Modeling and Analysis of MRR and SR in EDM of AISI 1020 through RSM

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ABSTRACT

AISI 1020 steel have many potential engineering applications for manufacturing industry. Nowadays there is a critical need for cost-effective machining processes for this material. Not much work hitherto been reported for machining of AISI 1020 steel with Electrical Discharge Machining (EDM) process. In this work, an attempt has been made to model the machinability evaluation through the Response Surface Methodology (RSM) was machined manufactured through stir casting method. The experimental analysis presented in this paper aims at the selection of optimal machining conditions for EDM of AISI 1020 steel. The work piece material has been cleverly considered as control factor along with the combined effect of five controllable input variables namely Peak Current, Discharge Voltage, Pulse on Time, Pulse off Time, Oil Pressure, and its effect on the Surface Roughness and Material Removal Rate has been investigated with the minimum number of experiments. Analysis of variance is performed to get contribution of each parameter on the performance characteristics and it was observed discharge current is the significant process parameter that affects the EDM robustness. The contour plots were generated to study the effect of process parameters as well as their interactions. The experimental results for the optimal setting show that there is considerable improvement in the process. The application of this technique converts the response variable to a single response process, there by parameters are optimized using central composite design based approach RSM and therefore simplifies the optimization procedure. Result of confirmation experiments shows the established mathematical models can predict the output response that will satisfy the real requirement in practice.

KEY WORDS: Steel Material, Optimization, Response Surface Methodology, Surface Roughness, Material Removal Rate, Electrical Discharge Machining.

1. INTRODUCTION

EDM is recently a well-known electrical type unconventional machining process specifically utilized in precise machining for work pieces of intricate shape, as a choice to more traditional approaches and for details concerning the phenomena of the exterior, inherent to this process. The non-conventional techniques of machining encompass numerous explicit benefits compared to conventional machining techniques. And these promise formidable tasks to be undertaken and set a new record in the manufacturing technology whereas these involved techniques are not restricted by material’s toughness, hardness and brittleness producing any complicated shape on any work piece material by a suitable control across numerous process parameters which involve physically.

EDM is a process of thermal erosion where an electrically produced spark vaporizes the material that conducts electrically. Both electrode (tool) and work piece has to be conductive electrically ocuring the spark in a gap occupied with dielectric solution among the work piece and tool. The process removes metal via electrical and thermal energy, having no mechanical contact with the work piece. Its exclusive feature of utilizing thermal energy is machining og parts that conducts electrically without even considering their hardness; its exclusive benefit is in the manufacture of above mentioned modern industry. Additionally, EDM does not create explicit contact among the work piece and electrode, getting rid off mechanical stresses, chatter and vibration problems while machining. Today, an electrode as tiny as 0.1 mm could be utilized in making hole into curved surfaces at steep angles excluding drill and generates the spark because of a gap among a tool and work piece. The smaller the gap produce the better surface roughness.

Probability of estimating a global optimum solution and its preciseness rely on the kind of optimization modeling technique utilized in expressing the objective functions and constraints in terms of the decision variables. Accurate and process reliable models could compensate for inability to entirely understand and often brief the mechanism of process.

Hence, formulation of optimization model is the predominant task in optimization involving expression off optimization problem in a standard format as a mathematical model that could be explicitly resolved by RSM. For process parameters optimization of EDM, type of target function and constraints, number of objective and extend of the importance or priority to be given to objective depend on SR and input parameters namely Peak Current (Ip), Pulse On Time (Ton), Pulse Off Time (Toff), Discharge Voltage, Gap Width and Oil Pressure as input parameters. RSM have been utilized in analyzing the influence of the five input parameters and output parameter of MRR and SR of EDM process. Main objective for the EDM processes is to minimize surface roughness.

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1.1. Literature survey: Different researchers did the various investigations about EDM. The results were summarized as follows: Ho and Newman (2003) went through the research work performed from the inception to the die-sinking EDM development and have also reported on the EDM arch associated for improvising performance measures, the process variables optimization, monitoring and the sparking processes control, the electrode design simplification and manufacturing. Fig.1 presents the classification of the various research areas and possible future research directions. Margaret (2004) exhibited the various inputs analysis into EDM and the out coming outputs into the environment. A simplified model is used in analyzing the process; the main categories of flow in the model are material and energy flow was accomplished that the materials machined by EDM do not possess any effect towards environment.

