Effect of Spray and Complete Submerged Method on Material Removal Rate for EDM Die Sinking

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Abstract

This Electrical discharge machining (EDM) technology is increasingly demanded to be used in tool, die and mould making industries for machining of heat-treated tool steels and advanced materials such as super alloys, ceramics, and metal matrix composites. One of the well applied EDM technology; EDM die sinking has the ability to produce a highly precise dimension, complex shapes, and good surface finish products. The disadvantage of this technology is the slow machining process and time consuming aspect is the major drawback that affected the productivity of a process. In the present study, two methods of EDM; spray and completed submerged methods were being investigated focused in machining time, and machining parameters and the performance results was compared. Three parameters were identified as variable factors which are discharge current, pulse on-time, and pulse off time, in which the design of experiment (DOE) was carried out using Taguchi method. Final result indicated that the time taken for EDM process with spray method is faster compare to complete submerged method. This provides the new direction to be further studied towards the better EDM Die Sinking machining process.

Keywords: EDM Die sinking; Tool Steel; Material Removal Rate; Taguchi method; Discharge current.

INTRODUCTION

An Electrical Discharge Machining (EDM) is becoming the most important technology in manufacturing industries since many complex 3D shapes can be machined using a shaped tool electrode [1][2]. EDM technology is being used in the tool, die and mould making industries, for machining of heat-treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes, and high surface finish [3]. EDM technology is quite popular among manufacturing industries because the ability of the EDM machining process to produced high accuracy workpiece in creating a complex or simple shape within parts and assemblies. EDM technique is especially useful when the workpiece is hard, brittle and requires higher surface finish. The cost of machining is quite high and a company require a huge initial investment and maintenance for the machine but it is a very desirable machining process when high accuracy is required. The EDM concept is utilizing the removal phenomenon [4] of electrical-discharge in the dielectric fluid and the electrode plays an important role, which affects the material removal rate and the tool wear rate during machining.

In general, the EDM die sinking is a slow and time consuming process, depending to the complexity of products being machined. Suitable parameters for different machining process are also essential to ensure the time consumed for this slow machining is worth with the machining output. As for the slow process, the production line will affect to lead time of a project. [5]. In consequence, the production cost will increase due to the EDM die sinking process. Many studies focused on the surface roughness of the EDM workpiece, but as for mould maker industry they demand a faster EDM process as the surface finish needs to be further polish by workers normally.

As the motivation to improve these main drawbacks, an approach is introduced in the present study, which the EDM process is carried out with dielectric spraying method instead of submerging into dielectric fluid. The performance in terms of the effects of electrode and specimen as well as the material removal rate (MRR) then is being compared with the normal practice, which is the complete submerged method. With aims to improve time consumed for the EDM die sinking process, both machining methods were studied and the data were analysed accordingly.

EXPERIMENTAL

Two methods of EDM process have been carried out and investigated in this study, which are spray and complete submerged methods. Figure 1 illustrates the spray method during machining process. The workpiece was clamped and the dielectric fluid nozzle was pointed and flushed directly to the workpiece during machining. While Figure 2 shows the normal procedure of EDM die sinking process which the workpiece was completely submerged in the dielectric fluid during machining process.
The research works on determining the parameters that affecting the material removal rate (MRR) of the end product. Tool steel was used as the workpiece material, and graphite were used as the EDM electrodes [6] whereas kerosene oil works as the EDM dielectric fluid.

In the experiment, there are three parameters used as the variables factor, which are discharged current (I), pulse on-time (Ton) and pulse off time (Toff) [7]. Ton time is the duration of time (µs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this Ton-time. This energy is controlled by the peak current and the length of the Ton-time. Toff is the duration of time (µs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be washed out of the arc gap. This parameter is to affect the speed and the stability of the cut. These parameters were identified as the major considerable MRR parameters in EDM Die sinking process [8].

