Research Article

Parametric Optimization of Wire Electrical Discharge Machining in AA7075 Metal Matrix Composite

K. Raju, M. Balakrishnan, C. B. Priya, M. Sivachitra, and Dasari Narasimha Rao

1Department of Mechanical Engineering, M. Kumarasamy College of Engineering, Karur 639113, Tamilnadu, India
2Department of Mechanical Engineering, Dhanalakshmi Srinivasan Institute of Technology, Samayapuram, Trichy, India
3Department of Department of Electrical and Electronics Engineering, Kongu Engineering College, Perundurai 638060, Tamilnadu, India
4Department of Electrical Power Engineering, Defence University College of Engineering, Bishoftu, Ethiopia

Correspondence should be addressed to Dasari Narasimha Rao; dasari.narasimha@dec.edu.et

Received 11 March 2022; Revised 25 April 2022; Accepted 24 May 2022; Published 24 June 2022

Academic Editor: Francesco Colangelo

Copyright © 2022 K. Raju et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Aluminium 7075 metal matrix composite reinforced with silicon nitride was fabricated using the stir casting technique. Composite fabricated was machined and subjected to wire electrical discharge machining to study the significant process parameter. Taguchi design of experiment using L9 orthogonal array was selected with three factors, current, pulse ON time, and wire feed at three levels. Influencing process parameters were identified using analysis of variance. Pulse ON time of 130 μs, current of 20 A, and wire feed of 1 mm/min were identified as optimized parameters for higher material removal rate. For a good surface finish, the optimized parameter was identified as 130 μs pulse ON time, 20 A current, and wire feed rate of 2 mm/min. Pulse ON time was identified as an influencing parameter followed by the current in achieving better material removal rate with good surface finish, whereas wire feed has no influence on the output parameters. Results of experimentation showed improved machining characteristics for higher pulse ON time and current for machining the synthesized composite through the Taguchi design of the experiment.

1. Introduction

Wire electrical discharge machining (WEDM) is advanced machining method to machine harder materials with accuracy at faster rate. Materials such as aluminium 7075 composites used in aerospace, defence, and military are in need of good surface finish and accuracy. Conventional machining methods find it difficult to machine harder materials and complex shapes with accuracy and good surface finish to meet the requirements. Adding ceramic materials in aluminium metal matrix composite makes the surface hard leading to more wear rate of the tool and poor surface finish [1]. Due to high fatigue and tensile strength, good corrosion resistance, aluminium alloy (AA) 7075 is predominantly used as matrix material [2]. Increasing the content of silicon nitride (Si₃N₄) as reinforcement increases the hardness of the composite. Decreasing in hardness is found with increased load and dwell time [3]. Hybrid metal matrix composite (MMC) reinforced with aluminium oxide (Al₂O₃) and silicon carbide (SiC) showed decreased material removal rate (MRR) and lower surface finish for increased reinforcement percentage [4]. Increased cutting speed for machining ceramic-reinforced MMC increases tool wear with reduced MRR [5]. In analyzing the input parameters such as voltage, current, and pulse on and off time using the response surface methodology (RSM) technique on MRR and surface roughness (Rₐ), the current was identified as the most influencing parameter [6]. In turning operations, to control Rₐ, depth of cut along with feed and speed is to be considered [7]. In machining aluminium metal matrix composite (AMMC) containing 10 percentage fly ash and SiC, speed of cutting was identified as significant parameter [8]. The weight percentage of reinforcement influences Rₐ along with gap voltage for MRR [9]. Stir-casted AA7075 with 10 percentage of SiC particles showed lower Rₐ when turned using carbide and polycrystalline diamond (PCD) inserts.
[10]. AMMC with SiC reinforcement showed surface defects when optimized using Box–Behnken design [11]. Modelling of a process parameter, dielectric medium, and electrode material is the main objective of WEDM [12]. SiC-reinforced AA6063 MMC showed decreased MRR for an increased percentage of reinforcement using the Taguchi L9 orthogonal array [13]. MMC-containing ceramic reinforcements showed lower MRR and surface finish for increased volume of SiC and Al2O3 reinforcements [14]. Increased current and pulse on time increases MRR and Rz in machining Al–SiC MMC [15]. Increasing gap voltage increases current leading to increased MRR. MRR is found to be directly proportional to current [16]. The thickness of the workpiece is to be considered for a good surface finish when maintaining a pulse on time at constant with a lower power supply [17]. Current, pulse time, and flow of dielectric liquid are to be considered to get better MRR and lower Rz [18]. Die steels and hard metals and MMC use WEDM for machining with good accuracy [19]. Kerf width and Rd are influenced majorly by pulse on time [20]. MRR is decreased when increasing gap voltage and pulse off time. Increased pulse ON time and current increase MRR [21]. MRR has direct proportional to pulse on time and inverse proportional to pulse off time [22]. In machining DC53 die steel, the significant variable was concluded as current and pulse on time [23]. In optimization, pulse off time, pulse on time, servo voltage, current, wire tension, and gap voltage are to be considered as input parameters [24]. Regression equation in Taguchi design of experiment (DOE) is used to correlate MRR to get optimized process parameters [25]. Pulse on and off time are the major parameters in attaining hardness and better surface finish [26]. Pulse on time is seen to have direct proportional to wire wear and MRR whereas surface finish is seen to be inversely proportional to pulse on time [27]. Their different studies focus on the optimization of process parameters in machining with coated cutting tools, steels, and composite materials [28–30]. Lots of investigations were seen on optimization of process parameters using WEDM using SiC and Al2O3, with AA7075. In this study, AA7075 reinforced with Si3N4 MMC was machined using WEDM to identify the optimal process parameter. Si3N4 reinforcement was selected for this study due to its high hardness, wear resistance, and thermal conductivity.

