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PARAMETRIC STUDY AND OPTIMIZATION OF HIGH CARBON HIGH CHROMIUM D-7 STEEL

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ABSTRACT

High Carbon High Chromium Steel is the most popular material in forming and blanking tool and die for the mechanical, automobile and structural engineering industry. It posses excellent harden ability, wear resistance and hot hardness to withstand the cyclic and compressive stress imposed on the punch and die during sheet metal operations. The form stability of tool material determines the quality of the blanked or punched component. In the present work, to study the machining characteristics of high carbon-high chromium steel, a wire electro discharge machining process was applied, since the green material was hardened and tempered to 62 H.R.C. Design of experiment with 4 levels on 16 orthogonal experiments were conducted on sprint cut WEDM machine. The input parameters selected being pulse-on time, pulse-delay time, wire tension and EPA. The output response observed is material removal rate and surface finish. The results were subjected to Taguchi optimization analysis. It was found EPA is most important for material removal rate but ranks the least for surface finish, with pulse on time ranking first and pulse off time second.. The analysis of variance results indicates pulse on time and EPA are the most significant parameter for finish and the material removal rate respectively. Optimization trials indicates, the careful selection of parameter and its range, can be improve the finish by 8.69% and material removal rate by 10.71%.

Keywords: tool and die, high carbon high chromium steel, taguchi analysis, wire electrical discharge machining.

1. INTRODUCTION

Wire electrical discharge machining is the most popular method to slice/shape hard, conductive material into desired shape and size, economical, fast, reliable, precise, preserves material characteristics, low air, water or noise pollution and once programmed unmanned machining is possible. Due to many input process parameters and the conflicting requirements of output responses, it is difficult to select parameter range that would yield best performance. Using the design of experiments and Taguchi analysis, the best operating parameters can be found in fewer experiments thus saving valuable man and machine hours.

WEDM in the aerospace, nuclear and automotive industries is indispensable process for machining and shaping hard and difficult to cut materials in the tool and die industry process [1]. Material hardness is not a limiting factor for machining materials through this process. Investigations into the influences of machining input parameters on the performance of WEDM have been widely reported [2-5]. The pulse-on time, pulse-off time, wire tension, wire speed, supply voltage, peak current, dielectric pressure and duty factor were most studied parameters. Sarkar and Bhattacharyya [6] investigated the effects of individual process parameters of WEDM on γ titanium aluminide. Muthuraman *et al* [7-9] studied the influences of process variables during WEDM of O1 tool steel and optimized the WEDM parameters through Taguchi and grey relational analysis.

2. MATERIAL AND METHODS

The tool electrode is a small diameter wire ranging from 0.05 to 0.25 mm. The wire is continuously supplied from the supply spool through the clamped work -piece to the take away wire traction rollers. The movement of the wire is numerically controlled. A gap of 0.025 to 0.05 mm is maintained constantly between the wire and work piece. A collection tank that is located at the bottom is used to collect the used wire. The wires once used cannot be reused again due to the variation in dimensional accuracy. De-ionized water is continuously fed into the spark gap along the wire at sufficient pressure, in the sparking area to remove the by-products formed during the erosion and to cool the work. The composition of HC-HCR Steel is presented in Table-1. It retains its hardness (62 HRC) up to a temperature of 425°C. An Electronica sprint cut CNC WEDM machine sliced 16 components as per the design of experiment of L16 orthogonal array with piece size of 12 mm length and 12.5 mm width from 75mm x 75mm x 12.43mm parent plate. The machining time was noted for 16 different experimental parameter level settings. The roughness (µm) of the sliced surface was measured thrice through a Mitutoya, Talysurf surftronic 3+ at 0.8 mm cut-off value and the average is taken. Table-2 displays ranges and the four parameter levels chosen to avoid linearity effect. Table-3 show the array with coded input provided and output responses obtained by WEDM.

Table-1. Chemical composition Of Hc-Hcr steel.

