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An Experimental Study to Achieve Minimum Surface Roughness While Machining P20 Tool Steel Using Wire EDM

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Abstract
There is a rapid increase in the usage of hard materials. The conventional machining process has been left behind by complex and intricate part machining. Such complex machining of hard materials via conventional machining methods does often lead to poor quality characteristics such as low surface roughness. Thus, to achieve the goal of better quality characteristics while machining hard materials, non-conventional machining processes come into play. Wire Electric Discharge Machining (Wire-EDM), is an example of such non-conventional machining processes. This paper highlights a research analysis on parametric optimization of Wire EDM process while machining P20 tool steel. It deals with the optimization of parameters namely Pulse on time, Pulse off time, Peak current and Wire Tension so as to obtain low surface roughness. Taguchi's design of experiments and Analysis of Variance (ANOVA) has been used for the optimization purpose and L_9 orthogonal array has been used for the same. Furthermore, it was found that Pulse off time and Peak Current were the most significant factors, followed by Pulse on time and Wire Tension.

1. Introduction

Wire EDM is a non conventional machining process, which is based on the thermo-electrical energy principle. It is a process which uses a wire, which erodes the material from the workpiece, with the series of sparks being impulse. As the sparks are impulse, feed is continuously given to the wire, so that the machining process is carried out in continuity [1]. The workpiece should be electrically conductive, so as to facilitate the eroding process. Wire used in the process is generally made up of brass, and has a diameter of 0.25mm.

2. Methodology

Taguchi's design of experiments has been employed in this research analysis. L_9 Orthogonal array has been used for the same [2]. The classical design of experiment used the traditional full factorial design process, which involved numerous experiments to be conducted. In contrary to the classical approach, Taguchi's Orthogonal Arrays (OA) provided an advantage of less number of experiments to be conducted.
Signal to Noise ratio was used for the optimization purpose can be calculated using the equation 1

$$(S/N)_{LB} = -10\log(MSD)_{LB} \qquad \textbf{(1)}$$

Where,

$$(MSD)_{LB} = \frac{1}{R}\sum_{J=1}^{R}(y_j^2)$$

y_j = output characteristics,
R = number of trials
MSD = mean square deviation.
It has three approaches to take, which are "Larger is the best", "Nominal is the best and "Smaller is better". Since we require minimizing the surface roughness, and improving the quality characteristic of the specimen, "Lower the better" approach is chosen.

3. Experimentation

The material selected for the study was P20 tool steel and it is a widely used in today's manufacturing industries. This material has major applications in Plastic moulds, Precision plastic moulds, Backers, Bolsters and Dies holders. Table 1 shows the composition of P20 tool steel.
Taguchi's L9 Orthogonal array was selected for the study, process parameters of the sprint cut Wire EDM were chosen with the help of Ishikawa cause and effect diagram. All the parameters, which affect the output response (surface roughness in this case), were listed out,

Table 1: Composition of P20 tool steel

Element	C	Cr	Fe	Mn	Mo	P	Si	S
Percentage	0.28	1.4	96.91	0.6	0.35	0.03	0.4	0.03

and major causes were selected as the main parameters. Therefore, Pulse off time, Pulse on time, Peak Current and Wire Tension were selected as the major parameters. Pilot Experiments were conducted on the test specimen and three levels of the parameters were calculated and are tabulated in Table 2.

Table 2: Different levels for each Process Parameters

Level	**Pulse on Time**	**Pulse Off Time**	**Peak Current**	**Wire Tension**
Units	**Micro Seconds (µs)**	**Micro Seconds (µs)**	**Amperes(A)**	**KgF**
1	124	48	10	7
2	125	49	11	8
3	126	50	12	9

The setting of the profile of the cut in the machine was fed into the machine, the profile of which is shown in the figure 1.The Experimentation was done by considering different levels of input parameters and nine trial experiments were performed on the P20 Tool steel specimen which is shown in figure 2 and the cut specimens are shown in figure 3.

