that the best machining rate achieved by tap water. Rajurkar and William [2] reported that wire electrical discharge machine (WEDM) manufacturers and users are to achieve higher machining rate with desired accuracy and minimum surface damage. The complex and random nature of the erosion process in WEDM requires the application of deterministic as well as stochastic techniques. Surface roughness profiles were studied with a stochastic modeling and analysis methodology to better understand the process mechanism. With the application pf scanning electron microscopic (SEM) important features of WED machined surfaces are found out. Bhatti and Hashmi [3] found a manipulator for obtaining the intricate and complex shape with WEDM. Kanlayasiri and Boonmung [4] investigated the effects of machining parameters on the surface roughness of DC53 die steel on WEDM. In this study, the machining variables investigated were pulse peak current, pulse-on time, pulse-off time, and wire tension. Analysis of variance (ANOVA) technique was used to find out the variables affecting the surface roughness. Mishra, Prashad and Banerjee [5] investigated the wire rupture phenomenon on WEDM. They found that the main cause of wire rupture is thermal load, short-circuiting and vibration of wire. Out of these the thermal load is most important. Liao et al. [6] proposed an approach of determining the parameter settings based on the Taguchi quality design method and the analysis of variance. The results showed that the MRR and SF are easily influenced by the table feed rate and pulse on-time, which can also be used to control the discharging frequency for the prevention of wire breakage. Manna and Bhattacharyya [7] observed that the open gap voltage and pulse on period are the most significant machining variable for controlling the metal removal rate using Taguchi method is for WEDM on Al/SiCMMC. Sarkar et al. [8] presents an investigation on WEDM of γ-titanium aluminide alloy. The main aim of their study is to select the optimum cutting parameter with an appropriate wire offset to find best surface finish and dimensional accuracy. Spedding and Wang [9] optimized the process parameter settings by using artificial neural network modeling to characterize the WEDM work-piece surfaces. Tarng et al. [10] used a neural network system to determine settings of pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage, electric capacitance and table speed for the estimation of cutting speed and surface finish. Singh and Garg [11, 12, 13] optimized setting of wire electric discharge machine on material removal rate, gap current and other output characteristics. They used hot die steel (H-11) as the work-piece material and taguchi approach to optimized the parameters of the WEDM.

The review of literature revealed very limited work on the effects of WEDM machining parameters for optimizing surface roughness. There are other researcher [14] in this field who studied the effect of process parameters using cryogenic treated wire except taking workpiece as cryogenic. The present work was thus undertaken to investigate the effects of machining parameters—pulse on time, pulse off time, spark gap set voltage, peak current, wire feed and wire tension, on surface finish using Taguchi's technique during machining of cryogenic treated high carbon high chromium alloy tool steel (D-3).

Figure 2: WED Machine Tool

Constituent	C	Si	Mn	P	S	Cr	Mo	V
% composition	2.01	0.67	0.34	-	-	10.41	-	-

Table 1: Composition of D-3 Used For Experiment

2. METHODOLOGY

Cryogenic processor (CP200LH) as shown in Figure 1 was used for cryogenic treatment of work-piece. Various sets of experiments were performed using a Robofil 290 Charmilles Technologies WED machine toolas shown in Figure 2. As in the experiments the sr of the work-piece was measured. The work material, electrode and the other fixed machining parameters are as under:

1. Workpiece : Cryogenic treated high carbon high chromium alloy tool steel (D-3)

2. Electrode (tool) : 250 µm φ, CuZn37 Master Brass wire (900 N/mm^2 tensile strength)

3. Workpiece height :30 mm

4. Die-electric conductivity:20 mho

5. Cutting voltage (V): - 80V

6. Die-electric temperature: 22–25°C

7. Injection pressure : 4(around 6.5 bars)

8. Ignition pulse current (IAL) : 8 Amp

Figure 1: Cryogenic Processor

The percentage composition of various constituent in D-3 is shown in Table 1. An L27 (3^{13}) orthogonal array [15] has been employed as per Taguchi's method based robust design philosophy to evaluate the main influencing factors that affect the surface roughness (sr). Six WEDM parameters — factor A (pulse width), factor B (time between two pulses), factor A_j (servo reference mean voltage) ,factor T_{ac} (short pulse time), factor S (maximum feed rate) and factor W_b (wire mechanical tension), are considered as the controlling factors for optimal analysis during machining of D-3. Table 2 shows the various control factors and their levels selected while experimenting. The selection of parameters and their levels is based upon review of literature and some pilot experiments conducted by the authors.