Element	C	Mn	Si	Cr	Ni	W	V	P	S	Cu
Weight %	2	0.6	0.6	11	0.3	1	1	0.03	0.03	0.2

Table-2. Experiment level, ranges of l_{16} array

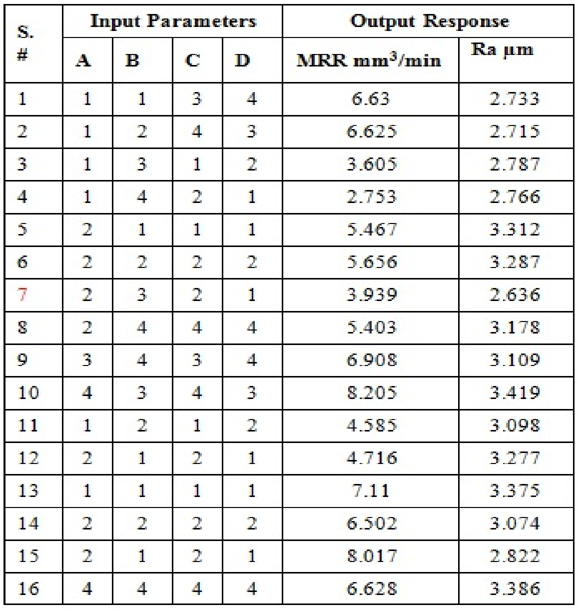
Control factors	Symbol	Level			
		1	2	3	4
Pulse on Time(μsec)	A	117	120	123	126
Off-time (μsec)	B	50	52	54	56
Wire tension(N)	C	6	7	8	9
EPA (%)	D	70	80	90	100

Using Taguchi method and anova the parameters of significance, their level and range that produce optimal results were identified and predicted values were tested thrice and averaged for better consistency. The material removal rate is evaluated from Equation (1)

$$MRR = ktv \quad mm^3/min \tag{1}$$

Where, t = thickness of work piece mm = 12.43 mm;
k = Kerf = (d+2 Δg) = 0. 35 mm, L = length of cut mm
d = diameter of wire = 0.25mm; v = L//T mm/min
Δg = wire-work spark gap = 0.05mm,

Table-3. Taguchi l_{16} with coded units and experimental results.



S. #	Input Parameters				Output Response	
	A	B	C	D	MRR mm³/min	Ra μm
1	1	1	3	4	6.63	2.733
2	1	2	4	3	6.625	2.715
3	1	3	1	2	3.605	2.787
4	1	4	2	1	2.753	2.766
5	2	1	1	1	5.467	3.312
6	2	2	2	2	5.656	3.287
7	2	3	2	1	3.939	2.636
8	2	4	4	4	5.403	3.178
9	3	4	3	4	6.908	3.109
10	4	3	4	3	8.205	3.419
11	1	2	1	2	4.585	3.098
12	2	1	2	1	4.716	3.277
13	1	1	1	1	7.11	3.375
14	2	2	2	2	6.502	3.074
15	2	1	2	1	8.017	2.822
16	4	4	4	4	6.628	3.386

In Taguchi method, a loss function is calculated, which is the deviation between the experimental value and the desired value. This loss function is converted into a signal-to-noise (S/N) ratio. Regardless of the category of the performance characteristics, greater S/N values implies a better performance. In machining lower surface roughness and higher MRR are indication of better performance.
For the higher is better (HB) and lower the better (LB), the loss function (L) for performance of n repeated trials are,

$$L_{HB}=1/n \sum_{i=1}^{n} 1/Y^2 \tag{2}$$

$$L_{LB}=1/n \sum_{i=1}^{n} Y^2 \tag{3}$$

Where, Y is the response and n denotes the number of experiments. The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below:

$$\text{S/N ratio of MRR} = -10 \log_{10} (L_{HB}) \tag{4}$$

$$\text{S/N ratio of SF} = -10 \log_{10} (L_{LB}) \tag{5}$$

By applying these Equations from (2) to (5), the S/N ratio values for each experiment of $L_{16,}$ was estimated (Table-4 and 5).

Table-4. MRR response for s/n ratios.

Larger is better: MRR versus A, B, C, D				
Level	**A**	**B**	**C**	**D**
1	13.20	16.25	15.15	12.99
2	14.09	**16.50**	14.12	14.17
3	15.44	13.59	**15.39**	**16.98**
4	**16.95**	13.34	15.34	16.54
Delta	3.75	3.17	1.26	3.86
Rank	2	3	4	1

Table-5. Ra response for S/N ratios.

Smaller is Better: Ra versus A, B, C, D				
Level	**A**	**B**	**C**	**D**
1	**-8.787**	-9.888	-10.144	-9.447
2	-9.800	-9.861	**-9.291**	-10.028
3	-10.165	**-9.039**	-9.599	**-9.427**
4	-9.981	-9.946	-9.776	-9.663
Delta	1.378	0.907	0.853	0.582
Rank	1	2	3	4

3. RESULTS AND DISCUSSIONS

From the above variables studied, Table-4 of MRR ranks, EPA as critical parameter, on-time ranks as second, off-time as third and wire tension as fourth in influence. For the surface roughness from Table-5,the order being, on-time ranks first, off-time is second in importance, wire tension is third and EPA is fourth in ranking and in significance. The higher ranking parameters need not be changed. Less significant parameters can be tuned for improvement.

