MATHEMATICAL MODELING OF MATERIAL REMOVAL RATE OF T90Mn2W50Cr45 TOOL STEEL IN WIRE ELECTRICAL DISCHARGE MACHINE

S. Rajendran¹ and K. Marimuthu²

¹Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore 641 049, INDIA
²Department of Mechanical Engineering, Coimbatore Institute of Technology, Coimbatore – 641 014, INDIA
*Corresponding author’s E-mail: methermal2005@gmail.com

Received 13 March 2012, Accepted 20 December 2012

ABSTRACT

The present study aims to develop a mathematical model so as to predict material removal rate using response surface methodology in a wire cut electrical discharge machine. In order to establish a mathematical model concerning process parameters and material removal rate, a central composite rotatable design matrix is employed. It includes four variables with five levels. Moreover, the process parameters such as Pulse; on time, off time, peak current, and wire tension are changed accordingly in the process of the experiments. A comparative study is made between the theoretically predicted values of material removal rate and the observations from the experiment. Both the experimental and predicted values are found to be concomitant.

Keywords: Wire electrical discharge machining, Response surface methodology, Central composite design, Analysis of variance.

1. INTRODUCTION

The wire cut electrical discharge machining is administered to machine hard materials that are electrically conductive. It is a burgeoning non-conventional machining process which is known for its high precision. In this process, material removal is achieved by executing a sequence of separate electrical discharges between the wire electrode and the work piece. The dielectric medium determines the discharges, in order that the temperature of the work piece increases only during the time of contact (Lee and Li, 2003). MRR amplifies correspondingly with the peak current when compared with the pulse-on time and pulse-off time. The peak current was the crucial aspect that affects the MRR and surface finish for both finishing and roughing operations (Jaharah et al., 2008). A mathematical model was developed so as to envisage the material removal rate. Scanning Electron Microscope (SEM) is used to analyse the surface integrity and roundness of cylindrical wire electrical discharge turning process. Brass and carbide were used as a work material (Jun et al., 2002a and 2002b). The temperature increases makes the exposed area of the electrical discharges to melt and vaporize. The important response of the method was the material removal rate (Salonitis et al., 2009). The surface roughness and cutting geometry of tungsten carbide was prefigured using Multi variable regression model and back propagate on neural network model(Panda and Bhoi, 2005; Pradhan and Biswas, 2010). Saha et al. (2008) studied the correlation between the criterions like pulse on time, pulse off time, peak current was estimated using second order multi-variable regression model. It was concluded that material removal mechanism is governed by sparks, making it too stochastic. Various sub factors related to wire electrical discharge machine process were considered and machining performance with different materials was evaluated (Saha et al., 2008; Liu et al., 2003; Lee and Li, 2001; Ndaliman et al., 2011). Influence of various process parameters on material removal rate, electrode wear rate and surface roughness were calculated with different materials (Puertas et al., 2004; Kao et al., 2010; Yanda et al., 2010). Higher concentration of SiC powder (above 20g/l) tends to increase the surface roughness. SiC powder concentration, with in the experimental range, is found to slightly reduce MRR and EWR compared to machining without SiC powder. The ANOVA revealed that powder concentration is the most influential parameter on surface roughness, than on MRR and EWR. The quadratic term of the factors also has significant effect (Ali et al., 2011).