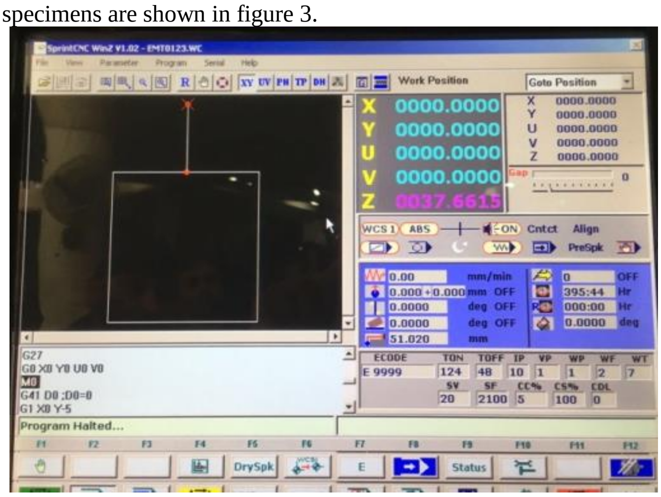

Fig 1: Profile of the workpeice to be machined

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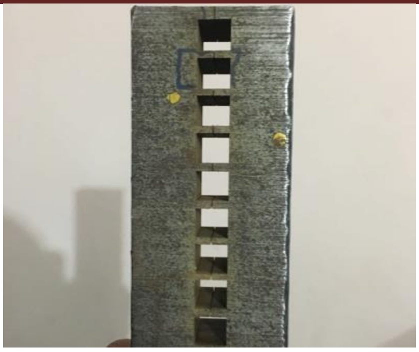

Fig 2: Machined Workpice

Fig 3: Cut Specimens

The experiments were conducted according to the above values of each parameter, and surface roughness for each machined specimen was recorded using Mitutoyu Surftest SJ210. Table 3 shows the L9 Orthogonal array which is used for the Experimentation.

Table 3: L9 Orthogonal Array

Trial Run	Pulse on Time (A)	Pulse off Time (B)	Peak Current (C)	Wire Tension (D)	Average Value of Surface Roughness
1	124	48	10	7	4.363
2	124	49	11	8	3.846
3	124	50	12	9	4.196
4	125	48	11	9	4.256
5	125	49	12	7	4.42
6	125	50	10	8	3.833
7	126	48	12	8	4.713
8	126	49	10	9	3.903
9	126	50	11	7	3.593

Table 4: Response Table for S/N Ratio Plot

LEVEL	A	B	C	D
1	-12.32	-12.95	-12.10	-12.27
2	-12.39	-12.15	-11.80	-12.28
3	-12.14	-11.75	-12.94	-12.29
DELTA	0.25	1.20	1.15	0.02
RANK	3	1	2	4

Table 5: Response Table for Means Plot

LEVEL	A	B	C	D
1	4.136	4.444	4.033	4.126
2	4.170	4.057	3.899	4.131
3	4.070	3.874	4.443	4.119
DELTA	0.100	0.570	0.544	0.012
RANK	3	1	2	4

4.Results and Discussions

After the experimentation at different levels of process parameters, the signal to noise ratio was calculated. The response table for Signal to noise ratio is represented in the table 4. The table of means of the responses at different levels was also calculated and is tabulated in table 5.

Further, using the Minitab software, the Main effects plot for signal to noise ratio and Data means have been plotted. Figure 4 and Figure 5 represents the Main effects plots for Signal to Noise ratio and Data means respectively.