Based on the analysis of S/N ratio, the optimal machining performance for the MRR was obtained at **A4B2C3D3**.i.e., pulse on time (Level 4) 126 µsec., pulse off time (Level 2) 52 µsec., wire tension (Level 3) 8 N and EPA (Level 3) 90%.

The mean graph of MRR with input is presented in Figure-1.On- time increase, Off-time decrease and EPA increase- increases the spark duration, hence MRR is high. Wire tension does not significantly influence the output.

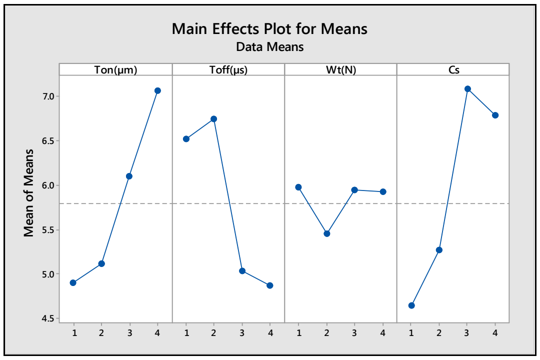


Figure-1. Mean of MRR with parameters.

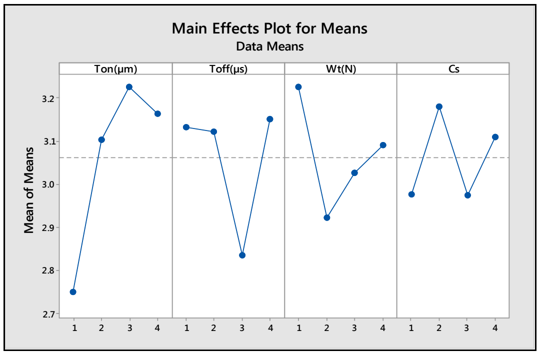


Figure-2. Mean of Ra with parameters.

The optimum machining parameter level that would yield lower surface finish was obtained at pulse-on time (Level 1) 117 µsec., pulse- off time (Level 3) 34 µsec., wire tension (Level 2) 7 N and EPA (Level 3) 90%. i.e. **A1B3C2D3.**

The results of ANOVA for the machining outputs are presented in Table-6 and Table-7 respectively.. Statistically, F-test provides at 95% confidence level the significance. Larger F-value indicates that the variation of the process parameter influence significantly the performance characteristics. Percent contribution indicates the relative power of a factor to reduce variation. High percent contribution indicates even a small variation will have a great influence on the performance. Accordingly, among the input parameters selected, statistically effective parameter with respect to MRR (Table-6) is EPA (40.15%) followed by off- time (30.22%) and on time (29.13%) respectively. Wire tension is least significant (0.50%) and is suitable for optimization trials.

Table-6. ANOVA for means of MRR.

Para-meter	df	Sum of Square	Mean Square	F Test	Contribution %
Ton (µm)	3	11.8483	2.80675	6.95	29.13
Toff(µs)	3	11.4656	2.90970	7.21	30.22
Wt (N)	3	0.5726	0.04949	0.12	0.50
EPA (%)	3	11.5995	3.86651	9.58	**40.15**
Error	3	1.2107	0.40357		
Total	15	36.6967			100.00

Table-7. ANOVA for means of Ra.

Para-meter	df	Sum of Square	Mean Square	F Test	Contribution %
Ton (µm)	3	0.54461	0.17687	10.74	**51.61**
Toff(µs)	3	0.27195	0.07394	4.49	21.58
Wt (N)	3	0.18955	0.06442	3.91	18.79
EPA (%)	3	0.08227	0.02742	1.67	8.02
Error	3	0.04941	0.01647		
Total	15	1.13780			100.00

From Table-7 of ANOVA for the surface finish, pulse on time was found to be the major factor affecting the surface finishes (51.61%) whereas pulse off time is significant second ranking factor (21.58%), followed by wire-tension parameter (18.79%).EPA is the least significant (8.02%). Regression analysis showed a good co-relation exists and prediction equation also was obtained.

$$MRR_{PRED} = 5.9556 - 1.05233\,Ton + 0.64022\,Toff + 0.02067\,Wt - 1.16389\,EPA \qquad (6)$$

$S = 0.6353$ R-Sq = 96.7%   R-Sq(adj) = 83.5%

From Figure-3 and Figure-4, it was observed, the normal probability plot closely follows the straight line. The residuals versus fitted values show randomness and no fixed pattern could be discerned. The histogram indicates an approximate bell shaped normal curve and the residuals are evenly distributed with low error values.