Fig.1.Classification of Major EDM Research Areas

1.2. The objectives of this work:
1.2.1. Design Variables: An optimization problem formulation commences with identifying the low lying design variables that are chiefly mottled while the process of optimization. In this paper peak current, discharge voltage, pulse on time, pulse off time and oil pressure considered as design variables.
1.2.2. Constraints: The constraints depict little functional association within the variables of design and other design fulfilling some physical phenomenon and certain resource are more or equal to, a value of resource. In this paper, oversize and the EDM hole are considered as constraints.
1.2.3. Objective Function: The chief function could be of two kinds. Either the objective function is to be minimized or it has to be maximized. In this paper, minimization of total SR and maximization of MRR are considered as objective function.
   a) The target of this study is to examine and report the machining parameters effect viz Peak Current, Discharge Voltage, Pulse on Time, Pulse off Time, Oil Pressure and Output as Surface Roughness and Material Removal Rate while machining of AISI 1020 steel and to compare the influential performances.
   b) To develop a model through RSM to predict SR and MRR machining of AISI 1020 steel.

2. EXPERIMENTAL DETAILS
Numerous experiments have been performed inorder to examine the performance and learn numerous machining parameters effects of EDM process on AISI 1020 steel in the form of rectanguar block of test pieces (120mm x 120mm x 8mm) dimensions. These studies were taken in for investigating the effects of Peak Current (I_p), Discharge Voltage (V), Pulse on Time (T_{on}), Pulse Off Time (T_{off}) and Oil Pressure (P_{oil}) on SR and MRR.

2.1. Work Material: The work materials chosen for the research of AISI1020 steel of rectangular piece (120mm x 120mm x 8mm dimensions) and are fabricated using stir die casting method. The material is chosen because of its progressing applications range in the tools manufacturing field in mould industries also used highly in aeronautical and automobile industries due to their high strength to weight ratio, mechanical and physical properties compared to monolithic material.

Table.1 Shows the physical and mechanical properties of AISI1020 Steel material

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (x1000 Kg/m³)</th>
<th>Tensile Strength (Mpa)</th>
<th>Hardness (HB)</th>
<th>Modulus of Elasticity(Gpa)</th>
<th>% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 1020 Steel</td>
<td>8.03</td>
<td>394.7</td>
<td>111</td>
<td>200</td>
<td>36.5</td>
</tr>
</tbody>
</table>

Table.2. Chemical Composition of Work Piece Material

<table>
<thead>
<tr>
<th>Work Material</th>
<th>AISI 1020 Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (%)</td>
<td>0.18-0.23</td>
</tr>
<tr>
<td>Mn (%)</td>
<td>0.30-0.60</td>
</tr>
<tr>
<td>P (%)</td>
<td>0.04 (Max)</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.05 (Max)</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>Balance</td>
</tr>
</tbody>
</table>

2.2. Tool Material: A cylindrical pure copper (Graphite Grade EDM) with a diameter of 10mm was used as a tool electrode (of positive polarity) and it is used to drill the work piece to 1mm depth as per ISO specification cutting...
tool was supplied by Sandwich and tool holder M16 type were used for the machining trials under various setting condition.

2.3. EDM Machine: Experiments are conducted on Electronica 5030 Die Sinking EDM machine as show in Fig.2. The dielectric fluid has been utilized (DEF-92) and the electrode suction flushing method has also been used. The scheme of experimental conditions for EDM machining is given in Table 3.

Table 3. EDM Machining Conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Descriptions</th>
<th>Conditions</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
<td>Electronica 5030 Die Sinking EDM Machine</td>
<td>Flushing Type</td>
<td>External</td>
</tr>
<tr>
<td>Test Specimen</td>
<td>AISI 1020 Steel Plate of Surface Dimensions</td>
<td>Depth of Cut (mm)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>124x94mm and of Thickness 15mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tool</td>
<td>Copper Electrode of Diameter 10mm</td>
<td>Gap (mm)</td>
<td>0.09</td>
</tr>
<tr>
<td>Polarity</td>
<td>Positive</td>
<td>Weight Measuring Instrument</td>
<td>Digital Balance (FX-3000)</td>
</tr>
<tr>
<td>Dielectric Fluid</td>
<td>EDM Oil (DEF-92)</td>
<td>SR Measuring Instrument</td>
<td>Portable Stylus Type Profilometer (Talysurf)</td>
</tr>
</tbody>
</table>