Table 2: Input Process Parameters and their Levels

Symbols	**Parameters**	**Units**	**Levels**		
			L1	**L2**	**L3**
A	Pulse width	µs	0.8	0.9	1.0
B	Time between two pulses	µs	6.6	9.0	11.4
A_j	Servo reference mean voltage	V	34.0	38.0	42.0
T_{ac}	Short pulse time	µs	0.4	0.5	0.6
S	Maximum feed rate	mm/min	13.0	18.0	23.0
W_b	Wire mechanical Tension	daN (kg)	0.8	1.3	1.8

3. RESULTS AND DISCUSSIONS

The WEDM experiments were conducted by using design of experiments of the Taguchi's Method. The effects of various process parameters on surface finish have been dicussed in this section. The average value and S/N ratio of the response characteristic for each variable at different levels were calculated from experimental data. The ANOVA of raw data and S/N data is found out to identify the significant and insignificant variables and to quantify their effects on the response characteristic. The optimal values of process parameters in terms of mean response characteristic were established by analyzing the response curves and the ANOVA Tables. The experimental data for surface finish are given in Table 3.

Table 3: Experimental Results for Surface Roughness

Trial No.	Surface Roughness			S/N Ratio
	R1	R2	R3	
1	1.87	2.2	2.5	-6.86842
2	2.64	2.07	2.14	-7.22472
3	1.98	2.05	2.16	-6.29698
4	1.96	2.16	2.18	-6.45409
5	2.11	2.05	2.11	-6.40372
6	1.92	2.09	2.01	-6.0547
7	2.06	2.11	2.01	-6.27905
8	2.07	2.09	1.87	-6.07451
9	2.11	2.01	2.05	-6.26501
10	2.33	2.12	1.94	-6.59184
11	2.12	2.01	2.33	-6.6787
12	2.14	1.93	2.05	-6.20032
13	2.15	2.18	2.13	-6.66262
14	1.98	2.09	2.29	-6.5426
15	15	2.24	2.11	2.05
16	16	2.09	2.01	2.23
17	17	2.12	2.15	2.04
18	18	2.42	2.33	2.17
19	19	2.32	2.4	2.36
20	20	2.44	2.37	2.32
21	21	2.2	2.53	2.23
22	22	2.03	2.41	2.15
23	23	2.39	2.36	2.03
24	24	2.38	2.23	1.87
25	25	2.19	2.32	2.3
26	26	2.1	2.12	2.36
27	27	2.2	2.19	2.08

It is observed from the Figures 3 and 4 that there are significant interactions between pulse width and time between two pulses. Table 4 and Table 6 shows the ANOVA of S/N data and pooled ANOVA for S/N data.

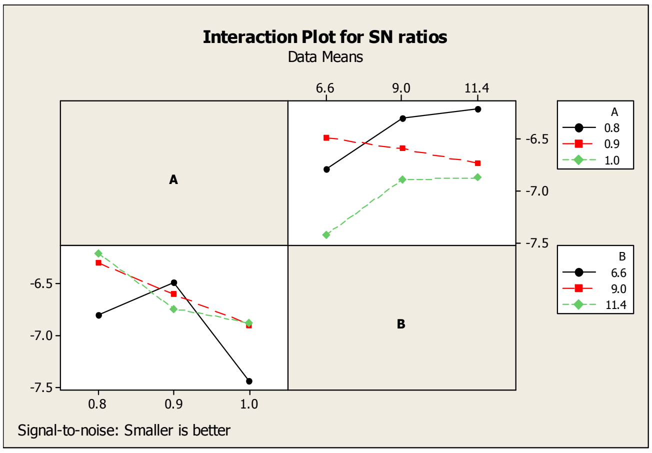

Figure 3: Interaction plots (S/N Data)

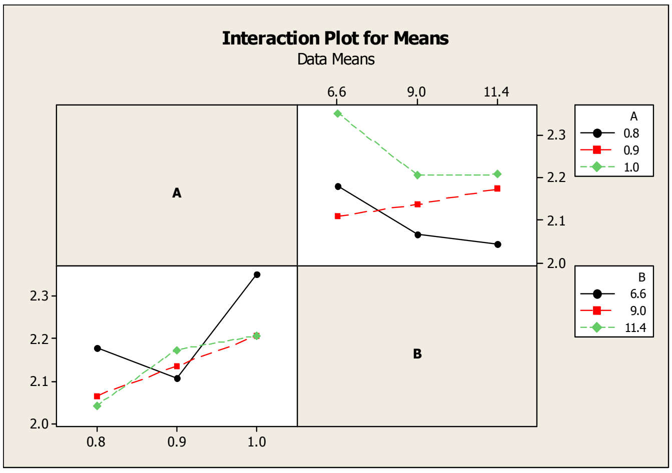

Figure 4: Interaction plots (Raw Data)

