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Optimization of Process Parameters in Wire Cut EDM of Mild Steel and Stainless Steel using robust design

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Abstract : Mild steel and stainless steel are difficult to machine in traditional machining method. Wire cut electrical discharge machining (WEDM), a hybrid manufacturing technology which enables machining of all engineering materials. This research article deals with the investigation on optimization of the process parameters of the wire cut EDM of mild steel and stainless steel. material removal rate, surface roughness, were studied against the wire cut EDM process parameters, such as pulse on, voltage and wire feed rate. A regression model was obtained for material removal rate and surface roughness. Thus, the machining parameters for WEDM were optimized for achieving the combined objectives of a higher rate of material removal and lower surface roughness value of the work material considered in this work. The obtained results show that the Taguchi's robust design analysis is being an effective technique to optimize the machining parameters for the WEDM process.
Keyword : mild steel, stainless steel, WEDM, Taguchi, material removal rate, surface roughness.

1. Introduction

The electrical discharge machining (EDM) is a thermo-electric non-traditional manufacturing process, which is gaining popularity, since it does not require cutting tools and allows machining involving hard, brittle, thin and complex geometry [1]. Proper selection of process parameters is essential to obtain good surface finish and higher Metal removal rate (MRR)[2-3]. In setting the machining parameters, particularly in rough cutting operation, the goal is the maximization of MRR, minimization of Surface finish. With a view to alleviating this difficulty, various investigations have been carried out by several researchers for improving theselection of optimal parametric values for the MRR and Surface finish[4-5]. However, the problem of selection of machining parameters is not fully depending on machine controls rather material dependent. To improve manufacturing processes with single performance characteristic, the optimal selection of process parameters, Taguchi method has been extensively adopted[6-7].To minimize the overall product-development cycle time, it is vital to have a new approach in developing a family of products, rather than a single product at a time. It was reported that the so called "robust technology development" recently developed and promoted by Dr.Genichi Taguchi and is a powerful approach towards process and product development[8-10]. Surface roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion [11-12].

Multiple regression models were used torepresent the relationship between the input and output variables process, to optimize theWEDM process [13]. The optimized machine parameter settings clearly improve quality characteristics of the machined workpiece compared to the quality levels achieved for initial machine parameter settings. Consideration on pulse ON time, voltage and wire feed rate which have good effects on Metal removal rate (MRR) and Surface roughness (SR) [14]. Increase in pulse on and adecrease in pulse off which improves the surface roughness response.Wire feed and wire tensions have no effect on MRR [15-17].

In the present work, a simple but reliable method based on statistically designed experiments has suggested the optimization of theWEDM process for machining of mild steel and stainless steel using robust design method to achieve higher Material Removal Rate (MRR) and lower surface roughness (Ra). Hence, the purpose of this study is an attempt to apply a “robust technology development” approach of Taguchi method for optimizing the WEDM machining process so as to achieve the above goals.

2. Materials And Method

The mild steel of grade AISI 1015 and Stainless steel of grade AISI 202J1 were chosen for this study. The chemical compositions of the materials are given in Table 1.

Table 1: Chemical composition of the materials

Chemical composition of mild steel (AISI 1015)		Chemical composition of stainless steel (AISI 202J1)	
Elements	**percentage**	**Elements**	**Percentage**
Carbon	0.17	Carbon	0.15
Silicon	0.39	Manganese	7.5
Manganese	0.75	Phosphorus	0.06
Sulphur	0.04	Cr	16
Phosphorus	0.04	Ni	4
Ferrous	rest	Ferrous	rest

Job size acceptable of this machine are 400mm×500mm×200 mm, max taper cutting angle is ±30º on 50 mm job, wire which is made up of brass and its diameter is 0.25mm, maximum cutting speed is 120 mm/min,axis of this machine are X,Y direction, De-ionized water is used as dielectric medium. Pulse of time gets fixed constant 8 µs while machining.

The process parameters such as Pulse on,Voltage, Wire feed rate were selected for the machining of mild steel and stainless steel. Table 2 shows the process parameter and their levels.