Fig.2. Electronica 5030 Die Sinking EDM Machine

2.4. Experimental Procedure: The machining process is performed in ELECTRONICA EMS5030 as show in Fig.3; the work piece is mounted on the V-block that has been spotted on the magnetic table of the machine. The tool holder holds tool and its alignment is verified with the assistance of dial gauge. Numerous runs was decided to be 32 with different parameter combinations based on Analysis of Variance. The input parameters that were varied for this study are Peak Current ($I_p$), Discharge Voltage ($V$), Pulse on Time ($T_{on}$), Pulse off Time ($T_{off}$) and Oil Pressure ($P_{oil}$) on SR and MRR.

Fig.3. Electronica 5030 Die Sinking EDM Machining Process Underway

2.5. Measurement Procedure: Roughness measurement has been done using a portable roughness tester SJ201 shown in Fig. 4. This portable instrument Evaluations of the parameter rely on microprocessor. The measurement outcomes are portrayed over an LCD screen and gives output to an optional printer or another computer for future investigation. Non-rechargeable alkaline battery (9V) is present in this instrument. It is equipped with a diamond stylus having a tip radius 5μm. The measuring stroke frequently gets initiated from the entirely outward position. While measuring by last pickup returns to the position alert for consecutive measurement. The selection of cut-off length determines the traverse length. Usually as a default, the traverse length is five times the cut-off length though the magnification factor can be changed. The profilometer was set to a cut-off length of 0.8mm, filter 2CR, and traverse speed 1mm/sec and 4mm traverse length. Roughness measurements, in the transverse direction, over the work pieces was recurred four times and four measurements average surface roughness parameter values has been recorded.

Fig.4. Experimental Set Up for Measuring Roughness
Material Removal rate is calculated my measuring the time of machining. It is calculated by using the formula.

\[ \text{MRR} = \frac{W}{t} \text{ in mg/s} \]

Where, \( W \) = weight of material removed, \( t \) = time taken for machining

2.6. Plan of experiment based on RSM: RSM is the wholesome of strategies of experiment, mathematical methods and statistical inferences enabling an experimenter for making well-organized system’s empirical exploration of interest. RSM is explained as a statistical technique which utilizes quantitative data from suitable experiments for determining and concurrently crack multi-variable equations. The work that originally produces interest in the techniques package was a paper by Box and Wilson [3] and Iqbal and Khan [4] was put in bringing up forecasting models utilizing this renowned RSM for their superior studies over machining and is a technique recently utilized in numerous fields namely chemistry, biology and manufacturing.

RSM can be used in the following ways:

a) To determine the factor levels that will simultaneously satisfy a set of desired specifications
b) To determine the optimum combination of factors that yields a desired response and describes the response near the optimum.

c) To determine how a specific response is affected by modification in the factor level over the specified levels of interest.
d) To accomplish a quantitative considerate of the system behavior over the region tested.
e) To forecast properties of product over the entire region, even for a factor grouping not really run.
f) To locate the circumstances essential for process stability (insensitive spot).

In design optimization using RSM, the first task is determination of the optimization model, such as the identification of the interested system measures and the selection of the factors that control the system measures significantly.

To do this, a considerate of the physical meaning of the problem and some experience are both useful. After this, the important issues are the design of experiments and how to improve the fitting accuracy of the response surface models.

A prior idea of the learnt process is hence essential in achieving a original model.

It is selected only five experimental factors efficient in affecting the studied process yield. The factors are Peak Current (\( I_p \)), Discharge Voltage (\( V \)), Pulse ON Time (\( T_{on} \)), Pulse OFF Time (\( T_{off} \)) and Oil Pressure (\( P_{oil} \)).

Initial step of RSM is to explore the restrictions of the experimental domain to be explored. These restrictions are created as much as feasible in obtaining a clear response from the model.

The Discharge Current (A), Discharge Voltage (B), Pulse ON Time (C), Pulse OFF Time (D) , and Oil Pressure (E) are the machining variables, selected for our investigation.