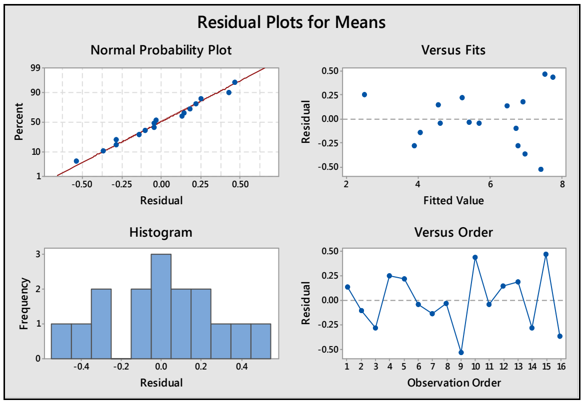


Figure-3. Residual plot of MRR .

$$Ra_{PRED} = 3.05481 - 0.30456\ Ton + 0.06435\ Toff + 0.17119\ \ Wt - 0.01925\ EPA \quad (7)$$

S = 0.1283 R-Sq = 95.7% R-Sq(adj) = 78.3%

It is observed that R value to be high which is a positive and the prediction equation could provide accurate result.

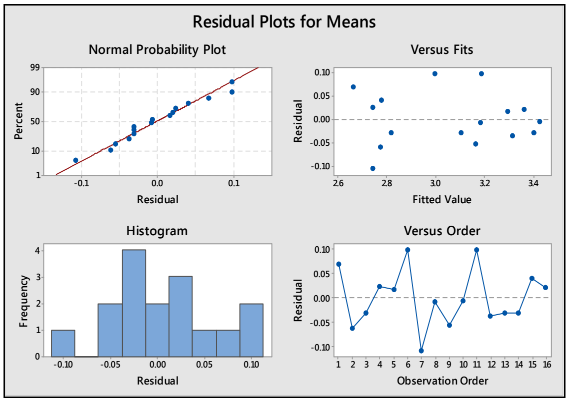


Figure-4. Residual plot of Ra.

Confirmation experiment was conducted to validate the optimal parameters. Prediction and verification of the improvement is obtained using the optimal levels of the machining parameters and are evaluated from,

$$\eta_{opt} = \eta_m + \sum_{i=1}^{p}(\eta_i - \eta_m) \quad (8)$$

Where, η_m is total mean of S/N ratio, η_i is the mean of S/N ratio at the optimal level, and p is the number of main machining parameters that significantly affect the performance. Table-8, show the comparison of the predicted material removal rate with the actual material removal rate using optimal machining parameters. The material removal rate is increased by 12%, and the finish from Table-9, displays improvement by 8.20% due to proper optimization, selection of ranges, according to the significance.

The experimental results confirmed the validity of the used Taguchi method for enhancing the machining performance and optimizing the machining parameters of HC- HCR tool steel, with output response being, maximizing material removal rate and minimizing the surface finish.

Table-8. Results of confirmation test of MRR.

Responses	Levels	Values	Improvement
MRR average (mm^3/min)	A2B2C2D2	5.80	12%
MRR predicted (mm^3/min)	A4B2C3D3	9.008	
MRR experimental (mm^3/min)	A4B2C3D3	6.496	

Table-9. Results of confirmation test of MRR.

Responses	Levels	Values	Improvement
Ra average (µm)	A2B2C2D2	3.06	8.20%
Ra predicted (mm^3/min)	A1B3C2D3	2.35	
Ra optimal (mm^3/min)	A1B3C2D3	2.81	

4. CONCLUSIONS

In this work, an investigation on the optimization and the effect of machining parameters on the material removal rate and the surface finish in WEDM operations on high carbon high chromium steel been carried out. The effect of parameter such as pulse on time, pulse off time, wire tension and EPA been studied and optimal values were predicted, tested and proven that through this approach the output response efficiency can be improved. The level of importance of the machining parameters on the material removal rate and surface finish was determined by using ANOVA Method, optimum parameters for maximum MRR and minimum surface roughness were obtained. The confirmation tests indicated that it is possible to increase MRR and decrease surface roughness significantly by using the statistical technique. The experimental results confirmed the validity of the Taguchi method for enhancing the machining performance and optimizing the machining parameters in WEDM operations. A regression equation was developed to predict the material removal rate and surface roughness for WEDM of HC-HCR tool steel.

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