After machining the samples were taken to analyze MRR and Surface roughness. The material removal rate (MRR) for Wire cut EDM is calculated by using the equation(1),

$$MRR = F \times D_w \times H \quad (1)$$

Where,
F is the machine feed rate (mm/min),
$D_w$is wire diameter (mm),
H is the thickness of the workpiece (mm).

The average surface roughnesses (Ra) of the machined samples were measured by using Mitutoyo SJ-310 surface roughness measurement device. The measurement was taken at a distance of 5 mm from top, middle, thebottom of the cut surface. Each test was carried out trice and the averages of the result are taken for the study.

Table 2: Parameters and their levels

Sl. No.	Parameter	Symbol	Units	Level 1	Level 2	Level 3
1	Pulse ON	A	µs	4	5	6
2	Voltage	B	V	50	60	70
3	Wire feed rate	C	m/min	2	4	6

3. Results and Discussions

3.1 Responses for the experiment sets

The machinability of the mild steel and stainless steelis prepared and the test was conducted. The results of responses are reported here. This includes material removal rate and surface roughness.

3.2 Material removal rate

The material removal rate which controlled mainly by apulse ON, voltage, wire feed rate. Observation from the Figure 1, 2 indicates the material removal rate varied with different level of theprocess parameter. Clear to see that material removal get increased by increasing pulse on time and decreasing voltage and wire feed rate for mild steel and stainless steel.

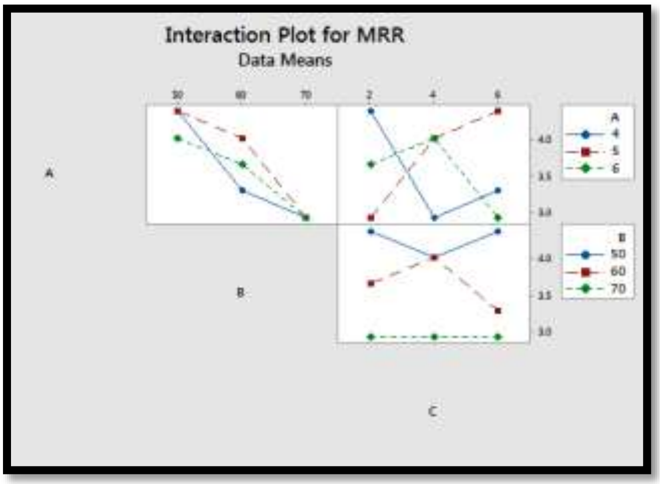

Figure 1: Interaction plot for MRR Vs Process parameter for mild steel

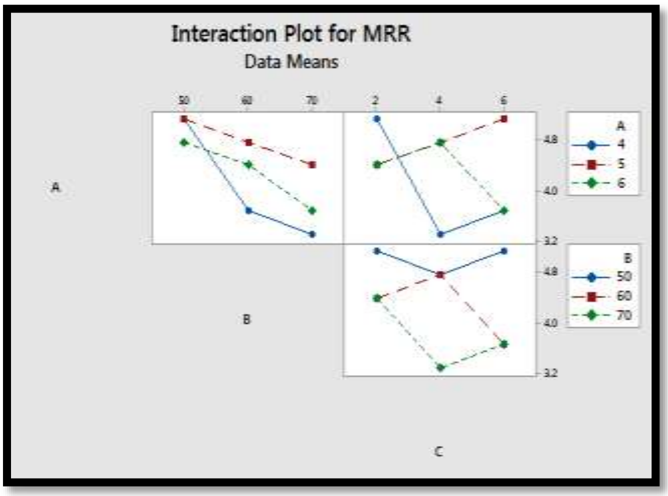

Figure 2: Interaction plot for MRR Vs Process parameter for stainless steel

3.3 Surface Roughness (Ra)

Surface roughness specifies the state of themachined surface. Observation of Figure 3, 4 indicates a surface roughness minimized by increasing pulse voltage and wire feed rate.