2.7. Experimental setup: The tests were conducted under different machining conditions using on Electronica 5030 Die Sinking EDM machine, which is 3HP/2.2kW power. The input parameter was derived from the setting machining and the work piece surface shape. The tests have been performed with normal above mentioned procedure. The levels were specified for each process parameter as given in the Table 4. The parameter levels have been finalized among the intervals suggested by the machining tool manufacturer and investigation of the present study. Five process parameters at two and three levels led to a total of 32 tests for machining operation. After each test, the work piece is measured with the surface roughness tester SJ201 for determining the material removal rate and SR calculated by formula. The observations are expressed in the Table 5 for additional examination and studies. The machining operations have been performed as per the conditions given by the design matrix at random to avoid systematic errors.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coding</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge Current (Ip) in A</td>
<td>A</td>
<td>10 65 70</td>
</tr>
<tr>
<td>Discharge Voltage in V</td>
<td>B</td>
<td>25 10 15</td>
</tr>
<tr>
<td>Pulse on time (Ton) in μs</td>
<td>C</td>
<td>15 30 45</td>
</tr>
<tr>
<td>Pulse off Time (Toff) in s</td>
<td>D</td>
<td>1 7 9</td>
</tr>
<tr>
<td>Oil Pressure in kg/cm²</td>
<td>E</td>
<td>20 0.2 0.3</td>
</tr>
</tbody>
</table>

In the consecutive step, the aim in accomplishing the experiments using RSM involving a central composite design with five variables. Total numbers of experiments conducted with the combination of parameter corresponding to machining and the corresponding recorded SR and MRR are established in Table 5.
2.8. Mathematical Modelling:

Modeling of SR: Table 6 shows the ANOVA table for SR Estimated Regression Coefficients and Table 7 shows the ANOVA table of Variance Analysis for SR when EDM machining of MMC with copper tool. The regression model fitted for SR was obtained and is represented by Equation.

\[ SR = -9.19010 + 0.17994 A + 0.08520 B + 0.70224 C - 2.29177 D + 0.21528 E - 0.00114 A*B - 0.00065 B*B - 0.01438 C*C + 0.66207 D*D - 0.00278 E*E - 0.00154 A*B - 0.00102 A*C + 0.00018 A*E + 0.00460 B*D + 0.00031 B*E - 0.00425 C*E \]

Table 6. ANOVA Table for SR Estimated Regression Coefficients

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.271665</td>
<td>-33.999</td>
<td>0.000</td>
<td>A*B</td>
<td>-0.00154</td>
<td>0.000017</td>
<td>-92.517</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.17919</td>
<td>0.004446</td>
<td>40.304</td>
<td>0.000</td>
<td>A*C</td>
<td>-0.00102</td>
<td>0.000083</td>
<td>-12.276</td>
<td>0.000</td>
</tr>
<tr>
<td>B</td>
<td>0.08620</td>
<td>0.002094</td>
<td>41.172</td>
<td>0.000</td>
<td>A*D</td>
<td>0.00050</td>
<td>0.000835</td>
<td>0.599</td>
<td>0.561</td>
</tr>
<tr>
<td>C</td>
<td>0.70324</td>
<td>0.017855</td>
<td>39.386</td>
<td>0.000</td>
<td>A*E</td>
<td>0.00118</td>
<td>0.000083</td>
<td>2.096</td>
<td>0.060</td>
</tr>
<tr>
<td>D</td>
<td>-0.140269</td>
<td>-16.356</td>
<td>0.000</td>
<td>B*C</td>
<td>-0.00005</td>
<td>0.000033</td>
<td>-1.497</td>
<td>0.163</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.21678</td>
<td>0.021811</td>
<td>9.939</td>
<td>0.000</td>
<td>B*D</td>
<td>0.00460</td>
<td>0.000334</td>
<td>13.773</td>
<td>0.000</td>
</tr>
<tr>
<td>A*A</td>
<td>-0.000106</td>
<td>-10.754</td>
<td>0.000</td>
<td>B*E</td>
<td>0.00031</td>
<td>0.000033</td>
<td>9.282</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>B*B</td>
<td>-0.00017</td>
<td>-37.995</td>
<td>0.000</td>
<td>C*E</td>
<td>0.00100</td>
<td>0.000167</td>
<td>0.599</td>
<td>0.561</td>
<td></td>
</tr>
<tr>
<td>C*C</td>
<td>-0.000426</td>
<td>-33.768</td>
<td>0.000</td>
<td>C*E</td>
<td>-0.00425</td>
<td>0.000167</td>
<td>-25.450</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>D*D</td>
<td>0.66207</td>
<td>0.042582</td>
<td>15.548</td>
<td>0.000</td>
<td>D*E</td>
<td>-0.00100</td>
<td>0.000167</td>
<td>-0.599</td>
<td>0.561</td>
</tr>
<tr>
<td>E*E</td>
<td>-0.000426</td>
<td>-6.527</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ S = 0.0166996 \quad R^2 = 99.98\% \quad R^2_{(adj)} = 99.94\% \]