The experiment was done on ONA R250 WIRE EDM machine. Moreover, the responses were checked experimentally and by using ANOVA, mathematical expression is found out. The results concluded that only power affects surface roughness and no factor affects roundness. Power, wire speed, voltage, wire tension, time-off, servo, and rotational speed are some factors affecting the surface roughness. Among these, wire speed, power, and servo on roundness are significant agents (Mohammadi et al., 2008). Taguchi method was used to optimize the wire electrical discharge machining process parameters and abrasive hot air jet machining processes (Mahapatra and Patnaik, 2007; Jagannatha et al., 2012). Taguchi’s robust design approach was used for wire electrical discharge machine (WEDM). The parameter includes pulse on time, wire tension, delay time, wire feed speed, and ignition current intensity. The responses like material removal rate, surface roughness, and wire wear ratio were consulted for every testing. Heat treated tool steel was used as the work piece. It was found out that increase in pulse on time further than level three enhances the surface roughness and wire wear ratio in consequence of greater discharge energy. Increase in wire tension causes wire breakage (Ramakrishnan and Karunamoorthy, 2006). The white layer depth increases with increasing pulse on time during the initial cut. It also decreases with increasing pulse on time during trim
cubic. Break even trim cutting speed is detected to be 3
mm/min (Puri and Bhattacharyya, 2005). In this
presentation, process parameters were maximized by
response surface methodology so as to predict the
material removal rate (Kansal et al., 2005). Variations in
material removal rate (MRR), surface roughness (Ra) and
corner deviation (CD) were analyzed for wire electrical
discharge machine (WEDM) process with pure tungsten
as work material. A fusion technique that comprise
response surface methodology (RSM) and back-
propagation neural network (BPNN) integrated simulated
annealing algorithm (SAA) was used. Higher pulse on
time caused the high MRR but at same time it produced
rough surface (Yang et al., 2012). Already some study
has been carried out in developing a mathematical model
and to analyze the wire cut electrical discharge
machining process to predict the efficiency in terms of
material removal rate. In the present study, a
mathematical model has been formulated in order to
calculate the material removal rate by means of response
surface methodology. Analysis of variance is applied to
validate the model.

2. RESPONSE SURFACE METHODOLOGY

The response surface methodology (RSM) is a set of
Mathematical and statistical techniques that are valuable
to model the relationship among response and the crucial input features. Based on the
model, a near optimal point can be construed. It is
frequently executed in the characterization and
optimization of processes. The mathematical model used is:

\[ Y = f(t_{on}, t_{off}, I_p, W_T) + \varepsilon \]  

(1)

where, 
\[ Y \] = machining response 
\[ t_{on} \] = pulse on time
\[ t_{off} \] = pulse off time
\[ I_p \] = peak current
\[ W_T \] = wire tension
\[ \varepsilon \] = fitting error.

The quadratic equation for a nonlinear relationship
between a specific response and four independent
process parameters can be given as

\[ Y = b_0 + b_1 t_{on} + b_2 t_{off} + b_3 I_p + b_4 W_T + b_5 t_{on}^2 + b_6 t_{off}^2 + b_7 I_p^2 + b_8 W_T^2 + b_9 t_{on} t_{off} + b_{10} t_{on} I_p + b_{11} t_{on} W_T + b_{12} t_{off} I_p + b_{13} t_{off} W_T + b_{14} I_p W_T + \varepsilon \]  

(2)

The aforementioned equation is applied to explain
the functional relationship among the machining response. Y
\[ X_1, X_2, X_3, \] and \[ X_4 \] coded values of input process
parameters pulse on time, pulse off time, peak current,
and wire tension, respectively. The coefficient, \[ b_0, b_1, b_2, b_3, \] and \[ b_4 \] etc. are to be estimated by the method of least
squares. The calculated coefficients of the equation (2)
need to be tested for statistical significance.

3. EXPERIMENTAL DETAILS

With the intention of developing a model based on
experimental data, meticulous examination of the
experiment is indispensable. Pulse on time, pulse off
time, peak current, and wire tension were the parameters
acknowledged for experimentation and analysis of wire
cut electrical discharge machining of T90Mn2W50Cr45
tool steel.

3.1 Experimental design matrix

Properly prepared design matrix can considerably
decrease the number of experiments. Hence, it is
necessary to develop a good design matrix to conduct
the procedures. Table 1 illustrates the range of values of each
factor that are chosen based on pilot experimentation set
at five diverse levels

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_1) : Time on (µs)</td>
<td>105 - 125</td>
</tr>
<tr>
<td>(X_2) : Time off (µs)</td>
<td>43 - 63</td>
</tr>
<tr>
<td>(X_3) : Peak Current (A)</td>
<td>150 - 230</td>
</tr>
<tr>
<td>(X_4) : Wire Tension (g)</td>
<td>4 - 10</td>
</tr>
</tbody>
</table>

(\(t_{on}\) - Pulse on time(µs); \(t_{off}\) - Pulse off time(µs),
\(I_p\) - Peak Current (A); \(W_T\) - Wire Tension (g))