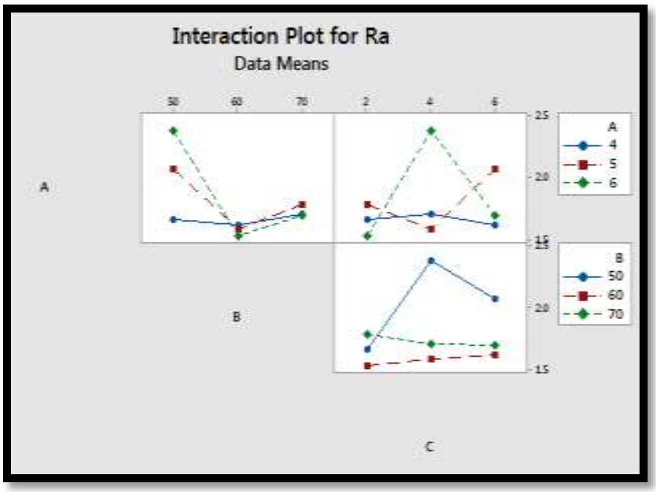

Figure 3: Interaction plot for Ra Vs Process parameter for mild steel

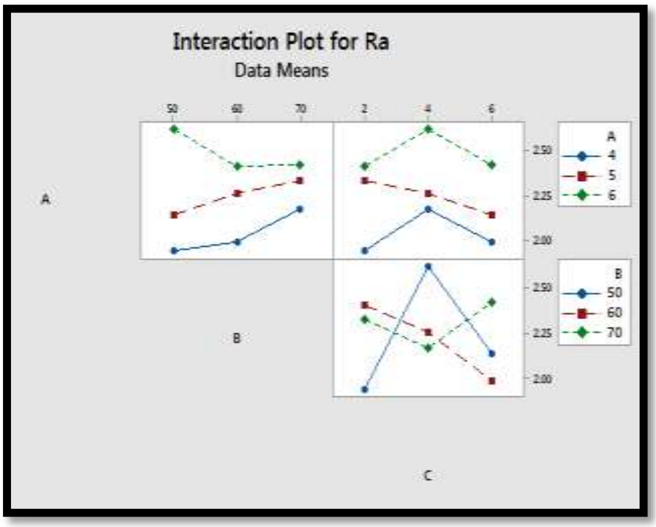

Figure 4: Interaction plot for Ra Vs Process parameter for stainless steel

3.4 Design of experiment

The overall objective of the method is to produce ahigh-quality product at low cost to the manufacturer. The experimental design proposed by using anorthogonal array to organize the process parameter with a minimum number of thetrail, which helps to save time and resources. Analysis of variance which helps to select new parameter values to optimize the performance of machining.

3.5 Delta Rank experimental analysis

Taguchi'sexperimental analysis is made using the statistical software specifically used for thedesign of experiment application known as MINITAB 17. It is used to predict the optimum value.

Table 3: Delta rank for material removal rate for Mild steel

Level	Pulse ON (µs)	Voltage (V)	Wire feed rate (m/min)
1	10.846	12.601	11.151
2	11.427	11.241	11.175
3	10.900	9.331	10.846
Delta	**0.581**	**3.270**	**0.329**
Rank	**2**	**1**	**3**

Table 4: Delta rank for material removal rate for stainless steel

Level	Pulse ON (µs)	Voltage (V)	Wire feed rate (m/min)
1	11.94	13.98	13.30
2	13.53	12.56	12.48
3	12.56	11.49	12.24
Delta	**1.59**	**2.49**	**1.06**
Rank	**2**	**1**	**3**

Table 3,4 shows delta rank for material removal rate for mild steel and stainless steel respectively. Delta rank mainly hires the preference and gives the rank based upon the performance or contribution of the machining process parameters.

Table 5: Delta rank for Surface roughness for Mild steel

Level	Pulse ON (µs)	Voltage (V)	Wire feed rate (m/min)
1	-4.435	-6.102	-4.402
2	-5.135	-3.971	-5.406
3	-5.278	-4.775	-5.040
Delta	**0.843**	**2.131**	**1.005**
Rank	**3**	**1**	**2**

Table 6: Delta rank for Surface roughness for stainless steel

Level	Pulse ON (µs)	Voltage (V)	Wire feed rate (m/min)
1	-6.154	-6.910	-6.914
2	-7.013	-6.900	-7.392
3	-7.984	-7.251	-6.754
Delta	**1.740**	**0.351**	**0.639**
Rank	**1**	**3**	**2**

Table 5,6 shows the delta rank for surface roughnessof the analysis results of the machined samples of mild steel and stainless steel respectively. Delta rank mainly hires the preference and gives the rank based upon the performance or contribution of the factor.