Table 7. Analysis of Variance for SR

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>16</td>
<td>13.5567</td>
<td>13.5567</td>
<td>0.84729</td>
<td>3183.21</td>
<td>0.00</td>
</tr>
<tr>
<td>Linear</td>
<td>5</td>
<td>6.5961</td>
<td>2.9422</td>
<td>0.58844</td>
<td>2210.71</td>
<td>0.00</td>
</tr>
<tr>
<td>Square</td>
<td>5</td>
<td>4.2728</td>
<td>4.2728</td>
<td>0.85456</td>
<td>3210.51</td>
<td>0.00</td>
</tr>
<tr>
<td>Interaction</td>
<td>6</td>
<td>2.6878</td>
<td>2.6878</td>
<td>0.44797</td>
<td>1682.99</td>
<td>0.00</td>
</tr>
<tr>
<td>Residual Error</td>
<td>15</td>
<td>0.0040</td>
<td>0.0040</td>
<td>0.00027</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack-of-Fit</td>
<td>10</td>
<td>0.0039</td>
<td>0.0039</td>
<td>0.00039</td>
<td>23.46</td>
<td>0.01</td>
</tr>
<tr>
<td>Pure Error</td>
<td>5</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.00002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>13.5607</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Predicted result with experimental validation of AISI 1020 steel for SR

<table>
<thead>
<tr>
<th>Optimization for surface roughness</th>
<th>Machining parameters</th>
<th>Predicted Ra</th>
<th>Actual Ra</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

From the Table 6–8 the value of “P” in Table 7 for model is less than 0.05 which indicates that the model is adequately significant at 95% confidence level, which is desirable as it indicates that the terms in the model have a significant effect on the response. The discharge current holds the most dominant effect on SR, followed by the discharge voltage and the spark gap. This is expected because, it is well known that increase in current will increase SR; the classical energy is primarily a part of the discharge current. The forecasted outcomes have been discussed.
through the Table viii with experimental validation. The error range obtained during that analysis was 7% and it was considered as acceptable model.

**Modelling of MRR:** Analysis of Variance (ANOVA) for the sufficiency of the model is then performed in the subsequent step. The F ratio is calculated for 95% level of confidence. The value which are less than 0.05 are well thought-out significant and the values greater than 0.05 are not significant and the model is sufficient in establishing the relationship among machining response and the machining parameters. Since the EDM process seems to be non-linear naturally the linear polynomial would be helpless in forecasting the answer precisely hence the Second-order model (quadratic model) is used which is noticed from the sufficiency test by ANOVA that linear terms \( I_p, V, T_{on}, T_{off} \) interaction terms \( I_p \times V, I_p \times T_{off}, V \times T_{off}, T_{on} \times T_{eff}, T_{on} \times P_{oil}, \) and \( T_{eff} \times P_{oil} \) and square terms \( I_p^2, V^2, T_{on}^2, \) and \( P_{oil}^2 \). The levels of significant are illustrated in the Table 9. The fit summary suggested that the quadratic model seems to be significant \( (R^2 = 99.89\% \text{ and } 99.78\% \text{ respectively}), \) and lack of fit is non-significant \( (p\text{-value is less than } 0.05). \) The final model tested for variance analysis (F-Test) indicates that the adequacy of the test is established. The computed values of response parameters, model graphs are generated for the further analysis.