2. Materials and Methods

2.1. Composite Fabrication. Composite was fabricated using stir casting process with 90% of aluminium alloy 7075 reinforced with 10% of silicon nitride ceramic reinforcement of particle size ranging from 20 to 40 μm. The stir-casting process was selected for composite fabrication due to its easy fabrication at low cost. Matrix material AA7075 was melted to 750°C and maintained at the same temperature. Preheated silicon nitride at 600°C for an hour was then added to the melt and stirred well and cast in the mould to get a defect-free casting for the analysis. Electronica Wire electrical discharge machine was selected for machining the prepared composite. A brass wire of 0.25 mm with water as the dielectric liquid was taken for machining the composite.

2.2. Design of Experiments

2.2.1. Analysis of Variance. Analysis of variance (ANOVA) is a logical approach to identify the factors that considerably affect the experimental outcome. ANOVA includes (i) all experimental values allocated for summing squares, (ii) impartial difference, (iii) decaying total sum of squares considering all elements taken for analysis, (iv) calculating impartial variances of all elements above the DOE, (v) determining the variance ratio, and (vi) analyzing the error variance to identify the significant factors affecting the experimental values. ANOVA-based regression equation generated was considered to calculate the predicted values for MRR and Rz. The obtained values are then compared with the experimental values to identify the error percentage and accuracy of the analysis.

2.2.2. Taguchi Analysis. Taguchi DOE is the process in which design parameters are investigated to identify the optimal values to get improved efficiency that is not influenced by noise factors. Taguchi DOE gives the entire study of parameters with a low number of experiments. Designed experimental data were identified using an L9 orthogonal
array to find the parameters influencing MRR and $R_a$. The superiority characteristics considered for MRR are larger the better, and similarly, the superiority characteristics considered for $R_a$ are smaller the better which takes continuous and nonnegative values ranging between 0 and 1. Parameters and its levels are listed in Table 1. Table 2 shows the identified experimental data for conducting the experiment using MINITAB 19 software. Experimental levels of parameters were selected based on the studies of Bisaria and Shandilya 2020 [31].

### 3. Result and Discussion

#### 3.1. Experimental Results

Experimental results for the L9 orthogonal arrayed input parameters are listed in Table 3. MRR was tabulated by calculating the difference in weight of the specimen before machining and after machining using the weighing balance of 0.001-gram accuracy. $R_a$ was found using a surface roughness tester of make: Mitutoyo Surf test and model: SJ-201P.

#### 3.2. Taguchi Analysis

Figures 2(a) and 2(b) show the mean effect plots for MRR and $R_a$. The larger the better signal to noise ratio ($S/N$ ratio) is selected for MRR, and the smaller the better $S/N$ ratio is selected for $R_a$. From Figure 2(a), increased values of pulse ON time and current showed increased MRR whereas the increase in wire feed has no influence on MRR. Figure 2(b) shows decreased $R_a$ for increased current and pulse ON time.