3.6 Effect of Signal noise ratio

The experimental data are further transformed into asignal to noise (S/N) ratio analysis. There are several ratios available depend upon the type of responses. Lower the better (LB), Nominal the best (NB), higher the better (HB). Sohigher the better(HB) is preferred for MRR analysis and Lower the better (LB) is preferred for surface roughness analysis.

Table 7: S/N ratio for output response for Mild steel

Run	S/N ratio of MRR in dB	S/N ratio of Ra in dB
1	12.8532	-4.45433
2	10.3545	-4.19030
3	9.3314	-4.65992
4	12.8532	-6.31941
5	12.0975	-4.02794
6	9.3314	-5.05706
7	12.0975	-7.53154
8	11.2696	-3.69383
9	9.3314	-4.60898

Table 8: S/N ratio for output response for Stainless steel

Run	S/N ratio of MRR in dB	S/N ratio of Ra in dB
1	14.1922	-5.75603
2	11.2696	-5.97706
3	10.3545	-6.72919
4	14.1922	-6.60828
5	13.5485	-7.08217
6	12.8532	-7.34712
7	13.5485	-8.36603
8	12.8532	-7.64034
9	11.2696	-7.67631

Table 7, 8showsthe Signal to Noise (S/N) ratio for the output responses in dB.This signal to noise ratio which used to analysis the main effects plots for MRR and surface roughness.

3.7 Analysis of optimum value through S/N ratio for the output responses

In order to obtain the effect of control factors on response factors for each different level, the S/N values of each control factors and the level of each response factor are summed up. Figure 5,6, show the average response for MRR for mild steel and stainless steel and Figure7, 8shows the average response for Ra for mild steel and stainless steel.

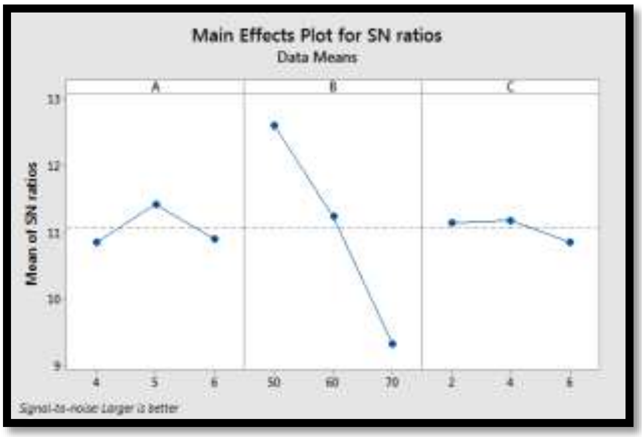

Figure 5:Main effect plot of S/N ratios for MRR (Mild steel)

From Figure 5, the observed optimum values for maximum material removal rate are A2B1C1 for MS.

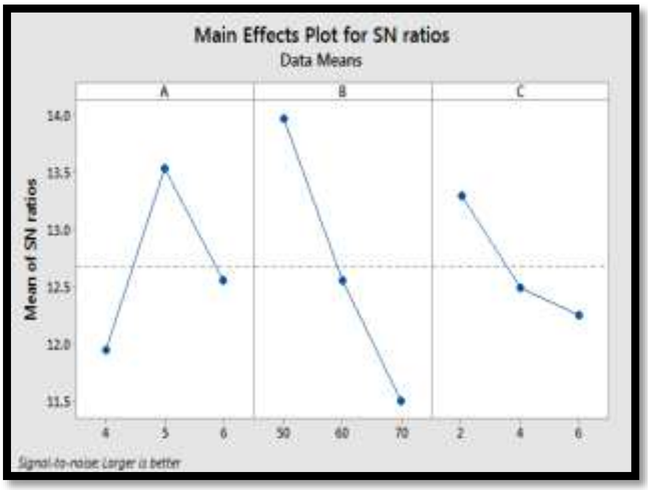

Figure 6:Main effect plot of S/N ratios for MRR (Stainless steel)

From Figure 6, the observed optimum values for maximum material removal rate are A2B1C1 for SS.