The ultimate response equation for MRR is represented as follows:

\[
\text{MRR} = \frac{[+2.62099 + 0.02124 A + 0.01388 B + 0.16666 C - 0.02621 D + 0.06225 E - 0.00026 A^2 - 0.0009 B^2 - 0.00371 C^2 - 0.00087 E^2 - 0.00014 A*B + 0.00093 A*D - 0.00755 B^*C - 0.00075 B*D + 0.00270 C^*D - 0.00075 C^*E - 0.00130 D^*E]}{S = 0.00554571 \text{ R-Sq } = 99.92\% \text{ R-Sq(adj) } = 99.78\%}
\]

**Table 9. ANOVA Table for MRR Estimated Regression Coefficients**

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-</td>
<td>0.090216</td>
<td>-</td>
<td>0.000</td>
<td>A*B</td>
<td>-0.00014</td>
<td>0.000006</td>
<td>-24.343</td>
<td>0.000</td>
</tr>
<tr>
<td>A</td>
<td>0.02128</td>
<td>0.001476</td>
<td>14.410</td>
<td>0.000</td>
<td>A*C</td>
<td>-0.00002</td>
<td>0.000028</td>
<td>-0.811</td>
<td>0.434</td>
</tr>
<tr>
<td>B</td>
<td>0.01358</td>
<td>0.000695</td>
<td>19.538</td>
<td>0.000</td>
<td>A*D</td>
<td>0.00093</td>
<td>0.000277</td>
<td>3.336</td>
<td>0.007</td>
</tr>
<tr>
<td>C</td>
<td>0.16567</td>
<td>0.005929</td>
<td>27.940</td>
<td>0.000</td>
<td>A*E</td>
<td>0.000000</td>
<td>0.000078</td>
<td>0.090</td>
<td>0.930</td>
</tr>
<tr>
<td>D</td>
<td>0.03506</td>
<td>0.004582</td>
<td>0.753</td>
<td>0.467</td>
<td>B*C</td>
<td>-0.00010</td>
<td>0.000011</td>
<td>-0.992</td>
<td>0.343</td>
</tr>
<tr>
<td>E</td>
<td>0.05921</td>
<td>0.007243</td>
<td>8.174</td>
<td>0.000</td>
<td>B*D</td>
<td>-0.00075</td>
<td>0.000111</td>
<td>-6.762</td>
<td>0.000</td>
</tr>
<tr>
<td>A*A</td>
<td>-</td>
<td>0.000035</td>
<td>-6.960</td>
<td>0.000</td>
<td>B*E</td>
<td>0.000001</td>
<td>0.000011</td>
<td>1.172</td>
<td>0.266</td>
</tr>
<tr>
<td>B*B</td>
<td>-</td>
<td>0.000066</td>
<td></td>
<td>0.000</td>
<td>C*D</td>
<td>0.000270</td>
<td>0.000555</td>
<td>4.869</td>
<td>0.000</td>
</tr>
<tr>
<td>C*C</td>
<td>-</td>
<td>0.000141</td>
<td></td>
<td>0.000</td>
<td>C*E</td>
<td>-0.00075</td>
<td>0.000555</td>
<td>-13.524</td>
<td>0.000</td>
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<tr>
<td>D*D</td>
<td>-</td>
<td>0.014141</td>
<td>-1.444</td>
<td>0.177</td>
<td>D*E</td>
<td>-0.00130</td>
<td>0.000555</td>
<td>-2.344</td>
<td>0.039</td>
</tr>
<tr>
<td>E*E</td>
<td>-</td>
<td>0.000141</td>
<td>-5.829</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Table 10. ANOVA Table for MRR Estimated Regression Coefficients after Backward Elimination**

<table>
<thead>
<tr>
<th>Optimization for MRR</th>
<th>Machining parameters</th>
<th>MRR</th>
<th>Predicted Ra</th>
<th>Actual Ra</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>25</td>
<td>54.29</td>
<td>20.15</td>
<td>1</td>
<td>26.46</td>
<td>0.51493</td>
</tr>
</tbody>
</table>