P20 tool steel material is a pre hardened high tensile tool steel which offers ready machine ability in the hardened and tempered condition, therefore does not require further heat treatment. This is the common material used in EDM Die sinking and suitable for this experiment.

Graphite is the preferred electrode material for 90% of all sinker EDM applications. Graphite has an extremely high melting point. Graphite does not melt, but sublimes directly from a solid to a gas at a temperature thousands of degrees higher than the melting point of Copper. This resistance to temperature makes graphite an ideal electrode material.

In Figure 3 shows the machined electrodes and specimen for the experiment. The graphite material was machined into EDM electrodes into 20mm diameter. The workpiece material was machined into 20mm x 70mm x 10mm rectangular sizes by using a conventional milling machine.

Experimental design

Taguchi method was chosen to suit the design of experiment (DOE) in order to analyze the data collected from the three machining process parameters [9][10]. Three control factors with their levels are tabulated in Table 1. This control factors are the main parameters used for the EDM die sinking machining.

Table 2 shows the detail of level in conducting the experiment by using Taguchi method for L8 orthogonal array with three control factor.

<table>
<thead>
<tr>
<th>Table 1: Control factors and their levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (A)</td>
</tr>
<tr>
<td>Ton (µs)</td>
</tr>
<tr>
<td>Toff (µs)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Taguchi L8 design matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. No.</td>
</tr>
<tr>
<td>01</td>
</tr>
<tr>
<td>02</td>
</tr>
<tr>
<td>03</td>
</tr>
<tr>
<td>04</td>
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<td>05</td>
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<tr>
<td>06</td>
</tr>
<tr>
<td>07</td>
</tr>
<tr>
<td>08</td>
</tr>
</tbody>
</table>
Experimental procedure

The polarity is set based on the machine default which is positive on the workpiece and negative on the electrode. In die sinking EDM, finding the suitable parameters settings can give the best result in terms of MRR and surface roughness [11] [12]. From the control factors, the discharge current (I) is set to 4A and 6A, pulse on-time (Ton) to 25 µs and 50 µs and pulse off time (Toff) 25 µs and 50 µs. The depth of cut is set at 1mm. The experiment was conducted repetitively for complete submerged and then continued by spray method. The results for both experiments were collected and presented in Table III. The results data were analysed by using Taguchi method and summarized in table form for easier understanding. In Figure 4 shows the simplified methodology of the experiment.

RESULTS AND DISCUSSIONS

Effect on electrodes and specimen by Spray and Complete Submerged method

Material removal rate in a die sinking machining is important as the results of machining will influence to the productivity of a process. As the productivity increased, a company manage to extend the profit from this improvement. In Table 3 presents the experiment results of time consumed and MRR for both spray and complete submerged method. It can be observed that the machining time for spray method was reduce for almost two minutes to complete 1 mm depth. Based on spray method machining observation, the machining spark is bigger due to the spray application of dielectric fluid onto the workpiece. It is also produced a rough surface finish on the workpiece. Due to the spray technique, machining time was drastically reduced because of the filling and draining the dielectric fluid already been eliminated. Complete submerged method observation found that the machining produced a fine surface finish but it required a longer machining time. Figure 5 shows the specimen after complete submerged machining and in Figure 6 shows the spray technique in EDM machining process.

\[(S/N)_{HB} = -10 \log (MSDHB)\]  
\[MSDHB = \frac{1}{r} \sum_{i=1}^{r} (y_i - \bar{y})^2\]

Where MSDHB indicates mean square deviation for higher the better response, r is the number of trial, and \(y_i\) is the \(i^{th}\) measured value in a row.
Data of the L8 Orthogonal Array with S/N ratio for the MRR is shown in Table 4. The machining managed to get the same MRR result for both methods. It is observed that for 4A, the MRR was the highest to be at 0.1g/min.