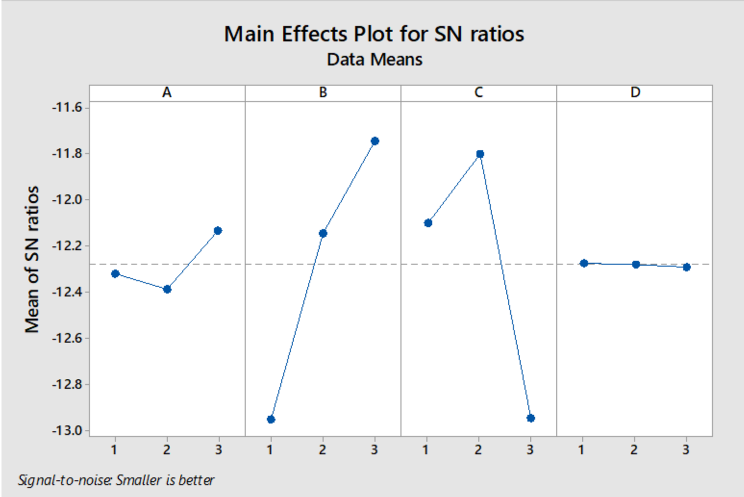

Fig.4: Main Effects Plots for S/N ratio

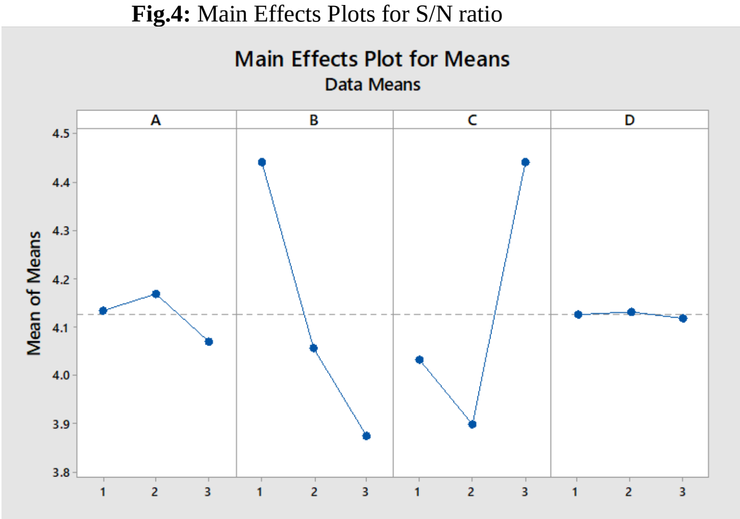

Fig. 5: Main Effects Plot for Means

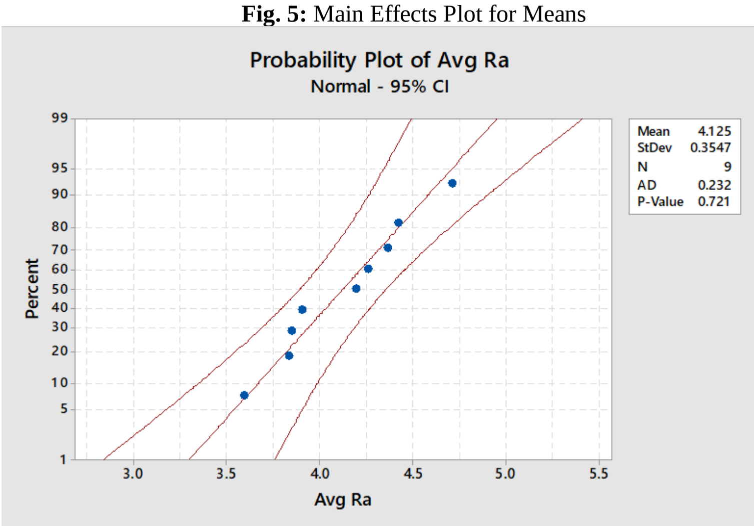

Fig.4: Probability plot for Surface Roughness Values

From the above response table and S/N ratio plot, the point of consideration is the maximum values or the peak values for each parameter, as they are suitable for calculating the minimum surface roughness. Therefore, from the S/N plot, we infer that Factor A (Pulse on time) is maximum at third level, Factor B (Pulse off time) is maximum at the third level, Factor C (Peak Current) is maximum at the second level and Factor D (Wire Tension) is maximum at the first level. Therefore, we can conclude that, the optimum levels for each parameter obtained are A_3, B_3, C_2 and D_1 respectively.