The selected design matrix is a central composite
rotatable, four factor and five level factorial design
comprising 31 set of coded conditions and composing a
complete duplication of \(2^4 = 16\) full factorial design for
determination of features each at five levels with 16 cube
points in addition to eight start points and seven
replicated at centre points. All the wire cut electrical
discharge machining process attributes at the
intermediate (0) level constitute the centre points while
the blend of each process parameters at either its lowest
value or its highest value ± 2 with the other parameters of
the intermediate levels form the star points. Therefore,
the 31 experiments authorized the evaluation of the
linear, quadratic and two way interaction outcomes of
the wire cut electrical discharge machining variables on the
material removal rate (Cochran and Cox, 1965). The
subsequent transforming equation is used to get the
coded values of variables used in Eq. (2)

\[ X_i = \frac{\text{Chosen parametric value - Central rank value}}{\text{Incremental parametric value}} \]  

(3)

Where \(X_i\) is coded value of pulse on time \((t_{on})\), \(X_2\) is the
coded value of pulse off time \((t_{off})\), \(X_3\) is the coded value of
peak current \((I_p)\), and \(X_4\) is the coded value of wire
tension \((W_T)\).

3.2 Experimental set up

An “ELETRA SPRINTCUT 734” wire-cut EDM
machine, with a pulse generator, was used for conducting
the experiments. The electrolytic copper wire of diameter
0.25 mm acted as an electrode. For every experiment,
deonized water served the purpose of dielectric fluid.
The T90Mn2W50Cr45 tool steel material (American designation is ASTM O2) of diameter 12 mm and 15 mm length was used as working material in this study. Table 2 illustrates the chemical composition of the work material. The properties of working material are given in Table 3. Photographic view and schematic illustration of experimental set up is given in Figure 1 and Figure 2, respectively.

Table 2 Chemical composition of test specimen (wt %).

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Cr</th>
<th>V</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9</td>
<td>1.5</td>
<td>0.3</td>
<td>0.02</td>
<td>0.02</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3 Properties of T90Mn2W50Cr45 tool steel.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting point (°C)</td>
<td>1370-1400</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>8000</td>
</tr>
<tr>
<td>Thermal conductivity (W/m.K)</td>
<td>16-16</td>
</tr>
<tr>
<td>Electrical resistivity (Ω.mm²/m)</td>
<td>0.7</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>16-17 x 10^-6/K</td>
</tr>
<tr>
<td>Ultimate tensile strength (MPa)</td>
<td>1158</td>
</tr>
<tr>
<td>Hardness (HB)</td>
<td>335</td>
</tr>
</tbody>
</table>

Figure 1 T90Mn2W50Cr45 tool steel material mounted on WEDM.

3.3 Experimental procedure

The T90Mn2W50Cr45 tool steel material of 15 mm length and 12mm diameter size for each specimen is mounted on the ELETRA SPRINCUT 734” wire-cut EDM machine. The experiments were conducted in 31 runs for diverse mixture of process aspects as given in Table 4.

Figure 2 Schematic diagram of WEDM process.

After machining, the material removal rate was measured. The following formula is used for calculating the material removal rate:

\[ MRR = \frac{W_i - W_f}{t} \]  \hspace{1cm} (4)

Where \( W_i \) was the final machining weights of work piece material and \( W_f \) was the initial machining weight of the work piece material, respectively. ‘t’ refers to the machining time. The weight of the work piece materials are measured by an electronic weighing machine.

4. RESULTS AND DISCUSSION

The pulse on time, pulse off time, peak current and wire tension were independent variables considered for the prediction of Y response. Based on the independent process parameters, their levels were calculated. The range of values of process parameters for each of the experiments are given in Table 4. The predictable coefficients obtained are employed to generate the model for the response consideration. The full form of the desired mathematical model is given as:

\[ MRR = -8.6 + 0.040 X_1 + 0.034 X_2 + 0.0622 X_3 - 0.468 X_4 + 0.000290 X_1^2 X_1 + 0.000455 X_2 X_3 - 0.000028 X_1^2 X_4 + 0.00847 X_1 X_4 + 0.000075 X_2^2 X_3 - 0.000338 X_1^2 X_3 - 0.00048 X_1^2 X_4 - 0.000473 X_2^2 X_3 + 0.00150 X_1^2 X_4 + 0.00150 X_2^2 X_4 \]  \hspace{1cm} (5)