3.1 Selection of Optimal Levels

To find the significance of the process parameters towards surface roughness ANOVA was performed. It was found that servo reference mean voltage, short pulse time, wire feed rate and wire mechanical tension are non significant process parameters for surface roughness as revealed from Table 5. The pooled version of ANOVA of the raw data for surface roughness is given in Table 7. It is investigated from the ANOVA that Pulse width and time between two pulses significantly affect the variation in the surface roughness values. Pulse width has the maximum effect on suface roughness followed by time between two pulses. As surface roughness is the 'smaller the better' type of quality characteristic. Based on Taguchi method, the S/N ratio calculation was decided lower the better LB by the following formula: LB: $\mu = -10\log[\frac{1}{n}\sum_{i=1}^{n} Yi^2]$

Where μ denote the S/N ratio calculated from the observed value Yi represent the experimentally observed value of i^{th} experiment and n is the repeated number of each experiment, each experiment in L27 array is conducted at three times. The main effects of plots of SN data and raw data are shown in Figure 5 and 6. It is clearly representable from the main effects plots for raw data (Figure 6) that the first level of pulse on time (A_1) and second level of time between two pulses (B_2) result in minimum value of surface roughness.

Table 4: Analysis of Variance for S/N Data

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	1.93996	1.93996	0.969978	149.30	0.007
B	2	0.55271	0.55271	0.276355	42.54	0.023
Aj	2	0.14689	0.14689	0.073446	11.30	0.081
Tac	2	0.20134	0.20134	0.100669	15.50	0.061
S	2	0.12615	0.12615	0.063073	9.71	0.093
Wb	2	0.07609	0.07609	0.038046	5.86	0.146
A*B	4	0.74320	0.74320	0.185800	28.60	0.034
A*Aj	4	0.23271	0.23271	0.058178	8.95	0.103
B*Aj	4	0.51147	0.51147	0.127868	19.68	0.049
Residual Error	2	0.01299	0.01299	0.006497		
Total	26	4.54351				

Table 5: Analysis of Variance for Raw Data

Source	DF	Seq SS	Adj S	Adj MS	F	P
A	2	0.122040	0.122040	0.061020	150.08	0.007
B	2	0.033705	0.033705	0.016852	41.45	0.024
Aj	2	0.008418	0.008418	0.004209	10.35	0.088
Tac	2	0.012119	0.012119	0.006060	14.90	0.063
S	2	0.007529	0.007529	0.003765	9.26	0.097
Wb	2	0.004179	0.004179	0.002089	5.14	0.163
A*B	4	0.047557	0.047557	0.011889	29.24	0.033
A*Aj	4	0.014784	0.014784	0.003696	9.09	0.102
B*Aj	4	0.031276	0.031276	0.007819	19.23	0.050
Residual Error	2	0.000813	0.000813	0.000407		
Total	26	0.282421				

Table 6: Pooled Analysis of Variance for S/N Data

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	1.9400	1.9400	0.96998	13.35	0.000
B	2	0.5527	0.5527	0.27635	3.80	0.042
A*B	4	0.7432	0.7432	0.18580	2.56	0.074
Residual Error	18	1.3076	1.3076	0.07265		
Total	26	4.5435				

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

Table 7: Pooled Analysis of Variance for Raw Data

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.12204	0.12204	0.061020	13.88	0.000
B	2	0.03370	0.03370	0.016852	3.83	0.041
A*B	4	0.04756	0.04756	0.011889	2.70	0.063
Residual Error	18	0.07912	0.07912	0.004395		
Total	26	0.28242				

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level.

Table 8: Response Table for Mean

Level	A	B
1	2.096	2.213
2	2.139	2.136
3	2.255	2.141
Delta	0.159	0.077
Rank	1	2

The Effects of process parameter are plotted for the SN ratio and Means.