#### 3.2.1. Analysis of Variance

Table 4 indicates the ANOVA for MRR. $P$ value closer to zero and $F$ value greater than one indicate the significant parameter to be concentrated during machining. From Table 4, it is clearly identified that MRR is highly influenced by pulse ON time ($T_{ON}$) followed by current ($I$) and wire feed ($W_f$).

Table 5 indicates the ANOVA for $R_a$. Similar to MRR, it is clearly identified that $R_a$ is highly influenced by pulse ON time ($T_{ON}$) followed by current ($I$) and wire feed ($W_f$) from Table 5.

From Tables 4 and 5, the percentage contribution ratio confirms pulse ON time as the most influencing parameter towards MRR and $R_a$ [32].

### Table 3: Experimental results of Taguchi-based DOE.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Pulse on time (µs)</th>
<th>Current (A)</th>
<th>Wire feed (mm/min)</th>
<th>MRR (g/min)</th>
<th>$R_a$ (µm)</th>
<th>Predicted MRR (g/min)</th>
<th>Predicted $R_a$ (µm)</th>
<th>MRR error (%)</th>
<th>$R_a$ error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>10</td>
<td>1</td>
<td>0.158</td>
<td>2.252</td>
<td>0.157</td>
<td>2.254</td>
<td>0.63</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>110</td>
<td>15</td>
<td>2</td>
<td>0.162</td>
<td>2.311</td>
<td>0.163</td>
<td>2.304</td>
<td>0.62</td>
<td>0.30</td>
</tr>
<tr>
<td>3</td>
<td>110</td>
<td>20</td>
<td>3</td>
<td>0.165</td>
<td>2.326</td>
<td>0.165</td>
<td>2.332</td>
<td>0</td>
<td>0.26</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>10</td>
<td>2</td>
<td>0.181</td>
<td>2.920</td>
<td>0.181</td>
<td>2.926</td>
<td>0</td>
<td>0.21</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>15</td>
<td>3</td>
<td>0.188</td>
<td>2.931</td>
<td>0.187</td>
<td>2.933</td>
<td>0.53</td>
<td>0.07</td>
</tr>
<tr>
<td>6</td>
<td>120</td>
<td>20</td>
<td>1</td>
<td>0.192</td>
<td>2.990</td>
<td>0.193</td>
<td>2.983</td>
<td>0.52</td>
<td>0.23</td>
</tr>
<tr>
<td>7</td>
<td>130</td>
<td>10</td>
<td>1</td>
<td>0.211</td>
<td>3.112</td>
<td>0.212</td>
<td>3.105</td>
<td>0.47</td>
<td>0.22</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
<td>15</td>
<td>1</td>
<td>0.220</td>
<td>3.128</td>
<td>0.222</td>
<td>3.134</td>
<td>0</td>
<td>0.19</td>
</tr>
<tr>
<td>9</td>
<td>130</td>
<td>20</td>
<td>2</td>
<td>0.224</td>
<td>3.202</td>
<td>0.223</td>
<td>3.204</td>
<td>0.45</td>
<td>0.06</td>
</tr>
</tbody>
</table>

### Figure 2: Mean effect plots for MRR and $R_a$. (a) MRR. (b) $R_a$.
3.2.2. Regression Equation. Table 6 shows the regression equation generated for the experimental results of MRR and $R_a$. The equation is used to identify the predicted results used to analyze the error % by comparing it with the actual obtained experimental values. Error % less than 5 indicates the accuracy of the analysis.

Figures 3(a) and 3(b) indicate the comparison of experimental values with predicted values for MRR and $R_a$. From the graph, it is understood that the error percentage is less than 1 which is too minimum to prove the accuracy of the experiment.

3.2.3. Model Summary. Table 7 shows the model summary for MRR and $R_a$. The values obtained are 99.5% indicating that there is no external factor influencing the analysis.