4.1 Scrutinizing the adequacy of the model expounded

The adequacy of the model is checked by means of the analysis of variance (ANOVA) technique. In this way, if the calculated \( F \)-ratio of the developed model did not exceed the standard tabulated values of \( F \)-ratio for desired level of confidence (92% for material removal rate) the model is deemed to be within the confidence level. Table 5 elucidates the ANOVA table for material removal rate. Some of the P-values for different set of analysis in Table 5 are less than 0.05 (given as superscript *). Those sets of analyses are significant. Also, the mean effect of linear factor pulse on time \((X_1)\) is significant. The model contain a square effect of wire tension \((X_2)\) are significant. The P-value of wire tension 0.023 is below 0.05 for material removal rate. In addition the model contains a single, two way major interaction (pulse off time x peak current) and (peak current x wire tension). The P-values of 0.018 and 0.004 for pulse off time x peak current, and peak current x wire tension respectively are less than 0.05 for response. From the above analysis it is understood that peak current \((X_3)\) as a linear factor is not significant. When combined with pulse off time \((X_2)\) and with the wire tension \((X_4)\), the analyses become significant. The interaction of parameters \((X_3 \) and \(X_4)\) is relatively essential for material removal rate. Other model terms may be considered insignificant for material removal rate prediction. These insignificant model terms can be eliminated and it may emanate as an enhanced model. The Eq. (5) is reduced to Eq. (6), which is the final empirical model for material removal rate.

\[ MRR = -8.6 + 0.040 X_1 - 0.468 X_4 + 0.000473 X_2^2 X_3 + 0.000150 X_2^2 X_4 \]  \hspace{1cm} (6)

Further, using this model, the experimental and predicted values were plotted in a scatter diagram (Figure 3). The observed values and predicted values of the response were scattered close to the 45° line, indicating an almost
ideal match of the developed model. These figures and ANOVA analysis for material removal rate indicates that the model is extremely convincing and sufficient to embody the actual correlation between the process parameters and response, with very small P value (<0.05) and high values of coefficient of determination ($R^2 = 0.92$).

Table 4 Design matrix and response.

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>$t_{on}$</th>
<th>$t_{off}$</th>
<th>$I_p$</th>
<th>$W_t$</th>
<th>MRR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Observed</td>
</tr>
<tr>
<td>1</td>
<td>120</td>
<td>48</td>
<td>210</td>
<td>6</td>
<td>0.644</td>
</tr>
<tr>
<td>2</td>
<td>110</td>
<td>58</td>
<td>210</td>
<td>10</td>
<td>0.220</td>
</tr>
<tr>
<td>3</td>
<td>110</td>
<td>58</td>
<td>170</td>
<td>10</td>
<td>0.187</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>58</td>
<td>210</td>
<td>6</td>
<td>0.488</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
<td>58</td>
<td>210</td>
<td>6</td>
<td>0.184</td>
</tr>
<tr>
<td>6</td>
<td>120</td>
<td>58</td>
<td>170</td>
<td>6</td>
<td>0.737</td>
</tr>
<tr>
<td>7</td>
<td>110</td>
<td>48</td>
<td>210</td>
<td>6</td>
<td>0.336</td>
</tr>
<tr>
<td>8</td>
<td>120</td>
<td>58</td>
<td>170</td>
<td>10</td>
<td>0.618</td>
</tr>
<tr>
<td>9</td>
<td>120</td>
<td>48</td>
<td>170</td>
<td>10</td>
<td>0.474</td>
</tr>
<tr>
<td>10</td>
<td>120</td>
<td>48</td>
<td>210</td>
<td>10</td>
<td>0.686</td>
</tr>
<tr>
<td>11</td>
<td>110</td>
<td>58</td>
<td>170</td>
<td>6</td>
<td>0.518</td>
</tr>
<tr>
<td>12</td>
<td>110</td>
<td>48</td>
<td>210</td>
<td>10</td>
<td>0.351</td>
</tr>
<tr>
<td>13</td>
<td>110</td>
<td>48</td>
<td>170</td>
<td>6</td>
<td>0.315</td>
</tr>
<tr>
<td>14</td>
<td>120</td>
<td>48</td>
<td>170</td>
<td>6</td>
<td>0.811</td>
</tr>
<tr>
<td>15</td>
<td>110</td>
<td>48</td>
<td>170</td>
<td>10</td>
<td>0.096</td>
</tr>
<tr>
<td>16</td>
<td>120</td>
<td>58</td>
<td>210</td>
<td>10</td>
<td>0.490</td>
</tr>
<tr>
<td>17</td>
<td>105</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.079</td>
</tr>
<tr>
<td>18</td>
<td>115</td>
<td>43</td>
<td>190</td>
<td>8</td>
<td>0.385</td>
</tr>
<tr>
<td>19</td>
<td>115</td>
<td>53</td>
<td>150</td>
<td>8</td>
<td>0.348</td>
</tr>
<tr>
<td>20</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>4</td>
<td>0.584</td>
</tr>
<tr>
<td>21</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>12</td>
<td>0.405</td>
</tr>
<tr>
<td>22</td>
<td>115</td>
<td>53</td>
<td>230</td>
<td>8</td>
<td>0.279</td>
</tr>
<tr>
<td>23</td>
<td>115</td>
<td>63</td>
<td>190</td>
<td>8</td>
<td>0.424</td>
</tr>
<tr>
<td>24</td>
<td>125</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.682</td>
</tr>
<tr>
<td>25</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.352</td>
</tr>
<tr>
<td>26</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.311</td>
</tr>
<tr>
<td>27</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.330</td>
</tr>
<tr>
<td>28</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.345</td>
</tr>
<tr>
<td>29</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.356</td>
</tr>
<tr>
<td>30</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.360</td>
</tr>
<tr>
<td>31</td>
<td>115</td>
<td>53</td>
<td>190</td>
<td>8</td>
<td>0.368</td>
</tr>
</tbody>
</table>