**Table 11. Analysis of Variance for MRR**

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-</td>
<td>0.08747</td>
<td>-</td>
<td>0.000</td>
<td>C*C</td>
<td>-0.000138</td>
<td>-</td>
<td>0.000</td>
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<tr>
<td>A</td>
<td>0.02124</td>
<td>0.00115</td>
<td>18.34</td>
<td>0.000</td>
<td>E*E</td>
<td>-0.000138</td>
<td>-</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.01378</td>
<td>0.00505</td>
<td>23.70</td>
<td>0.000</td>
<td>A*B</td>
<td>-0.000064</td>
<td>-</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.16667</td>
<td>0.00576</td>
<td>28.92</td>
<td>0.000</td>
<td>A*D</td>
<td>0.00093</td>
<td>0.000278</td>
<td>3.325</td>
<td>0.004</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>0.19300</td>
<td>-0.193</td>
<td>0.000</td>
<td>B*D</td>
<td>0.000111</td>
<td>-</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.06220</td>
<td>0.00704</td>
<td>8.833</td>
<td>0.000</td>
<td>C*D</td>
<td>0.00270</td>
<td>0.000556</td>
<td>4.852</td>
<td>0.000</td>
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<tr>
<td>A*A</td>
<td>-</td>
<td>0.00003</td>
<td>-0.000</td>
<td>0.000</td>
<td>C*E</td>
<td>0.000056</td>
<td>-</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>B*B</td>
<td>-</td>
<td>0.00000</td>
<td>-0.000</td>
<td>0.000</td>
<td>D*E</td>
<td>0.000556</td>
<td>-</td>
<td>0.033</td>
<td></td>
</tr>
</tbody>
</table>

S = 0.00554647   R-Sq = 99.89%   R-Sq(adj) = 99.78%

**3. RESULT AND DISCUSSION**

3.1. Result and Discussion for SR: The effect of the machining parameters \( I_p, V, T_{on}, T_{off} \) on the response variables SR have been evaluated by conducting experiments. The results are put into the Minitab software for further analysis. The Analysis Of Variance (ANOVA) was used to check the sufficiency of the second order model.

Fig.5 shows the calculated response surface for SR in association with the process parameters of \( I_p \) and \( T_{on} \) while \( T_{off} \) and \( V \) remain constant at their lowest values where the figure explains that the SR rises up predominantly with the rise in \( I_p \) for any value of \( T_{on} \). On the other hand, the SR progresses up with rise in \( T_{on} \), particularly at higher
Therefore, least amount SR is achieved at low peak current (5A) and low pulse on time (15μs) which is because of their dominant restriction over the input energy, i.e. with the rise in Ip producing powerful spark creating greater temperature and crater, for this reason work piece rough surface and low Ip creates small crater and consequently surface is smooth.

The effect of Ip and T_off is on the estimated response surface of SR is depicted in Fig.6. T_on, V and P_oil remains constant in its lower levels which could be illustrious that the SR goes up on rise in Ip, the description is similar, as declared earlier. Fig.7 depicts SR as a function of T_on and T_off, while the Ip, V and P_oil remains constant at its lower levels and noticed that the SR values are low when T_on is low with higher T_off. Even though the effect of this two parameter is highly fewer when compared with the influence of Ip on SR. Fig.8 depicts SR as a purpose of T_on and V, whereas the Ip, T_off and P_oil remains constant at its lower levels which is noticed that the SR values are low when T_on and V are low.

Figure 9 represents SR as a function of V and T_off, whereas the Ip, T_on and P_oil remains constant at its lower levels. It is observed that the SR values are low when V is low with higher T_off.

Finally, the remaining figures represents the influence of oil pressure with other four parameters (Ip, V, T_on and T_off) on SR which could be noticed that there exists no significant variation of SR with the variation of P_oil. On noticing it could be finalized that Ip, V and Ton are directly proportional, and T_off is inversely to the SR for the provided range of experiments conducted for our test.

<table>
<thead>
<tr>
<th>Parameters technique</th>
<th>Ip (A)</th>
<th>V (μs)</th>
<th>T_on (μs)</th>
<th>T_off (μs)</th>
<th>P_oil (MPa)</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSM</td>
<td>5</td>
<td>25</td>
<td>15</td>
<td>1.65</td>
<td>20</td>
<td>0.72095</td>
</tr>
</tbody>
</table>

From this Table 12 the higher value of SR is achieved with Ip=5A, V=25μs, T_on=15μs, T_off=1.6s and P_oil=20kg/cm².

3.2. Result and Discussion for MRR: The effect of the machining parameters (Ip, V, T_on, T_off and P_oil) on the response variables MRR have been evaluated by conducting experiments. The results are put into the Minitab software for further analysis. The second-order model was explained for finding the association among the MRR and the process variables accounted. The Analysis Of Variance (ANOVA) has been involved for checking the adequacy of the second order model.