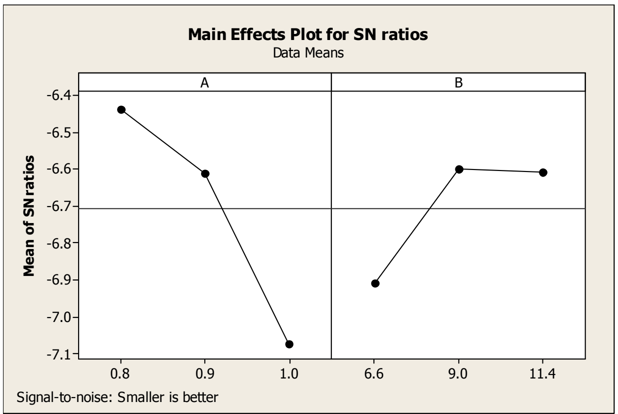

Figure 5: Main Effects plots for SN Ratio

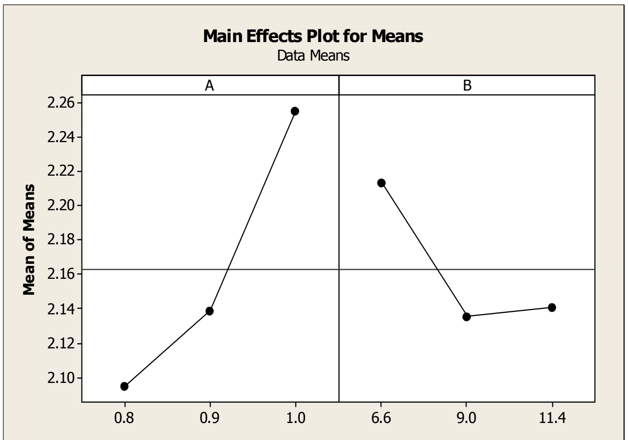

Figure 6: Main Effects plots for Raw data

Optimum Value of Surface Roughness (sr)

The optimum value of sr is predicted at the selected levels of significant variables pulse width (A_1) and time between two pulses (B_1) (Table 8). The estimated mean of the response characteristic can be determined as:

$$\mu_{sr} = \overline{A_1} + \overline{B_2} - \overline{(T)} \qquad (1)$$

Where, $\overline{T}$ = overall mean of surface roughness = $(\sum R_1+\sum R_2+\sum R_3)/81 = 2.163$ µm

Where R_1, R_2, and R_3 values are taken from the Table 2, and the values of A_1 and $\overline{B}_2$ are estimated from the experimental data reported in the same table.

$\overline{A_1}$= average value of surface roughness at the first level of pulse width = 2.096 µm

$\overline{B}_2$ = average value of surface roughness at the first level of time between two pulses =2.136 µm

Substituting the values of various terms in the above equation,

$$\mu_{cr} = 2.096+2.136-2.163 = 2.069$$

The 95 % confidence intervals of confirmation experiments (CI_{CE}) and population (CI_{POP}) are calculated as:

$$CI_{CE} = \sqrt{F_\alpha(1,f_e)V_e\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]} \quad \text{and}$$

$$CI_{POP} = \sqrt{\frac{F_\alpha(1,f_e)V_e}{n_{eff}}}$$

Where, $F_\alpha(1, f_e)$ = The F ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e.

$$n_{eff} = \frac{N}{1+\left[\text{DOF associated in the estimate of mean response}\right]}$$

= 81 / (1+4) = 16.2

N = Total number of results = 27 x 3 =81, R = Sample size for confirmation experiments = 3

V_e = Error variance = 0.004395 ; f_e = error DOF = 18 (Table 7)

$F_{0.05}(1, 18) = 4.4139$ (Tabulated F value (Ross, 1996))

So, $CI_{CE} = \pm 0.0875$, and $CI_{POP} = \pm 0.0346$

Therefore, the predicted confidence interval for confirmation experiments is:

Mean μ_{cr} - CI_{CE} < μ_{cr} < Mean μ_{cr} + CI_{CE} i.e. $1.9815 < \mu_{cr} < 2.1565$

The 95% confidence interval of the population is:

Mean μ_{cr} – CI_{POP} < μ_{cr} < Mean μ_{cr} + CI_{POP} i.e. $2.0344 < \mu_{cr} < 2.1036$

The optimal values of process variables at their selected levels are as follows:

(A_1) : 0.8 machine units; (B_2): 6.6 machine units ;

4. CONFIRMATION EXPERIMENT

Confirmation Experiment is plays an important role in any parametric optimization of any machine tool, as in confirmation experiment set the significant parameters according to our optimal values which are find out by Taguchi approach. After set the machine tool at the optimal setting and check the response at this setting to find the actual value of the response. In Table 9 optimal setting of the parameters are shown and also the actual value of the response is calculated.

Table 9: **Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments**

Performance Measures/ Responses	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Intervals at 95% confidence level	Actual value(average of three confirmation experiments)
Cryogenic SR	A_1B_2	2.069	CI_{POP} : $2.0344 < \mu_{Sr} < 2.1036$; CI_{CE} : $1.9815 < \mu_{Sr} < 2.1565$	1.98 µm

5. CONCLUSION

I. Influences of wire-ED machining process parameters on surface roughness of newly developed cryogenic treated high carbon high chromium alloy tool steel (D-3) were investigated in this paper.

II. Results showed that pulse width and time between two pulses were significant variables to the surface roughness of wire-EDMed cryogenic treated D-3.

III. The surface roughness for the test specimen became larger when the pulse width was increased.

IV. Surface roughness first decrease and then increases with increase in time between two pulses.

V. (A_1) – 0.8 machine units, (B_1) – 6.6 machine units, $(A_j)_2$ – 34, $(T_{ac})_2$ – 0.6, (S_3) – 13, is the optimized setting of machine tool for the present study.

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