4.2 Testing the coefficients for significance
From the ANOVA Table 5, material removal rate of the regression co-efficient R was 0.959. Calculated value was statistically significant and it was significant at 95% confident level. The values of the regression coefficient give a suggestion to what degree the factors change the response. Unimportant co-efficient can be discarded without renouncing much of the precision to evade unwieldy mathematical effort. For achieving this purpose, t-test and F-tests were used. The statistical software was used to perform the test of significance. For the period of backward steps, a variable was eliminated from the model and for the period of forward steps; a variable is added to the model. Subsequently, to determine the significant coefficient, these coefficients were used to construct the critical models.

Figure 3 Predicted and observed value of material removal rate.

4.3 Effect of working parameters on the material removal rate
Figure 4 demonstrates the variation of material removal rate for the four variables pulse on time, pulse off time, peak current and wire tension on material removal rate. From Figure 4, it was understood that, pulse on time (105-125 µs) is directly proportional to the material removal rate whereas Wire tension (4-12 g) is inversely proportional to the material removal rate.

Figure 4 Main effects plot for material removal rate.

For the variation of Pulse off time (43-63 µs) and peak current (150-230 A), the material removal rate is more or less constant. Figure 5 shows the pictorial representation of effect of pulse on time (105-125 µs) and wire tension (4-12 g) on the material removal rate, when peak current (150-230 A) and pulse off time (43-63 µs) remain
constant. From Figure 5 shows that the material removal rate is low for the lower value of pulse on time and optimized value (9g) of the wire tension. Material removal rate is incredibly high for the lower wire tension and higher pulse on time. It also shows variation of peak current and pulse on time. It also shows Figure 5 establishes the material removal rate for the lower wire tension and wire tension of (7.5 g). Material removal rate is optimum for the optimum values of peak current (200 A) and wire tension of (7.5 g).