3.2.4. Interaction Plot. Figures 4(a) and 4(b) indicate the interaction plot of each input parameter for MRR and $R_a$. From the interaction plot for MRR from which it is noted that an increase in $T_{ON}$ increases the MRR. For the increase in wire feed, there is a decreased MRR and similarly increased current increases MRR. Thus, it is noted that $T_{ON}$ and current are the influencing parameters for MRR as confirmed in Figure 4(a). Figure 4(b) shows the interaction plot for $R_a$ showing the similar trend as noted in the

---

**Table 5: ANOVA table for $R_a$.**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>PCR (%)</th>
<th>Adj MS</th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>2</td>
<td>1.18770</td>
<td>99.1</td>
<td>0.593851</td>
<td>4406.15</td>
<td>0.000</td>
</tr>
<tr>
<td>Current</td>
<td>2</td>
<td>0.00934</td>
<td>0.78</td>
<td>0.004670</td>
<td>34.65</td>
<td>0.028</td>
</tr>
<tr>
<td>Wire feed</td>
<td>2</td>
<td>0.00090</td>
<td>0.07</td>
<td>0.000448</td>
<td>3.32</td>
<td>0.231</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>0.00027</td>
<td>0.05</td>
<td>0.000135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>1.19821</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6: Regression equation for MRR and $R_a$.**

MRR = $0.189000 - 0.027333\ Ton_{110} + 0.002000\ Ton_{120} + 0.029333\ Ton_{130} + 0.005667\ Current_{10} + 0.004667\ Current_{20} + 0.001000\ wire\ feed_{1} + 0.000000\ wire\ feed_{2} - 0.001000\ wire\ feed_{3}$

$R_a = 2.79689 - 0.50056\ Ton_{110} + 0.15011\ Ton_{120} + 0.35044\ Ton_{130} - 0.03556\ Current_{10} - 0.00689\ Current_{15} + 0.04244\ Current_{20} - 0.00689\ wire\ feed_{1} + 0.01411\ wire\ feed_{2} - 0.00722\ wire\ feed_{3}$

**Table 7: Model summary for MRR and $R_a$.**

<table>
<thead>
<tr>
<th>Model summary</th>
<th>S</th>
<th>R-sq (%)</th>
<th>R-sq(adj) (%)</th>
<th>R-sq(pred) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRR</td>
<td>0.0015275</td>
<td>99.91</td>
<td>99.63</td>
<td>98.11</td>
</tr>
<tr>
<td>$R_a$</td>
<td>0.0116094</td>
<td>99.98</td>
<td>99.91</td>
<td>99.54</td>
</tr>
</tbody>
</table>

---

**Figure 3: Comparison graph for experimental values with predicted values: (a) MRR, (b) $R_a$.**
Figure 4: Interaction plots for (a) MRR and (b) $R_a$.

Figure 5: Contour plot for MRR: (a) $T_{on}$ and current, (b) wire feed and current, and (c) $T_{on}$ and wire feed.
3.2.5. Contour Plot. Figures 5(a)–5(c) indicate the contour plot for MRR. It is noted that higher MRR is attained for higher TON and current from Figure 5(a). Figure 5(b) shows better MRR for increased current and lower wire feed. Higher TON with lower wire feed showed improved MRR as seen in Figure 5(c).

Figures 6(a)–6(c) indicate the contour plot for $R_a$. It is noted that higher $R_a$ is attained for higher TON and current noted from Figure 6(a). Figure 6(b) shows better $R_a$ for increased current at lower wire feed and lower current with higher wire feed. Higher TON with higher wire feed showed improved $R_a$ as seen in Figure 6(c). Thus, $R_a$ increases with the increase in pulse on time and discharge energy [33, 34].

Thus, from the interaction plots of Figure 4, it is obviously understood that TON and current are the parameters mainly influencing both MRR and $R_a$. Contour plots of MRR and $R_a$ also confirm the same which can be noted in Figures 5 and 6. A confirmatory test was conducted for the optimal parameter results with an error percentage of less than one confirming the accuracy of the study [35].

4. Conclusion

The conclusions derived from the WEDM analysis on AA7075 metal matrix composite reinforced with silicon nitride are as follows:

1. Taguchi-based ANOVA analysis confirms Pulse ON time as the influencing parameter in achieving higher MRR and $R_a$.
2. Pulse ON time of 130 μs, current of 20 A, and wire feed of 1 mm/min were identified as optimized parameters for higher material removal rate.
3. For a good surface finish, the optimized parameter was identified as 130 μs pulse ON time, 20 A current, and wire feed rate of 2 mm/min.
4. Regression equation obtained shows minimal error indicating the accuracy of the analysis.
(5) Pulse ON time and current have a direct influence on MRR and $R_s$.

(6) Interaction plot and contour plot also confirm the ANOVA analysis proving pulse ON time as the influencing parameter followed by current.

**Data Availability**

The data used to support the findings of this study are included within the article.

**Conflicts of Interest**

The authors declare that there are no conflicts of interest.

**References**