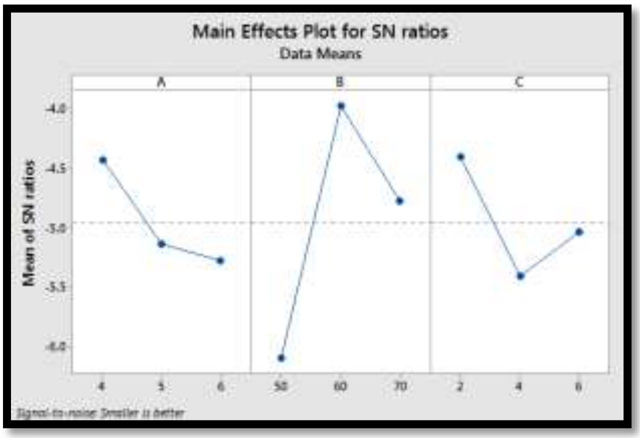

Figure 7:Main effect plot of S/N ratios for surface roughness (mild steel)

From Figure 7, the observed optimum values for minimum surface roughness areA1B2C1.

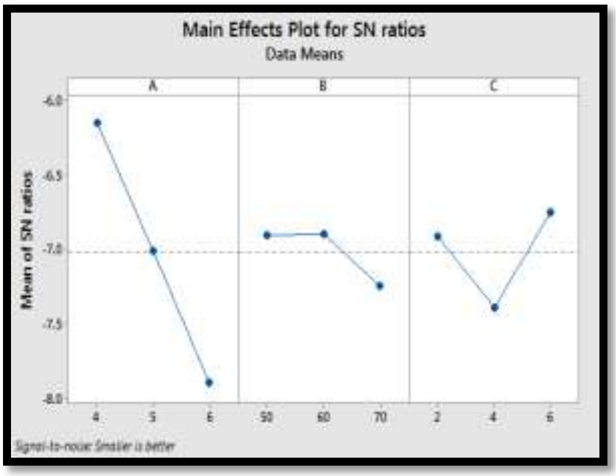

Figure 8:Main effect plot of S/N ratios for surface roughness (stainless steel)

From Figure 8, the observed optimum values for maximum material removal rate are A1B2C3 for SS.

Table 9: Optimum parameters from main effect plot of S/N ratio for mild steel

Parameters	MRR	Ra
Pulse ON(μs)	5	4
Voltage(V)	50	60
Wire feed rate (m/min)	2	2

Table 9shows the optimum parameters for material removal rate and surface roughnessfor mild steel.

Table 10: Optimum parameters from main effect plot of S/N ratio for stainless steel

Parameters	MRR	Ra
Pulse ON(μs)	5	4
Voltage (V)	50	60
Wire feed rate (m/min)	2	6

Table 10 show the optimum parameters for material removal rate and surface roughness for stainless steel.

3.9 Regression equations

Material removal rate (MRR for MS) = 7.767+0.000*Pulse on – 00.0671*Voltage – 0.0305 Wire feed rate.
Surface roughness (Ra for MS) = 2.063+0.102*Pulse on – 0.0153*Voltage + 0.0333 Wire feed rate.
Material removal rate (MRR for SS) = 7.89+0.122*Pulse on – 0.0610*Voltage – 0.1220 Wire feed rate.
Surface roughness (Ra for SS) = 0.952+0.2250*Pulse on – 0.00367*Voltage – 0.0108 Wire feed rate.

4. Conclusion

In this research work optimum parameters of material removal rate and surface roughness of the mild steel and stainless steel machining using WEDM was studied. Experiments were conducted with different process parameters for the determination of optimum condition. The following conclusions were drawn;

- This work proves that the voltage plays an important role for material removal rate and surface roughness.
- The increase in pulse ON time with minimum voltage and wire feed rate leads to increases in material removal rate. The optimum value is A2B1C1 for mild steel and A2B1C1 for stainless steel.
- The increase in voltage and wire feed rate leads to improved surface roughness of the machined components. The optimum value is A1B2C1 for mild steel and A1B2C3 for stainless steel.

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