Table 5 ANOVA table for material removal rate.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>9</td>
<td>0.9532</td>
<td>0.0680</td>
<td>13.14</td>
<td>0.000*</td>
</tr>
<tr>
<td>X1</td>
<td>1</td>
<td>0.7336</td>
<td>0.7336</td>
<td>141.62</td>
<td>0.000*</td>
</tr>
<tr>
<td>X2</td>
<td>1</td>
<td>0.0088</td>
<td>0.0088</td>
<td>1.71</td>
<td>0.209</td>
</tr>
<tr>
<td>X3</td>
<td>1</td>
<td>0.0027</td>
<td>0.0027</td>
<td>0.52</td>
<td>0.478</td>
</tr>
<tr>
<td>X4</td>
<td>1</td>
<td>0.0504</td>
<td>0.0504</td>
<td>9.73</td>
<td>0.007*</td>
</tr>
<tr>
<td>X1^2</td>
<td>1</td>
<td>0.0065</td>
<td>0.0065</td>
<td>0.10</td>
<td>0.598</td>
</tr>
<tr>
<td>X2^2</td>
<td>1</td>
<td>0.0024</td>
<td>0.0024</td>
<td>0.47</td>
<td>0.411</td>
</tr>
<tr>
<td>X3^2</td>
<td>1</td>
<td>0.0064</td>
<td>0.0064</td>
<td>1.25</td>
<td>0.410</td>
</tr>
<tr>
<td>X4^2</td>
<td>1</td>
<td>0.0328</td>
<td>0.0328</td>
<td>6.33</td>
<td>0.023*</td>
</tr>
<tr>
<td>X1*X2</td>
<td>1</td>
<td>0.000056</td>
<td>0.000056</td>
<td>0.01</td>
<td>0.918</td>
</tr>
<tr>
<td>X1*X3</td>
<td>1</td>
<td>0.0182</td>
<td>0.0182</td>
<td>3.51</td>
<td>0.079</td>
</tr>
<tr>
<td>X1*X4</td>
<td>1</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.06</td>
<td>0.795</td>
</tr>
<tr>
<td>X2*X3</td>
<td>1</td>
<td>0.0357</td>
<td>0.0357</td>
<td>6.89</td>
<td>0.018*</td>
</tr>
<tr>
<td>X2*X4</td>
<td>1</td>
<td>0.0036</td>
<td>0.0036</td>
<td>0.69</td>
<td>0.417</td>
</tr>
<tr>
<td>X3*X4</td>
<td>1</td>
<td>0.0573</td>
<td>0.0573</td>
<td>11.07</td>
<td>0.004*</td>
</tr>
<tr>
<td>Residual Error</td>
<td>16</td>
<td>0.08289</td>
<td>0.005180</td>
<td>0.41</td>
<td>0.900</td>
</tr>
<tr>
<td>Lack-of-Fit</td>
<td>10</td>
<td>0.03350</td>
<td>0.003350</td>
<td>0.41</td>
<td>0.900</td>
</tr>
<tr>
<td>Pure Error</td>
<td>6</td>
<td>0.04938</td>
<td>0.008230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>1.03616</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R^2 = 0.92

Significant

Figure 5 Surface plot of material removal rate vs. pulse on time, wire tension.

Figure 6 establishes the material removal rate for the variation of peak current and pulse on time. It also shows that the material removal rate was low for the optimized value of pulse on time and for the variation of peak current. The material removal rate was high for the maximum pulse on time and for the minimum peak current. According to Figure 7, material removal rate is inversely proportional to the material removal rate whereas Wire tension is directly proportional to the material removal rate.

5. CONCLUSION
The experimental investigation asserts the machining criteria like material removal rate which is influenced by a range of major machining parameters considered in the current research. Response surface methodology adopted in this research has ascertained its adequacy as an efficient means for analysing the machining process. From the study, the subsequent deductions were drawn:

- Peak current and wire tension of the regression models were observed to be greatly important when equated with other parameters. The intended model for material removal rate was considered to be sufficient and can be adopted to envisage the different facets contained by the investigational range.
- In this research paper, wire electrical discharge machining process parameters were optimized by the use of response surface methodology. The material removal rate was investigated experimentally for the variation of pulse on time, pulse off time, peak current and wire tension.
- Pulse on time is directly proportional to the material removal rate whereas Wire tension is inversely proportional to the material removal rate.
• Material removal rate is very high for the lower wire tension and higher pulse on time.
• Material removal rate was optimized at 0.5 for the optimum value of peak current (200 A) and wire tension of (7.5g).
• For the wire tension less than 7.5g material removal rate was high and when more than 7.5g material removal rate remains constant.

REFERENCES