Also, to check whether the output data (surface roughness), so obtained is normally distributed or not, probability plot up to 95% confidence interval was plotted. The middle line represents an almost linear relationship and all the values fall within the 95% Confidence Intervals. It can also be inferred that, there is no sudden increase or decrease in the surface roughness values, as these values fall closely to the line of zero, hence representing an almost linear relationship. Figure 6 represents the Probability plot for the surface roughness values.

4.1analysis of Variance

Analysis of variance, often abbreviated as ANOVA, is a statistical technique, which is used to find the significance or contribution of each factor towards surface roughness in the context of this research analysis. ANOVA is performed using Minitab'17 software and General Linear Model is used for the same, with each factor having a DOF as 2. The ANOVA table is shown in table 6.

Table 6: ANOVA Table

Source	DOF	Seq. SS	Adj. SS	Adj. MS	P-Value (%)
A	2	0.01548	0.015484	0.007742	1.54
B	2	0.50848	0.508477	0.254238	50.51
C	2	0.48260	0.482595	0.241298	47.93
D	2	0.00022	0.000225	0.000112	0.02
Error	0	-	-	-	-
Total	8	1.00678			100

Where, DOF represents Degree of freedom, Seq.SS represents sequential Sum of squares ,Adj.SS represents Adjusted Sum of squares and Adj.MS represents Adjusted Mean squares.

The optimum levels of each process parameter is listed in the below table-7.This shows that the high level of Pulse on time, high level of Pulse off time, Medium level of Peak Current and low level of wire tension will be the optimum setting of the machine to obtain the minimum surface roughness.

Table 7: Optimum Levels and Values for process parameters

Process Parameter	Optimum Level	Value
Pulse On Time	3	126
Pulse Off Time	3	50
Peak Current	2	11
Wire Tension	1	7

Now the theoretical value of Surface Roughness can be calculated with the help of the equation 2

$$Y_{th,\,opt} = T_{mean} + (A_3 - T_{mean}) + (B_3 - T_{mean}) + (C_2 - T_{mean}) + (D_1 - T_{mean}) \quad (2)$$

Where,

$Y_{th,\,opt}$ = Theoretical Optimized Surface Roughness,

T_{mean} = Mean of Average Roughness = 4.125185,

$A_3 = 4.070$,

$B_3 = 3.874$,

$C_2 = 3.899$,

$D_1 = 4.126$

Note that the values of above factors at their optimum levels are taken from the Response Table for Means plot (Table 5).

Now, putting the values of each term in the above equation, we get,

$Y_{th,opt} = 4.125185 + (4.070 - 4.125185) + (3.874 - 4.125185) + (3.899 - 4.125185) + (4.126 - 4.125185)$

$Y_{th,opt} = 3.593445$ µm

Thus the Theoretical Optimized Surface Roughness value obtained is 3.593445 µm.

4.2 Confirmation Experiment

A confirmation experiment was conducted, in order to validate the accuracy of the above optimization analysis. The experiment was carried out on the optimal parametric settings, which were obtained from above S/N ratio analysis. A specimen was machined using the optimal settings, and the surface roughness for the same was measured using Mitutoyo SurfTest SJ 201. Three values for surface roughness were recorded, and the average was then computed. The average surface roughness value came out to be 3.634 µm. This value when compared to the theoretical optimized value generated an error of only 0.86%, which further validates our experiment.

5.Conclusions

Experimental analysis on P20 tool steel is done on SprintCut Wire EDM using brass wire of 0.25 mm diameter. The analysis involves several conclusions, which have been listed as follows:

- The Optimum values for obtaining minimum surface roughness were found to be as follows: Pulse on time, Pulse off time, Peak Current and Wire Tension are 126 µs, 50 µs, 11 A and 7 kgf respectively.
- Pulse off time and Peak Current came out to be the most significant factors, followed by Pulse on time and Wire Tension. Pulse off time was the major contributor, with the % contribution of 50.51.
- The confirmation experiment validated the optimization analysis, with an error of only 0.86%.

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