**MRR comparison to Current, Ton, Toff for Spray and Complete Submerged Method**

Based on Table 5, a summarized results for pulse-on time (Ton), pulse-off time (Toff), discharge voltage (V) and discharge current (A) is assigned as rank 1, 2 and 3 respectively according to their larger value of delta. Rank 1 means highest contribution factor for MRR, Rank 2 for in between and Rank 3 means lowest contribution factor for MRR.

Table 5 shows the main effect plot of S/N ratio for MRR by using spray method. It is observed that MRR goes on increasing with a higher value of pulse-on time (Ton). Material removal rate (MRR) has the highest value at the pulse-on time (Ton) 50µs and has the lowest value at current discharge 4A. By increasing the pulse off time, the material removal rate of
tool steel (P20) using graphite diminished. The increase of pulse off time causes the plasma channel to become smaller, which reduces the attack of positive ions on the workpiece surface and lowers the MRR. Comparison of results of material removal rate with methods that use kerosene as a dielectric shows that material removal rate decreases considering that the sparks are less stable.

**Figure 7:** MRR using Spray Method for S/N Ratio

Based on Table 6, pulse-on time (Ton), the discharge current (A), and pulse-off time (Toff) are assigned as rank 1, 2, and 3, respectively according to their larger value of delta. Rank 1 means highest contribution factor for MRR and Rank 3 means lowest contribution factor for MRR using sinking method.

Figure 8 shows the main effect plot of S/N ratio for MRR using sinking method. It is observed that MRR goes on increasing with a higher value of pulse-on time (Ton). Material removal rate (MRR) has the highest value at the pulse-on time (Ton) 50µs and has the lowest value at the pulse-off time and (Toff) value 50 µs.

**Table 6:** Response table for S/N Ratio for Complete Submerged Method

<table>
<thead>
<tr>
<th>Level</th>
<th>Current</th>
<th>Ton</th>
<th>Toff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.01</td>
<td>36.33</td>
<td>27.13</td>
</tr>
<tr>
<td>2</td>
<td>30.43</td>
<td>22.11</td>
<td>31.31</td>
</tr>
<tr>
<td>Delta</td>
<td>2.42</td>
<td>14.22</td>
<td>4.18</td>
</tr>
<tr>
<td>Rank</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

The experiments were conducted in order to analyse the effect of MRR of tool steel (P20) by using spray and complete submerged method for EDM Die Sinking process. A complete machining time was recorded for each run and based on the MRR data collected the result were determined. Run number five and six shows significant time reduced as much as 12 minutes. But it is found that the surface roughness produced by spray method was rough compare to the complete submerged method.

Accordingly, in Fig 9, the machining time can be improved if the user decided to use spray method by neglecting the surface roughness of the final workpiece, instead of complete submerged method.

**Figure 8:** MRR using Completed Submerged Method for S/N Ratio

**Figure 9:** Machining Time Comparison for Both Method

Optimum parameters in Table 7 shows the suitable parameters for EDM die sinking machining from the Taguchi method.

**Table 7:** Suitable setting EDM Die sinking parameters for higher MRR

<table>
<thead>
<tr>
<th>Current</th>
<th>Ton 1</th>
<th>Toff 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4A</td>
<td>50µs</td>
<td>25µs</td>
</tr>
</tbody>
</table>

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CONCLUSION

The following conclusion can be drawn:

a) Machining process by using spray method in EDM Die Sinking is faster than complete submerged method, and the method can be recommended if the user is neglecting the surface finished quality. Common practice in plastic injection mould, the surface of the cavity requires further polishing process after the EDM machining process. Thus, by using spray method to EDM machining, it helps to improve the productivity of plastic injection mould maker.

b) The highest MRR is found during the pulse on stage for both machining process. Thus, to achieve higher MRR, a higher Ton time is needed, followed with Toff time and lastly is the current.

Further research can be done by using different type of electrode and workpiece. A suitable EDM machining parameters can be propose with the spray technique method to improve the productivity of the manufacturing sector.

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