Figure 11 depicts the predictable response surface for MRR in association to the parameters of process of pulse current and pulse on time which could be noticed from the figure, the MRR goes up, significantly with rise in peak current for any value of pulse on time. Hence, maximum MRR is achieved at high peak current (25A) and high pulse on time (25μs) which is because of their dominant control over the input energy i.e. with the rise in pulse current producing powerful spark creating greater temperature cause the more material to melt and erode from the work piece.
The effect of \( I_p \) and \( T_{off} \) on the estimated response surface of MRR is depicted in the Figure 12, the parameters \( T_{on} \), \( V \) and \( P_{oil} \) remains constant in its maximum level of 25\( \mu \)s, 75v and 30kg/cm\(^2\) respectively noticing that the MRR goes up on rise in \( I_p \), the description is identified to be similar, as explained previously, on the other hand with the rise in \( T_{off} \), MRR goes down, which is because when \( T_{off} \) rises, where ending up in an unwanted heat loss that does not provide to MRR ending up in decline of the work piece temperature prior to consecutive spark begins and hence MRR drops. The maximum MRR is achieved with high \( I_p =25 \) A and lower \( T_{off} =1s \) for the given range of input parameters.

Figure 13 represents MRR as a function of \( T_{on} \) and \( T_{off} \), whereas the \( I_p \), \( V \) and \( P_{oil} \) remains constant in its higher level which could be viewed that the greatest values of MRR takes place at the elevated \( T_{on} \) and lower \( T_{off} \).

Figure 14 details MRR as a function of \( V \) and \( I_p \), while the \( T_{on}, T_{off} \) and \( P_{oil} \) remains constant in its superior level which could be viewed that the greatest MRR values takes place at the greater \( I_p \) and \( V \).

Figure 15 illustrates MRR as a function of \( T_{on} \) and \( V \), whereas the \( I_p, T_{off} \) and \( P_{oil} \) remains constant in its higher level which could be viewed as the greatest values of MRR takes place at elevated \( T_{on} \) and \( V \).

Figure 16 represents MRR as a function of \( V \) and \( T_{off} \), whereas the \( I_p \), \( T_{on} \) and \( P_{oil} \) remains constant in its higher level which could be viewed that the greatest of MRR values takes place at the elevated \( V \) and lower \( T_{off} \).

Figure 17 represents MRR as a function of \( P_{oil} \) and \( I_p \), whereas the \( T_{on} T_{off} \) and \( V \) remains constant in its higher level which could be seen that the highest MRR values occurred at the higher \( I_p \) and medium \( P_{oil} \) (25kg/cm\(^2\)).

Table 13. Comparison Table for Optimal MRR Values

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Techniques</th>
<th>( I_p )</th>
<th>( V )</th>
<th>( T_{on} )</th>
<th>( T_{off} )</th>
<th>( P_{oil} )</th>
<th>MRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSM</td>
<td></td>
<td>25</td>
<td>54.29</td>
<td>20.15</td>
<td>1.65</td>
<td>26.46</td>
<td>0.5149</td>
</tr>
</tbody>
</table>

From this Table 13 the higher value of MRR is achieved when \( I_p=25A \), \( V=54v \), \( T_{on}=20\mu s \), \( T_{off}=1s \) and \( P_{oil}=26.5kg/cm^2 \).
4. CONCLUSION

Collection of parameters corresponding to machining is one of the highly significant features to take into thoughtfulness in the majority of advanced manufacturing processes. RSM model have been brought up for forecasting surface roughness The optimized machining condition that gives better surface finish when machining AISI1020 steel have been identified: \( I_p = 5A, \ V = 25V, \ T_{on} = 15\mu s, \ T_{off} = 1.65s \) and \( P_{oil} = 20kg/cm^2 \) The surface roughness improves with increase of the discharge current whilst increasing pulse off time adversely affects the surface roughness among the parameters of machining, discharge current has the most dominant effect on surface roughness through ANOVA. The higher value of MRR is achieved when \( I_p = 25A, \ V = 54v, \ T_{on} = 20\mu s, \ T_{off} = 1s \) and \( P_{oil} = 26.5kg/cm^2 \). The machining parameters for EDM process are optimized using RSM techniques for minimizing the surface roughness and maximizing material removal rate. The developed model was assessed experimentally and exhibit low values of error.

REFERENCES


